Macroeconomic Uncertainty and Capital-Skill Complementarity*

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December 2020

Newest Version: Here

Abstract

Segmentation by skills in the labor market is widespread. However, most existing studies of uncertainty do not distinguish labor by skills. In this paper I investigate the effects of macroeconomic uncertainty on relative skilled-to-unskilled wages and employment and I show that macroeconomic uncertainty shocks lead to different labor market outcomes for skilled and unskilled workers. First, I show empirically in a structural VAR model that uncertainty shocks are recessionary. As a result of the uncertainty shock, skilled workers experience a steeper fall in their wages than unskilled workers, and the relative employment increases. Second, I propose a dynamic New Keynesian model consistent with these findings. In this model the presence of capital-skill complementarity allows to distinguish different roles of skilled and unskilled labor in production. The uncertainty shock is contractionary and pushes the demand for labor and capital inputs down, relative wages fall and relative employment increases. The model uncovers a novel propagation channel relying on capital-skill complementarity and precautionary labor supply, which explains the effects of heightened uncertainty on the divergence of labor income and employment between skilled and unskilled workers.

JEL classification: Stochastic volatility; Capital-skill complementarity; Relative wages; Skill premium. *Keywords:* E32; J31.

*I am grateful to my advisor Céline Poilly for her support and guidance. I also thank Frédéric Dufourt, Efrem Castelnuovo, Lorenzo Rotunno for many insightful comments which helped improve the paper.

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1 Introduction

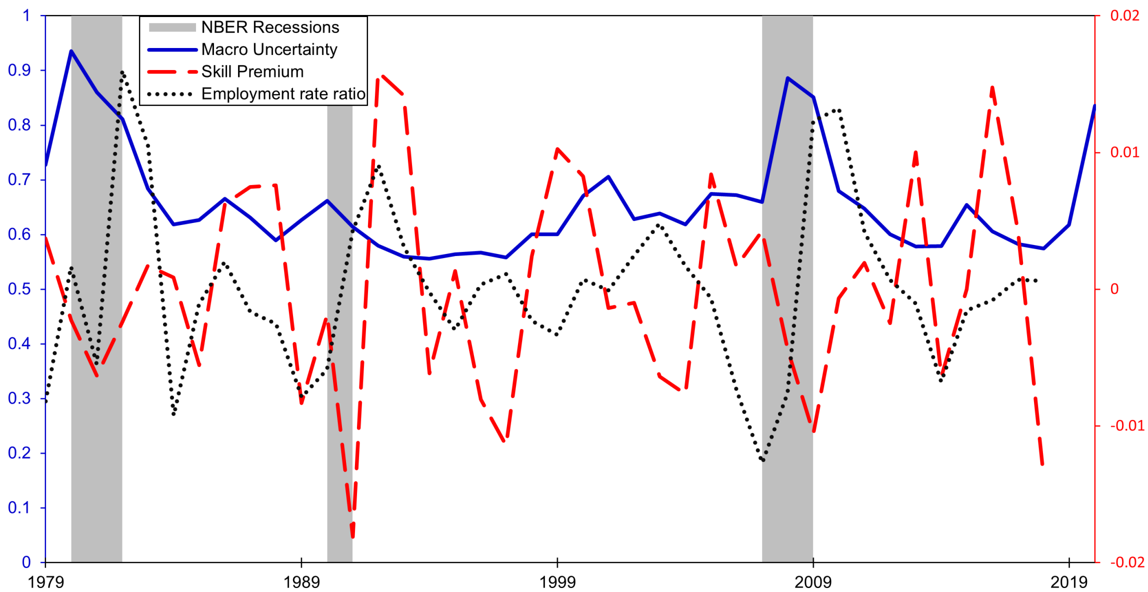
The Great Recession has sparked a wide debate among policymakers and researchers on the impact of uncertainty on economic activity. This is particularly relevant in the current Covid-19 crisis, which has been surrounded by the unprecedentedly high uncertainty. The persuasive evidence documents the important contribution of macroeconomic uncertainty to business cycle fluctuations (Bloom (2009), Basu and Budnick (2017)). Considerable part of macroeconomic uncertainty literature focuses on the transmission of uncertainty shocks through firms' investment decisions. Firms are more cautious to invest and "wait-and-see" until uncertainty is resolved due to real-option effects (Bernanke (1983))[1]. However, little attention has been paid to the role of labor market segmentation in the propagation of uncertainty onto the economy, even though this phenomenon at the business cycle frequency is not new. In particular, the implications of stochastic volatility for the labor market outcomes of skilled versus unskilled workers have not been investigated. Since capital is more complementary to qualified labor, we can expect that the effects of uncertainty on skilled and unskilled workers will differ through the tighter link of capital with skilled labor. This paper aims to contribute to this debate by studying the effects of aggregate uncertainty on employment and wages of workers with (skilled) and without (unskilled) college education, and by shedding light on the underlying propagation channels.

To motivate that the effects of uncertainty may differ for skilled and unskilled workers, Figure 1 provides preliminary evidence on the relationship between macroeconomic uncertainty, the relative skilled-to-unskilled employment rate and the skill premium[2]. I use the Current Population Survey (CPS) Merged Outgoing Rotation Groups (CPS MORG) data to plot the annual averages of the cyclical components of the relative skilled-to-unskilled employment rate and the skill premium between 1979 to 2018. The solid blue line represents the macro uncertainty measure from Jurado et al. (2015). I use the annual average of their monthly series with $h = 1$ (i.e., 1-month-ahead uncertainty). The dotted black line and the dashed red line represent the annual averages of the cyclical components of quarterly relative skilled-to-unskilled employment rate and skilled-to-unskilled wage premium respectively[3]. The left-hand-side axis is related to uncertainty, and right-hand-side axis

[1] Part of this literature explains an increase in unemployment after a rise in uncertainty, but it considers aggregate labor market Caggiano and Groshenny (2014), Choi and Loungani (2015), Schaal (2017), Leduc and Liu (2016), Cacciatore and Ravenna (2020), Guglielminetti (2016), and Leduc and Liu (2016).

[2] The skill premium is defined as the ratio of a skilled wage to an unskilled wage.

[3] Construction of the data is described in Section 2.



Note: The solid blue line represents the macro uncertainty measure from Jurado et al. (2015). I use the annual average of their monthly series with $h = 1$ (i.e., 1-month-ahead uncertainty). The dashed red line represents the annual average of the cyclical component of quarterly skilled-to-unskilled wage premium.

Figure 1: Macro Uncertainty and Skill Premium

is related to the relative employment rate and the skill premium. The picture highlights a strong positive correlation between the uncertainty measure and the relative employment rate (correlation coefficient is 0.4062) and a strong negative correlation between the uncertainty measure and the skill premium series (correlation coefficient is -0.4632). During the recent recessions macroeconomic uncertainty soared to the unusually high levels. This periods were also characterized by the increasing relative employment rate and declining wage premium. The evidence provided in Figure 1, while suggestive, does not imply any causality in one direction or the other. Below I present the empirical evidence that macroeconomic uncertainty shocks do indeed increase relative skilled-to-unskilled employment rate and reduce the skill premium in the US.

I start the analysis by estimating a structural vector autoregression (SVAR) model of quarterly macroeconomic variables, labor market variables, and the macroeconomic uncertainty index of Jurado et al. (2015) for the United States. I use the Current Population Survey (CPS) Merged Outgoing Rotation Groups to construct quarterly measures of wage and employment rates for college educated and non-college educated workers for the sample period 1979Q1–2018Q4. Empirically, a macroeconomic uncertainty shock has contractionary effects on aggregate economic activity, since it leads to a drop in consumption, output and investment. I find that a macroeconomic uncertainty shock has different consequences for skilled and unskilled workers – it produces an increase in the relative skilled-to-unskilled employment rate and a moderate fall in the skilled-to-unskilled wage ratio.

To rationalize these findings, I introduce an intuitive propagation mechanism whereby an increase in macroeconomic uncertainty affects wage and employment gaps between skilled and unskilled workers (the skill premium and relative employment), and generates responses of output, consumption and investment, which are in line with the empirical evidence. Existing models explain negative effects of uncertainty on aggregate economy through complex transmission channels such as real-options and aggregate demand channels[4]. However, these mechanisms do not distinguish between nor explain the relative effects of uncertainty shocks on the different types of labor used in the production process. I develop a New-Keynesian DSGE model with capital-skill complementarity, which allows to attain and explain the empirical effects of such shocks on skilled and unskilled workers. I model uncertainty as a second moment shock to technology. In the proposed mechanism I revisit the hypothesis of capital-skill complementarity. Capital-skill complementarity implies that although capital is likely to be complementary to both skilled and unskilled labor, it tends to be more complementary to skilled labor. The relevance of capital-skill complementarity for the cyclical behavior of aggregate economy and, in particular the skill premium, has been documented by empirical research[5]. In the macroeconomic uncertainty literature, however, the role of capital-skill complementarity is muted: the elasticity of substitution between labor and different types of labor is identical.

The model proposes a simple transmission mechanism that generates the observed patterns in the skill premium and relative employment in response to aggregate uncertainty shocks. This mechanism relies on the interaction of capital-skill complementarity and households' precautionary labor

[4] With the exception of the few papers that find no significant effect of uncertainty shocks (for example, Bachmann and Bayer (2013)) or consider different channels of uncertainty propagation (see discussion in Bloom (2009)).

[5] see Lindquist (2004), Balleer and van Rens (2013), Maliar et al. (2017), Correa et al. (2019), Dolado et al. (2020) among others. There is vast empirical evidence on the complementarity between skilled labor and physical capital, which suggests different types of labor have different elasticity of substitution with capital: Griliches (1969), Krusell et al. (2000), Lindquist (2004). Capital-skill complementarity has been shown to match the dynamics of the skill premium in the data (see Maliar et al. (2017), Skaksen and A. (2005), Krusell et al. (2000), Lindquist (2004), Pourpourides (2011), Duffy et al. (2004)). Capital-skill complementarity is one explanation for variations in wage inequality (Krusell et al. (2000)). For the long-run, Goldin and Katz (2008) provide historical evidence for the 20th century demonstrating that wage inequality has developed within a production sector characterized by capital-skill complementarity.

supply. Capital-skill complementarity in production implies non-trivial interactions between availability of skills and spikes in uncertainty. Due to capital-skill complementarity skilled and unskilled labor have different roles in production with relation to capital. As uncertainty increases, the relative prices of capital equipment and labor fall, thereby investment and employment are discouraged. In general equilibrium the capital-to-skilled labor ratio increases since capital is adjusted slower than labor in response to the shock. Since skilled labor is complementary to capital, the increase in the capital-to-skilled labor ratio reduces the decline in the marginal product of skilled labor from the shock and dampens the decrease in skilled labor demand. This effect leads to the increase in the skilled-to-unskilled labor ratio and it pushes up the skilled wage. As a consequence, the rise in the capital-to-skilled labor ratio puts an upward pressure on the skill premium. Both skilled and unskilled households are risk-averse and when faced with more uncertainty, they increase savings, cut consumption and increase precautionary labor supply. In the model, wealth effect on labor supply controls the degree of precautionary labor supply. If wealth effect is asymmetric between skilled and unskilled households, movements in skilled and unskilled labor supply will not be the same. I rely on evidence that individuals with more skilled jobs and higher education tend to spend like households with higher income (see Calvet and Comon (2003)) and, thus, have higher wealth elasticity of labor supply. Thus, larger skilled wealth effect increases the extent of precautionary labor supply by skilled households compared to unskilled households. Larger skilled labor supply attenuates the fall in skilled employment and puts a downward pressure on the skilled wage. This leads to a fall in the skill premium and a further increase in relative skilled-to-unskilled labor supply. All in all, the skill premium falls if the effect of a rise in relative quantities of skilled to unskilled labor exceeds the effect carried by the increase in the capital-to-skilled labor ratio. Additionally, asymmetric wage rigidity between skilled and unskilled workers allows to dampen the upward pressure on the skill premium carried by the capital-to-skilled labor ratio: skilled wages are more flexible and adjust more easily in response to the shock. The magnitude of a decrease in unskilled wages is smaller so that the skilled-to-unskilled wage ratio (i.e. the skill premium) falls.

This paper is part of the recently growing literature on uncertainty shocks as well as of the strand of literature on capital-skill complementarity. First, this paper is contributing to a highly pertinent literature on the propagation of uncertainty in the economy. Starting with the seminal work by Bloom (2009) the recent research has shown that uncertainty shocks are important in accounting for fluctuations in output, investment and employment through complex transmission channels. These studies have mainly focused on the behavior of firms in capital and product markets. In response to a rise in uncertainty households lower consumption, increase savings and hours worked, which lowers output due to nominal price rigidities[6]. Investment irreversibilities, such as non-convex adjustment costs, induce firms to pause investment and hiring and "wait-and-see" until uncertainty is resolved[7]. These channels yield a prediction of a fall in aggregate economic activity through a decline in investment in response to a rise in uncertainty. However, these channels focus on investment decisions of firms and do not distinguish between relative effects of uncertainty shocks on different types of labor used in production. This paper is a novel attempt in this area of research to use a general equilibrium model with capital-skill complementarity to analyze the effect of uncertainty shocks on the earnings and employment gaps between skilled and unskilled workers in the US.

Part of the literature, which considers the implications of uncertainty on labor market dynamics is more scarce. Empirical work (see Caggiano and Groshenny (2014), Choi and Loungani (2015), Leduc and Liu (2016)) shows that a rise in aggregate uncertainty leads to an increase in unemployment. Theoretical literature has shown that incorporating labor market frictions amplifies the effects of aggregate volatility[8]. Guglielminetti (2016) and Leduc and Liu (2016) replicate in theoretical models with labor search-and-matching frictions the empirical evidence that unemployment significantly rises after a volatility shock. However, these works do not consider neither investment irreversibility nor different types of labor. While previous studies focus on the effects of macroeconomic uncertainty on the aggregate employment and wages, I am interested in understanding the potentially differential effects of the transmission of uncertainty on the dynamics of employment and wages of skilled and unskilled workers.

This paper also relates to the academic work on the role of capital-skill complementarity. The hypothesis of capital-skill complementarity is not new as it was first formalized by Griliches (1969)[9]. This strand of literature is mostly concentrated on income inequality (Griliches (1969), Krusell et al.

[6]This is the aggregate demand channel studied by Basu and Budnick (2017).

[7]This option-value channel was documented by Bernanke (1983) and Bloom (2009).

[8]Uncertainty shocks generate a fall in vacancies and an increase in unemployment since labor represents a particular type of real rigidity through the option-value channel that arises from labor search frictions (Leduc and Liu (2016))

[9]Griliches (1969) was the first to formalize and test the capital-skill complementarity hypothesis, which he initially called "capital-schooling" complementarity. This hypothesis states that workers depending on their "skill" or "education" have different roles in production: skilled labor is more complementary with physical capital than unskilled or "raw" labor, which implies that skilled workers have a lower elasticity of substitution with capital than low-skilled workers do.

(2000), Angelopoulos et al. (2014), Lindquist (2004)). Krusell et al. (2000) show that capital-skill complementarity can be the source of the increase in the skilled premium in the United States. The capital-skill complementarity hypothesis has been adopted recently to study the implications of monetary and fiscal policies (Dolado et al. (2020), Angelopoulos et al. (2014), Angelopoulos et al. (2017)). The paper closest to this work is by Dolado et al. (2020). Differently to this paper, Dolado et al. (2020) focus on the expansionary monetary policy shocks, which they find, as other favorable aggregate demand shocks, increase labor earnings inequality as the skill premium, the relative employment and relative labor income share of skilled to unskilled workers increase. Their mechanism relies on the interaction of capital-skill complementarity with asymmetric search-and-matching frictions. My paper differs in several respects. First, the nature of the shock is different. Then my model explains empirical findings through the mechanism, which nests on the interaction of capital-skill complementarity with precautionary labor supply with no reliance on asymmetric search-and-matching frictions. I find that uncertainty shocks, which act as negative shocks, decrease the skill premium, but raise the relative employment and relative labor income share similar to positive monetary policy shocks. In this paper, I offer an alternative way of incorporating capital-skill complementarity in the DSGE framework, which helps uncover the effects of uncertainty shocks.

On the one hand, the literature on uncertainty has demonstrated that uncertainty shocks depress employment. On the other hand, the literature on the skill premium has shown that there are significant differences in wage dynamics of skilled and unskilled labor. Given that uncertainty affects employment and its impact is associated with skill levels, the previous studies render the main question of this paper pertinent – whether uncertainty has an asymmetric impact on skilled compared to unskilled labor. Surprisingly, the business-cycle theoretical research on this subject has been scarce despite both the empirical relevance of capital-skill complementarity hypothesis and labor market disparities between skilled and unskilled labor. This paper bridges these two strands of literature, which proves to be crucial to replicate the data. On the empirical side, I document the effects of macroeconomic uncertainty shocks on relative employment of skilled versus unskilled workers as well as on the wage gap between skilled and unskilled workers. The theoretical model developed in this paper rationalizes the empirical evidence and explains the propagation mechanism of these uncertainty shocks.

The rest of the paper is organized as follows. In Section 2 I motivate the further analysis by estimating the dynamic effects of uncertainty shocks on the macroeconomy in a structural VAR (SVAR) model. Section 3 presents the setup of the theoretical model. Section 4 provides underlying intuitions of the transmission mechanisms of macroeconomic uncertainty in the model. Section 5 describes the parametrization and solution method. Results and sensitivity analysis are presented and discussed in Section 6. The final two sections discuss policy implications and provide concluding remarks respectively.

2 Empirical Evidence

In this Section, I examine empirically the effects of macroeconomic uncertainty shocks on aggregate economic dynamics and, in particular relative employment rates and relative wages (i.e. the skill premium) of skilled to unskilled workers by estimating a structural vector autoregression (SVAR) model. I assess impulse responses to orthogonalized shocks to macroeconomic uncertainty measure. SVAR estimates are based on United States data of quarterly frequency from 1979Q1 to 2018Q4. Recent studies argue that macroeconomic uncertainty is exogenous when evaluating its effects on the US macroeconomy (see Carriero et al. (2018), Piffer and Podstawski (2018), Angelini et al. (2019), and Angelini and Fanelli (2019)). Based on this evidence, I consider macroeconomic uncertainty as exogenous to the business cycle[10].

As a measure of uncertainty, I use the macroeconomic uncertainty index estimated by Jurado et al. (2015) (JLN)[11], which is a broad measure of macroeconomic uncertainty. An advantage of using Jurado et al. (2015) index is that its sample period is the longest among other popular uncertainty measures. This index is also employed in empirical literature looking at the effects of total factor productivity TFP or aggregate uncertainty (for example, Born and Pfeifer (2017)[12]).

[10] For an extensive review on macroeconomic uncertainty and its exogeneity to the business cycle, see Castelnuovo (2019).

[11] The index of economic uncertainty developed by Jurado et al. (2015) is the common variation in uncertainty across hundreds of economic series. Jurado et al. (2015) measure uncertainty is based on squared forecast errors for a large panel of macroeconomic time series. Other proxies of macroeconomic uncertainty, namely the changes in VIX, i.e. an implied volatility measure derived from US S&P 500 options prices, are more likely to be affected by shocks specific to the stock market rather than an increase in uncertainty about the aggregate economy (see for example, Bekaert et al. (2013), Stock and Watson (2012), Caldara et al. (2016)). I use the Jurado et al. (2015) macroeconomic uncertainty index, available on the authors' personal websites, a quarterly average of monthly values for $h = 1$ (one month forecast horizon).

[12] Born and Pfeifer (2017) say that this is the broadest and at the same time cleanest uncertainty measure available. Also, Deutsche Bundesbank (January 2016) applies the methodology from Jurado et al. (2015) for the four largest euro area countries

The micro data on labor market variables come from the NBER extracts of the Current Population Survey (CPS) Merged Outgoing Rotation Groups (CPS MORG)[13], which is a monthly household survey of employment and labor markets. I use these data to construct series of employment rates, relative employment rate ratio, real hourly wages for each worker skill type and the skill premium. These data are widely used by economists for constructing the data on wages and labor supply (see for example, Katz and Murphy (1992), Krusell et al. (2000), Acemoglu and Autor (2011), Dolado et al. (2020) among others). Each monthly sample contains approximately 30,000 individuals associated with a person-level earnings weights, which when applied allow for nationally representative estimates of the US population. The data covers the period from 1979M1 to 2018M12. I restrict the sample to the individuals of the working age from 16 to 64 years old, discard self-employed individuals, observations with missing or negative person-level earnings weights, armed forces workers and observations with zero earnings. I also abstract from the individuals with missing labor force status from the dataset (no information on the employment status). I choose to classify workers as skilled and unskilled based on educational attainment. In this classification I follow an extensive literature, which has studied the division of the labor force between college and high school graduates and the resulting wage premium to skilled workers (see Acemoglu and Autor (2011), Goldin and Katz (2008) and Hornstein et al. (2005)). The skilled group of workers encompasses individuals having an education qualification of college and above, and the unskilled group are all other individuals having lower than a college degree[14].

Hourly wages are computed as weekly earnings divided by usual weekly hours for weekly workers and hourly earnings (on the main job) for hourly workers. To construct real hourly wage series, the resulting hourly wages are deflated into constant, 2012 dollars using Consumer Price Index research series from the Bureau of Labor Statistics of the United States. The weighted averages for each skill group are calculated using the CPS MORG earnings sampling weights *earnwt*. I obtain the skill premium as the ratio between the weighted average of real hourly wages of skilled and the unskilled workers. Employment for skilled (unskilled) individuals in a given quarter is just the sum of skilled (unskilled) individuals, weighted by their sampling weight, who report to be employed in that period. Employment rate of the skilled (unskilled) is the share of employed skilled (unskilled) workers in the skilled (unskilled) labor force. Relative employment rate ratio is the ratio between

[13] Data were extracted from the NBER website: https://data.nber.org/data/morg.html.

[14] Other studies, for example Acemoglu and Autor (2011), Angelopoulos et al. (2017), Dolado et al. (2020), use the same definition for skilled and unskilled groups of workers.

employment rate of skilled and unskilled workers. I aggregate these monthly time series into quarterly ones by taking three months averages. The resulting quarterly time series are adjusted for seasonality using the X-13-ARIMA algorithm. I choose not to detrend variables since detrending might distort the dynamics in the underlying time series[15]. The rest of the series are retrieved from the FRED database[16].

The SVAR-(p) model reads as follows:

$$AY_t = B\sum_{p=1}^{P} B_p Y_{t-1} + \epsilon_t$$

where p is the number of lags, B_p is the coefficient matrix for the $p-th$ lag of Y_t, ϵ_t is the vector of reduced form zero-mean innovations, and $Y_t = [\sigma_t^z \quad y_t \quad i_t \quad c_t \quad n_t^s \quad \left(\frac{n^s}{n^u}\right)_t \quad w_t^s \quad \left(\frac{w^s}{w^u}\right)_t \quad \pi_t]'$ is a vector comprising the following variables: σ_t^z the macroeconomic uncertainty measure – JLN index from Jurado et al. (2015)[17], y_t – real GDP, i_t – real gross private domestic investment, c_t – real personal consumption expenditures, n_t^s – the skilled employment rate defined as the share of skilled employed workers in the skilled labor force, $\frac{n_t^s}{n_t^u}$ – the employment rate ratio[18], w_t^s – weighted average of real hourly wage of employed in the skilled category[19], $\frac{w_t^s}{w_t^u}$ – wage ratio (the skill premium), π_t – the quarterly growth rate of GDP implicit price deflator. I take logs of the uncertainty measure, to interpret the impulse response functions (IRFs) in percentage terms. Output, consumption, capital investment, and skilled wage enter the SVAR in log levels. In order to determine the lag order p, I use Akaike Information criterion (AIC), which indicates that $p = 2$ is appropriate.

Uncertainty shock is defined as a one standard deviation increase in the JLN index of macroeconomic uncertainty. I identify the structural uncertainty shock via a recursive ordering (Cholesky

[15]As in Bachmann and Bayer (2013) and Jurado et al. (2015), I do not detrend any variables using the HP filter (Hodrick and Prescott (1997)) because since the HP filter uses information over the entire sample, it is difficult to interpret the timing of an observation. King and Rebelo (1993), Harvey and Jaeger (1993), Guay and Saint-Amant (2005) and Meyer and Winker (2005) discuss potential distortionary effects induced by using of HP filtered data. On the other hand, Bloom (2009) used the HP filter for every series except the volatility measure – VXO index.

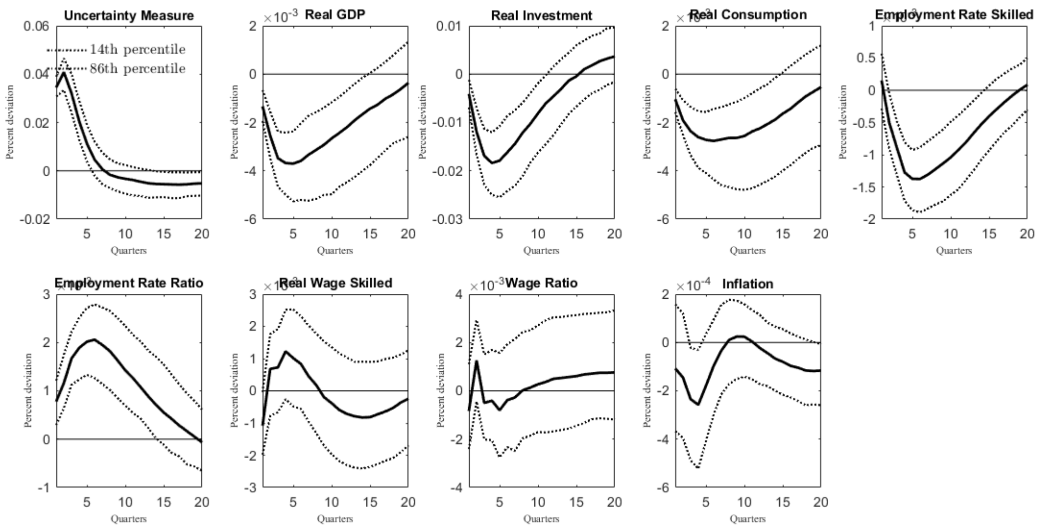
[16]Output is real GDP (GDPC1). Consumption is real personal consumption expenditures (PCEC9C6). Investment is real gross private domestic investment (GPDIC1). The economy-wide measure of the hourly real wage is compensation per hour in the business sector (HCOMPBS) divided by the GDP deflator (GDPDEF). I obtained inflation from the percentage change in implicit price deflator (GDPDEF).

[17]The Jurado et al. (2015) macro uncertainty measure is available at https://www.sydneyludvigson.com/data-and-appendixes/ and comes in monthly frequency, which I converted to quarterly using simple average.

[18]Inclusion of the wage and employment gaps in addition to the individual variables for skilled workers allows to interpret the responses of the respective variables for unskilled workers.

[19]Aggregated real hourly wage of employed in skilled category combines the usual hourly earnings for hourly workers (excluding otc), and non-hourly workers (including otc) in the usual hourly earnings.

Figure 2: Impulse responses to a 1-sd uncertainty shock



Note: Solid lines correspond to the median IRFs while the dashed lines are the 14^{th} and 86^{th} percentiles. Horizontal axes indicate quarters. I take logs of the uncertainty measure, to interpret the IRFs in percentage terms. Output, consumption, capital investment, and skilled wage are expressed in logs. Variables enter with two lags, selected according to the Akaike criterion.

decomposition), which is widely-employed in the uncertainty literature (see, for example Bloom (2009), Fernandez-Villaverde et al. (2015), Leduc and Liu (2016) and Basu and Budnick (2017)). It ensures that the uncertainty shock is orthogonal to the other stochastic elements in the SVAR. I order the uncertainty shock first since I assume that uncertainty is not contemporaneously affected by the state of the economy, and uncertainty has contemporaneous effect on all other variables with a delay of one quarter.

Figure 2 displays impulse responses to a one standard deviation uncertainty shock. An exogenous increase in macroeconomic uncertainty leads to a persistent and significant decline in output. By the 4^{th} quarter output falls by 0.36%, while consumption and capital investment drop by 0.24% and 1.76% respectively. A contemporaneous fall in inflation suggests that the uncertainty shock acts like a demand shock in line with Caggiano and Groshenny (2014), Fernandez-Villaverde et al. (2015), Bonciani and van Roye (2016), Leduc and Liu (2016), and Basu and Budnick (2017). Regarding the labor market variables, employment rate of skilled labor features a hump-shaped response and stays down for about 3 years with the lowest level occurring after 6 quarters. The relative employment rate ratio increases suggesting that firms tend to adjust unskilled employment more than skilled jobs. On the other hand, the skill premium declines implying that earnings of skilled workers fall more than of unskilled workers after an uncertainty shock. The response of the skill premium suggests that inequality in terms of wage income between skilled and unskilled groups is negatively related to an unexpected rise in uncertainty. The responses of the employment rate ratio and the skill premium mean that the uncertainty shock has heterogeneous impact across different workers. Therefore, heterogeneity of workers in skills is an important feature of the data that should not be overlooked when studying the propagation of uncertainty shocks and disentangling mechanisms through which uncertainty affects the economy.

The stylized facts relevant to this paper can be briefly summarized as follows:

- Macroeconomic uncertainty shock is recessionary – it lowers aggregate output, consumption, investment and employment.
- The skill premium decreases after a rise in the macroeconomic uncertainty.
- The relative employment rate of skilled labor increases as a response to a rise in the macroeconomic uncertainty.

These findings have an important implication for understanding the mechanism through which the uncertainty shock affects the labor market. The SVAR corroborates previous findings that uncertainty shocks lead to overall economic contraction. Regarding the responses of skilled and unskilled employment rates and wages, there are important reasons why we should expect them to differ. In the present paper I focus on the explanation of the behavior of the relative employment and the skill premium by complementarity between skills and capital[20]. The core idea of capital-skill complementarity is that skilled workers are more complementary to capital than unskilled workers are. In the presence of capital-skill complementarity, any changes in capital lead to corresponding adjustments in demand for more qualified labor, which in turn affects skilled wages. Reduction in investment directly translates into a fall in capital stock, which lowers skilled wages and the skill premium. This complementarity is an important factor to affect the demand for labor and is responsible for the different effects of uncertainty shocks on skilled and unskilled employment and wages. The decline in the skill premium suggests for a higher wage rigidity of unskilled wages in line with evidence that rigidity of wages increases as education declines reported by Doniger (2019). The 3^{rd} stylized fact indicates that elevated uncertainty has a more negative effect on unskilled em-

[20]Caggiano and Groshenny (2014) and Choi and Loungani (2015) are examples of previous studies that found the importance of this channel.

ployment than skilled employment. Skilled individuals may tend to exhibit a more precautionary behavior when uncertainty increases. They might increase their labor supply more relative to less skilled individuals as they would want to insure themselves against the possibility of adverse shocks arising in the future. This stronger precautionary behavior of skilled groups may be due to higher awareness of more qualified and/or educated individuals about the risks of future shocks brought about by higher uncertainty. Additionally, the higher relative employment might be due to the fact that skilled employment is usually more stable than unskilled employment. Labor hoarding could be another reason for an increase in the employment rate ratio. In downturns firms are likely to resort to hoarding of especially skilled, qualified and educated labor due to higher hiring and lay-off adjustment costs of skilled workers (see for example, Bentolila and Bertola (1990)). Additionally, firms that face uncertainty are more reluctant to adjust skilled employment due to skilled human capital being firm-specific (see for example, Becker (1964)).

In the following Section I describe the theoretical model, which is able to replicate the empirical findings above.

3 The Model

The economy consists of a continuum of infinitely-lived households, a continuum of firms producing differentiated intermediate goods, a perfectly competitive firm producing a final good, a fiscal authority, and a central bank determining monetary policy[21]. The model incorporates capital-skill complementarity framework through a CES production function[22]. Firms are of two types: wholesalers (or intermediate good firms), producing intermediate goods with skilled and unskilled labor and capital as inputs and facing capital adjustment costs, and one representative retailer, who combines intermediate goods to produce a homogeneous final good under staggered price setting à la Calvo (1983). Heterogeneity in the population shows through three types of households – entrepreneurs, and skilled and unskilled workers[23]. As for notation, I will for any real variable x_t

[21] The model bares a common structure with the model in Dolado et al. (2020).

[22] This assumption on technology is in line with the empirical evidence provided by numerous studies (see Maliar et al. (2017), Skaksen and A. (2005), Krusell et al. (2000), Lindquist (2004), Pourpourides (2011), Duffy et al. (2004)). Cantore et al. (2015) find that a model with a CES production function explains the actual U.S. data better than a model with a Cobb-Douglas production function.

[23] In modeling household types I follow the set-up as in Dolado et al. (2020). Broer et al. (2020) have a similar capitalist-worker framework, but they model workers as a single representative household without differentiation in

denote its value in nominal terms with X_t, its value in steady state x.

3.1 Households

Population is composed of three different types of household – skilled and unskilled workers and entrepreneurs – who share some common features. These households are indexed by $i \in \{s, u, e\}$ corresponding to skilled, unskilled and entrepreneur households respectively, and are of size π^i, $i \in \{s, u, e\}$. Total population of the economy is normalized to one so that $\sum_i \pi^i = 1$. The number of these three types of households in the population, π^i, is constant so that it is not possible to transition from one household type to another[24]. These households are ex-ante identical apart from that the entrepreneurs do not supply labor, but invest in capital, own firms and derive income from firms' dividends[25], whereas workers only receive wage income. The reason entrepreneurs are in the model is to isolate labor income as well as to avoid any income effects and labor supply effects stemming from receiving dividends and owning capital in the economy. This assumption also captures the notion that equity ownership is extremely concentrated (see for example, Kuhn and Rios-Rull (2016)).

3.1.1 Skilled and Unskilled Worker Households

Two skilled and unskilled worker households indexed by $i \in (s, u)$ respectively are differentiated by their level of skills and supply labor. These worker households have similar characteristics apart from their roles in the production process. Time constraints of working households are normalized to 1 so that for a i-type household $h_t^i + l_t^i = 1$, where h_t^i is hours worked and l_t^i is leisure. Each household i consumes c_t^i and saves by purchasing zero-coupon nominal non-state contingent risk-free government bond holdings B_t, which pay a gross nominal return R_t, pays a tax t_t^i levied to finance government expenditure, receives a real labor income w_t^i for hours worked h_t^i, where w_t^i is the real wage. Inflation rate is defined as $\pi_t = \frac{p_t}{p_{t-1}}$. I use the functional form of the utility à la Jaimovich and Rebelo (2009) for households allowed to work, since it allows to control for the strength of the wealth effect. The magnitude of the wealth effect affects the response of labor supply to movements in consumption. The utility of skilled and unskilled households depends positively on consumption

skills.

[24] Angelopoulos, Jiang and Malley (2017) show on time series data on relative skill supply that in business cycle frequencies there is not much labor movement between the skilled and unskilled sectors.

[25] The income from capital ownership could also be interpreted as income from human capital and therefore as a form of wage income. The key distinction is that capitalists supply their human capital inelastically and the return to human capital is flexible.

and negatively on labor and reads as

$$\mathrm{E}_0\sum_{t=0}^{\infty}\beta^t\left\{\frac{1}{1-\sigma_u^i}\left[\left(c_t^i-b_c c_{t-1}^i-\kappa_h(h_t^i)^{\phi^i}X_t^i\right)^{1-\sigma_u^i}-1\right]\right\} \tag{3.1.1}$$

where E_0 is the expectation operator conditional on the information available in period 0, $\beta \in (0,1)$ is the subjective discount factor, $\left(\phi^i-1\right)^{-1}$ is the Frisch elasticity of labor supply, κ_h is a scale parameter, σ_u^i is the intertemporal elasticity of substitution, b_c expresses the degree of habit in consumption, and where

$$X_t^i = (c_t^i - b_c c_{t-1}^i)^{\sigma_X^i}(X_{t-1}^i)^{1-\sigma_X^i} \tag{3.1.2}$$

Parameter σ_X^i controls the strength of the wealth effect on labor supply. Imposing $\sigma_X^i = 1$ gives the King et al. (1988) (KPR) preferences and $\sigma_X^i = 0$ gives Greenwood et al. (1988) preferences with zero wealth effect on labor supply, where supply of labor depends only on the current real wage, and is independent of the marginal utility of income. In this case X_t becomes a constant and can be normalized to one[26]. When σ_X^i and b_c are both small, anticipated changes in income will not affect current labor supply. As σ_X^i increases, the wealth elasticity of labor supply rises.

Budget constraint of worker households is

$$c_t^i + t_t^i + \frac{B_{t+1}\pi_{t+1}}{R_t} = w_t^i h_t^i + B_t \tag{3.1.3}$$

where on the r.h.s. is the i-household's income in period t, which equals the sum of the wages, and the household's receipts from government bonds B_t and on the l.h.s. is the household's expenditure on consumption c_t^i, taxes t_t^i and new acquisition of bonds.

The problem of the worker household is to choose consumption, and asset holdings to maximize the intertemporal utility subject to the budget constraint (3.1.3). The Lagrangian of the problem of the household in real terms reads as

$$\mathcal{L}^i = \sum_{t=0}^{\infty}\beta^t\left\{\frac{1}{1-\sigma_u^i}\left[\left(c_t^i-b_c c_{t-1}^i-\kappa_h\left(h_t^i\right)^{\phi^i}X_t^i\right)^{1-\sigma_u^i}-1\right]-\lambda_t^i\left[c_t^i+t_t^i+\frac{B_{t+1}\pi_{t+1}}{R_t}-w_t^i h_t^i-B_t\right]\right\}$$

where λ_t^i is the Lagrangean multiplier associated with the budget constraint, also interpreted as the marginal utility of wealth.

[26] See Jaimovich and Rebelo (2009) for more details.

The first order conditions with respect to B_{t+1}, c_t^i, X_t^i, and h_t^i are

$$B_{t+1} : \beta \mathrm{E}_t \left\{ \lambda_{t+1}^i \frac{R_t}{\pi_{t+1}} \right\} = \lambda_t^i \tag{3.1.4}$$

$$\begin{aligned} c_t^i : \lambda_t^i = & \left(c_t^i - b_c c_{t-1}^i - \kappa_h X_t^i (h_t^i)^{\phi} \right)^{-\sigma_u^i} - \beta b_c \left(c_{t+1}^i - b_c c_t^i - \kappa_h X_{t+1}^i (h_{t+1}^i)^{\phi^i} \right)^{-\sigma_u^i} + \\ & \sigma_X^i \upsilon_t^i (c_t^i - b_c c_{t-1}^i)^{\sigma_X^i - 1} (X_{t-1}^i)^{1-\sigma_X^i} - \beta b_c \sigma_X^i \upsilon_{t+1}^i (c_{t+1}^i - b_c c_t^i)^{\sigma_X^i - 1} (X_t^i)^{1-\sigma_X^i} \end{aligned} \tag{3.1.5}$$

$$X_t^i : \upsilon_t^i + \kappa_h (h_t^i)^{\phi^i} \left(c_t^i - b_c c_{t-1}^i - \kappa_h (h_t^i)^{\phi^i} X_t^i \right)^{-\sigma_u^i} = \beta \left(1 - \sigma_X^i \right) \mathrm{E}_t \left\{ \upsilon_{t+1}^i (c_{t+1}^i - b_c c_t^i)^{\sigma_X^i} (X_t^i)^{-\sigma_X^i} \right\} \tag{3.1.6}$$

$$h_t^i : \kappa_h \phi^i (h_t^i)^{\phi^i - 1} X_t^i \left(c_t^i - b_c c_{t-1}^i - \kappa_h X_t^i (h_t^i)^{\phi^i} \right)^{-\sigma_u^i} = \lambda_t^i w_t^i \tag{3.1.7}$$

where λ_t^i and υ_t^i are the Lagrangian multipliers associated to the budget constraint 3.1.3 and 3.1.2 respectively. Equation 3.1.4 is the Euler equation, which determines the intertemporal dynamics of the marginal utility of consumption as a function of the real return on bonds. Equation 3.1.5 describes the evolution of consumption as a function of the marginal disutility of hours worked, and the dynamics of the wealth effect on labor supply. Equation 3.1.6 determines the dynamics of X_t^i, i.e. the wealth effect on labor supply. The last condition 3.1.7 is the labor supply equation, which states that households supply labor by equating the real wage to the intratemporal marginal rate of substitution.

3.1.2 Entrepreneurs

I assume that the entrepreneur households own firms, invest in physical capital, do not participate in the labor market and enjoy leisure equal to 1. Entrepreneurs' preferences are described by the following utility function

$$\mathcal{U}_t^e = \mathbb{E}_t \sum_{t=0}^{\infty} \beta \Big[\frac{(c_t^e - b_c c_{t-1}^e)^{1-\sigma_u^e}}{1 - \sigma_u^e} \Big] \tag{3.1.8}$$

The entrepreneur household consumes c_t^e and saves by purchasing zero-coupon nominal non-state contingent government bonds B_t, which pay a gross nominal return R_t, or by investing in physical capital k_t^e, which it rents to intermediate goods firms at a rental rate R_t^k, receives dividends from firms, div_t. Budget constraint of the entrepreneur household is

$$c_t^e + t_t^e + \frac{B_{t+1}\pi_{t+1}}{R_t} + i_t^e = \operatorname*{div}_t + B_t + R_t^k k_{t-1}^e \tag{3.1.9}$$

where div_t is the household's share of firms' dividends, net of a government lump-sum tax[27]. Capital accumulation evolves according to the law of motion

$$i_t^e = k_{t+1}^e - (1-\delta_i)k_t^e + D\left(k_{t+1}^e, k_t^e\right) \tag{3.1.11}$$

The function $D\left(k_{t+1}^e, k_t^e\right)$ denotes capital adjustment costs (see Lucas and Prescott (1971) or Christiano et al. (2011)). This function implies that it is costly to change the level of capital. This adjustment cost is increasing in the change in capital, and there are no adjustment costs in the steady state. The log-linearized dynamics around the steady state are influenced only by the curvature of the adjustment cost function, $D''(1)$. I use the following specification of the functional form of capital adjustment cost $D\left(k_{t+1}^e, k_t^e\right)$

$$D\left(k_{t+1}^e, k_t^e\right) = \frac{\phi_i}{2}\left(\frac{k_{t+1}^e}{k_t^e} - 1\right)^2 k_t^e, \phi_i < 0$$

Parameter ϕ_i governs the magnitude of adjustment costs to capital accumulation and depreciation rate is $0 < \delta < 1$, $D(1) = D'(1) = 0$. When $\phi_i \to \infty$ investment and the stock of capital become constant.

The problem of the entrepreneur household is to choose consumption c_t^e, asset holdings B_{t+1}, investment i_t^e and next period capital k_{t+1}^e to maximize the intertemporal utility subject to the budget constraint and the law of motion of capital. The Lagrangian of the entrepreneur households' problem in real terms reads as

$$\begin{aligned}\mathcal{L}^e = \sum_{t=0}^{\infty}\beta^t \Bigg\{ \frac{(c_t^e - b_c c_{t-1}^e)^{1-\sigma_u}}{1-\sigma_u} - \lambda_t^e\Big[c_t^e + t_t^e + \frac{B_{t+1}\pi_{t+1}}{R_t} + i_t^e - \operatorname*{div}_t - B_t - R_t^k k_{t-1}^e\Big] \\ -Q_t\Big[k_{t+1}^e - (1-\delta)k_t^e + D\left(k_{t+1}^e, k_t^e\right) - i_t^e\Big]\Bigg\}\end{aligned}$$

where λ_t^e is the entrepreneur Lagrangian multiplier associated with the budget constraint, also interpreted as the marginal utility of wealth; and $q_t^i = \frac{Q_t}{\lambda_t^e}$ is the Tobin's Q marginal ratio with Q_t – the Lagrange's multiplier associated with the dynamics of capital stock.

[27]Wholesalers' profits are redistributed to the entrepreneur households in the form of dividends, see Section (3.2).

$$\pi^e \operatorname*{div}_t = x_t y_t - \left(w_t^s n_t^s + w_t^u n_t^u + R_t^k k_t\right) \tag{3.1.10}$$

The first order conditions with respect to c_t^e, B_{t+1}, and k_{t+1}^e are

$$c_t^e : \lambda_t^e = (c_t^e - b_c c_{t-1}^e)^{-\sigma_u^e} - \beta b_c (c_{t+1}^e - b_c c_t^e)^{-\sigma_u^e} \tag{3.1.12}$$

$$B_{t+1} : \beta^t \mathbb{E}_t \frac{\lambda_{t+1}^e R_t}{\pi_{t+1}} = \lambda_t^e \tag{3.1.13}$$

$$k_{t+1}^e : \lambda_t^e \left(1 + \phi_i \left[\frac{k_{t+1}^e}{k_t^e} - 1\right]\right) = \beta \lambda_{t+1}^e \left(1 + R_{t+1}^k - \delta + \frac{\phi_i}{2}\left(\frac{k_{t+2}^e}{k_{t+1}^e}\right)^2 - 1\right) \tag{3.1.14}$$

I assume complete markets, the perfect risk-sharing and full insurance between households by following Dolado et al. (2020). Combining equations of households' F.O.C. (3.1.13) and (3.1.4) leads to the following perfect risk sharing condition:

$$\frac{\lambda_{t+1}^i}{\lambda_{t+1}^e} = \frac{\lambda_t^i}{\lambda_t^e} = \frac{\bar{\lambda}^i}{\bar{\lambda}^e} \text{ for } i \in (s, u) \tag{3.1.15}$$

This equation 3.1.15 keeps the ratio of different agents' marginal utilities constant at its steady-state value.

3.2 Wholesale Firms

There is a continuum of perfectly competitive wholesalers that produce a homogeneous wholesale good y_t with identical production functions and sell it to retailers at a relative price x_t. Retailers then produce a differentiated final good[28]. The assumption of constant returns to scale in production implies that all firms have the same capital-labor ratio as well as the marginal product of labor and allows to aggregate across firms without loss of generality. The wholesale good is produced by the aggregate production technology $\mathcal{Z}_t f(k_t, n_t^s, n_t^u)$, where $\mathcal{Z}_t$ is aggregate TFP, $k_t = \pi^e k_t^e$ is aggregate capital with π^e population share of entrepreneurs, $n_t^s = \pi^s h_t^s$ and $n_t^u = \pi^u h_t^u$ are labor supplies of skilled and unskilled households with π^s and π^u population shares of skilled and unskilled households respectively.

Consistent with the recent empirical literature on the behavior of the skill premium (see, e.g., Krusell et al. (2000), I postulate that the production function exhibits capital-skill complementarity. The aggregate production function is a three factor-nested CES composite of production factors. This

[28]There are two types of firms – wholesalers and retailers in order to keep traction.

form of the production function allows me to capture capital-skill complementarity since it allows to set separately the elasticity of substitution between capital and skilled labor and the elasticity of substitution between skilled and unskilled labor[29].

$$y_t \equiv \mathcal{Z}_t f(k_t, n_t^s, n_t^u) = \mathcal{Z}_t([\mu(n_t^u)^\sigma + (1-\mu)(\lambda k_t^\rho + (1-\lambda)(n_t^s)^\rho)^{\frac{\sigma}{\rho}}]^{\frac{1}{\sigma}}) \tag{3.2.1}$$

where k_t is aggregate capital, n_t^s is aggregate skilled labor and n_t^u is aggregate unskilled labor, and $\sigma, \rho \in (-\infty, 1)$ in order to maintain strict quasi-concavity of the production function. Parameter λ governs the capital intensity of production process and parameter μ governs how skill-intensive production process is. The elasticity of substitution between capital and skilled labor is $\varepsilon_{k,n^s} = \frac{1}{1-\rho}$ and the elasticity of substitution between capital and unskilled labor (the same as the elasticity of substitution between skilled and unskilled labor)[30] is $\varepsilon_{k,n^u} \equiv \varepsilon_{n^s,n^u} = \frac{1}{1-\sigma}$[31]. In the CES framework, the values of ε_{k,n^s} and ε_{k,n^u} play a critical role because they determine how changes in either technology or supplies affect demand and wages. Following Krusell et al. (2000), capital-skill complementarity maintains if and only if the elasticity of substitution between capital and skilled labor is higher than the elasticity of substitution between capital and unskilled labor, i.e. $\frac{1}{1-\rho} < \frac{1}{1-\sigma}$, which implies $\sigma > \rho$[32].

I assume that labor markets are perfectly competitive, in which case wages are proportional to marginal products. The skill premium defined as the ratio of skilled wage to unskilled wage and associated with the production function in Equation 3.2.1 is given by

$$\frac{w_t^s}{w_t^u} \equiv \frac{mpl_t^s}{mpl_t^u} = \frac{(1-\mu)(1-\lambda)}{\mu}\Big[\lambda\Big(\frac{k_t}{n_t^s}\Big)^\rho + (1-\lambda)\Big]^{\frac{\sigma}{\rho}-1}\Big(\frac{n_t^u}{n_t^s}\Big)^{(1-\sigma)} \tag{3.2.2}$$

The condition $\sigma > \rho$) imposes capital-skill complementarity, i.e. skilled labor is more complementary to capital than unskilled labor. One can show that w_t^s/w_t^u is decreasing in the relative demand for skilled workers, $\frac{\partial(w_t^s/w_t^u)}{\partial(n_t^s/n_t^u)} < 0$, all else held constant. Following the literature, I call it the rela-

[29] In choosing the functional form of production function I follow the capital-skill complementarity literature, namely Hamermesh (1993), Krusell et al. (2000), Maliar and Maliar (2011), Lindquist (2004).

[30] This CES three-factor-nested production function has a symmetry property that the elasticity of substitution between capital equipment and unskilled labor is the same as the elasticity of substitution between skilled and unskilled labor.

[31] To derive this, I solved for $w^s \equiv \frac{\partial y}{\partial n^s}$, $w^u \equiv \frac{\partial y}{\partial n^u}$ and $R^k \equiv \frac{\partial y}{\partial k}$, divided, reorganized, took logs, and took a derivative to find $\varepsilon_{k,n^s} = \frac{\partial \log(\frac{n^s}{k})}{\partial \log(\frac{w^s}{R^k})} = \frac{1}{1-\rho}$ and $\varepsilon_{k,n^u} \equiv \varepsilon_{n^s,n^u} = \frac{\partial \log(\frac{n^u}{k})}{\partial \log(\frac{w^u}{R^k})} = \frac{1}{1-\sigma}$.

[32] The elasticity of substitution registers the effect of a change in the quantity of one factor on the price of another factor, holding marginal cost and quantities of other factors constant. The higher the elasticity of complementarity, the larger the positive effect of an increase in the quantity of one input on the price of the other input, see Sato and Koizumi (1973), Hamermesh (1985), and Stern (2011).

tive supply effect. The second effect is capital-skill complementarity effect – the skill premium is increasing in the capital-skill ratio, $\frac{\partial(w_t^s/w_t^u)}{\partial(k_t/n_t^s)} > 0$, all else held constant.

Maximization of profits by wholesalers yields the following F.O.C. with respect to capital, k_t, employment of skilled, n_t^s, and unskilled labor, n_t^u. Given the form of the production function in equation (3.2.1) I define the following F.O.C.

$$\begin{aligned}\frac{R_t^k}{x_t} = \frac{\partial y_t}{\partial k_t} &= (1-\mu)\lambda(\lambda k_t^\rho + (1-\lambda)(n_t^s)^\rho)^{\frac{\sigma}{\rho}-1} k_t^{\rho-1} \\ &\times \underbrace{\mathcal{Z}_t\big[\mu(n_t^u)^\sigma + (1-\mu)(\lambda k_t^\rho + (1-\lambda)(n_t^s)^\rho)^{\frac{\sigma}{\rho}}\big]^{\frac{1}{\sigma}-1}}_{\mathcal{Z}_t f(k_t, n_t^s, n_t^u)^{1-\sigma} \equiv y^{1-\sigma}} \\ &= (1-\mu)\lambda\big(\lambda k_t^\rho + (1-\lambda)(n_t^s)^\rho\big)^{\frac{\sigma}{\rho}-1} k_t^{\rho-1} y_t^{1-\sigma}\end{aligned} \tag{3.2.3}$$

$$\begin{aligned}\frac{w_t^s}{x_t} = mpl_t^s = \frac{\partial y_t}{\partial n_t^s} &= \mathcal{Z}_t(1-\mu)(1-\lambda)(\lambda k_t^\rho + (1-\lambda)(n_t^s)^\rho)^{\frac{\sigma}{\rho}-1}(n_t^s)^{\rho-1} \\ &\times \big[\mu(n_t^u)^\sigma + (1-\mu)(\lambda k_t^\rho + (1-\lambda)(n_t^s)^\rho)^{\frac{\sigma}{\rho}}\big]^{\frac{1}{\sigma}-1} \\ &= (1-\mu)(1-\lambda)(\lambda k_t^\rho + (1-\lambda)(n_t^s)^\rho)^{\frac{\sigma}{\rho}-1}(n_t^s)^{\rho-1} y_t^{1-\sigma}\end{aligned} \tag{3.2.4}$$

$$\begin{aligned}\frac{w_t^u}{x_t} = mpl_t^u = \frac{\partial y_t}{\partial n_t^u} &= \mathcal{Z}_t\mu\big[\mu(n_t^u)^\sigma + (1-\mu)(\lambda k_t^\rho + (1-\lambda)(n_t^s)^\rho)^{\frac{\sigma}{\rho}}\big]^{\frac{1}{\sigma}-1}(n_t^u)^{\sigma-1} \\ &= \mu(n_t^u)^{\sigma-1} y_t^{1-\sigma}\end{aligned} \tag{3.2.5}$$

where mpl_t^i is the marginal product of i-type labor. Since labor markets are competitive, the real wages w_t^s and w_t^u are simply given by the value of marginal product of labor times marginal cost.

In a recent paper Cacciatore and Ravenna (2015) study the importance of wage rigidity for the transmission of an uncertainty shock. They demonstrate that it greatly amplifies the response of the economy to surprise shock. Motivated by this evidence, I introduce wage rigidity in the model. Similarly to Krause and Lubik (2007) and Leduc and Liu (2016), I allow for real wage rigidity via the following form à la Hall (2005):

$$w_t^s = (\widetilde{w}_{t-1}^s)^{\rho_w^s}(w_t^s)^{(1-\rho_w^s)} \tag{3.2.6}$$

$$w_t^u = (\widetilde{w}_{t-1}^u)^{\rho_w^s}(w_t^u)^{(1-\rho_w^u)} \tag{3.2.7}$$

where $\widetilde{w}_t^s$ and $\widetilde{w}_t^u$ are the effective wages of skilled and unskilled workers respectively and ρ_w^s and

ρ_w^u indicate the indexation to previous period wage (indexes the degree of wage rigidity) of skilled and unskilled workers respectively.

I also define the labor share in income as

$$\begin{aligned}\frac{w_t^s n_t^s + w_t^u n_t^u}{y_t} &= \left[\mu(n_t^u)^\sigma + (1-\mu)\left(\lambda k_t^\rho + (1-\lambda)(n_t^s)^\rho\right)^{\frac{\sigma}{\rho}}\right]^{-1} \\ &\times \left[\mu(n_t^u)^\sigma + (1-\mu)\left(\lambda k_t^\rho + (1-\lambda)(n_t^s)^\rho\right)^{\frac{\sigma}{\rho}-1}(1-\lambda)(n_t^s)^\rho\right] \\ &= y^{-\sigma}\left[(1-\mu)(1-\lambda)(\lambda k^\rho + (1-\lambda)(n^s)^\rho)^{\frac{\sigma}{\rho}-1}(n^s)^\rho + \mu(n^u)^\sigma\right] \end{aligned} \tag{3.2.8}$$

3.3 Retailers

Wholesale firms sell the homogeneous good to a unit measure of retailers indexed by $j \in [0,1]$ at the relative price x_t. The retailer j transforms the homogeneous wholesale good into differentiated final goods $y_{j,t}$ with $p_{j,t}$ – the nominal sale price of this good, and sell them on to consumers. Retailers operate under monopolistic competition and face Calvo price adjustment costs. In this context, final output is produced according to the following constant return to scale technology:

$$y_t = \left(\int_0^1 y_{j,t}^{\frac{\varepsilon-1}{\varepsilon}} \mathrm{d}i\right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{3.3.1}$$

where ε is the elasticity of demand for a producer of wholesale goods (the elasticity of substitution across differentiated retail goods) and p_t is the aggregate price index. The maximization of profits yields the demand curve of each monopolistic retailer

$$y_{j,t} = \left(\frac{p_{j,t}}{p_t}\right)^{-\varepsilon} y_t \tag{3.3.2}$$

with

$$p_t = \left(\int_0^1 p_{j,t}^{1-\varepsilon} \mathrm{d}i\right)^{\frac{1}{1-\varepsilon}} \tag{3.3.3}$$

Calvo price setting Price setting in retailer sector is subject to the pricing scheme à la Calvo in the benchmark version. Retailers choose the price that maximizes discounted real profits. In each period, a fraction $(1-\kappa_p)$ of firms can change their prices. All other firms can only index their prices by past inflation. The probability of a price change is constant overtime and independent of the time elapsed since the last adjustment. This assumption implies that a retail firm keeps the same price on average during $1/(1-\kappa_p)$ periods. Indexation is controlled by the exogenous parameter $\chi \in [0,1]$, where $\chi = 0$ implies no indexation and gives back the standard Calvo model with the price remaining constant between re-optimization period assumed in the benchmark model, and $\chi = 1$ – total indexation. All price-updating firms adjust to the same price, p^*.

The problem of the retail firms is then:

$$\max_{p_{j,t}} \quad \mathrm{E}_t \sum_{\tau=0}^{\infty} (\beta\kappa_p)^{\tau} \frac{\lambda^e_{t+\tau}}{\lambda^e_t} \left\{ \prod_{s=1}^{\tau} \pi^{\chi}_{t+s-1} \frac{p_{j,t}}{p_{t+\tau}} y_{j,t+\tau} - \mathbb{S}\left(y_{j,t+\tau}\right) \right\}$$

subject to $y_{j,t+\tau} = \left(\prod_{s=1}^{\tau} \pi^{\chi}_{t+s-1} \frac{p_{j,t}}{p_{t+\tau}} \right)^{-\theta_p} y_{t+\tau}$. θ_p is the price elasticity of demand for intermediate good j. The firms, which can change prices, set them to satisfy:

$$g_{1,t} = \lambda^e_t \, y_t \, x_t + \beta \, \kappa_p \, \mathbb{E}_t \left(\frac{\pi_t{}^{\chi}}{\pi_{t+1}} \right)^{-\theta_p} \, g_{1,t+1} \tag{3.3.4}$$

$$g_{2,t} = \lambda^e_t \, \pi^*_t \, y_t \; + \beta \, \kappa_p \, \mathbb{E}_t \left(\frac{\pi^{\chi}_t}{\pi_{t+1}} \right)^{1-\theta_p} \left(\frac{\pi^*_t}{\pi^*_{t+1}} \right) g_{2,t+1}, \text{ where } \pi^*_t = \frac{p^*_t}{p_t} \tag{3.3.5}$$

$$\theta_p g_{1,t} = g_{2,t} \; (\theta_p - 1) \tag{3.3.6}$$

Given pricing à la Calvo, the price index evolves:

$$1 = \kappa_p \left(\frac{\pi_{t-1}{}^{\chi}}{\pi_t} \right)^{1-\theta_p} + (1 - \kappa_p) \; \pi^{*\,1-\theta_p}_t \tag{3.3.7}$$

We define price dispersion term $v^p_t = \int_0^1 \left(\frac{p_{j,t}}{p_t} \right)^{-\theta_p} di$. If there were no pricing frictions, all firms would charge the same price, and $v^p_t = 1$. By the properties of the index under Calvo's pricing the law of motion of price dispersion is

$$v^p_t = \kappa_p \left(\frac{\pi_{t-1}{}^{\chi}}{\pi_t} \right)^{-\theta_p} v^p_{t-1} + (1 - \kappa_p) \; \pi^{*\,-\theta_p}_t \tag{3.3.8}$$

In the aggregation I obtain:

$$y_t = \frac{\mathcal{Z} f(k_t, n^s_t, n^u_t)}{v^p_t} \tag{3.3.9}$$

This is the aggregate production function. Since $v^p_t \geq 1$, price dispersion results in an output loss – firms produce less output than you would given TFP, aggregate labor and capital inputs if prices are disperse.

3.4 Exogenous Processes

The model features two exogenous stochastic driving processes for the aggregate productivity $\mathcal{Z}_t$ and its volatility $\sigma_t^{\mathcal{Z}}$, which is time-varying.

$$\mathcal{Z}_t = \rho^{\mathcal{Z}} \mathcal{Z}_{t-1} + \sigma_t^{\mathcal{Z}} \varepsilon_t^{\mathcal{Z}} \text{ where } \varepsilon_t^{\mathcal{Z}} \sim \mathrm{N}(0,1) \tag{3.4.1}$$

$$\sigma_t^{\mathcal{Z}} = \left(1 - \rho^{\sigma^{\mathcal{Z}}}\right) \sigma^{\mathcal{Z}} + \rho^{\sigma^{\mathcal{Z}}} \sigma_{t-1}^{\mathcal{Z}} + \eta_{\sigma^{\mathcal{Z}}} \varepsilon_t^{\sigma^{\mathcal{Z}}} \text{ where } \varepsilon_t^{\sigma^{\mathcal{Z}}} \sim \mathrm{N}(0,1) \tag{3.4.2}$$

where $\varepsilon_t^{\mathcal{Z}}$ and $\varepsilon_t^{\sigma^{\mathcal{Z}}}$ follow i.i.d. standard normal process[33]. A level shock $\varepsilon_t^{\mathcal{Z}}$ is a first-moment shock that varies the level of $\mathcal{Z}_t$, keeping its distribution unchanged. An uncertainty shock $\varepsilon_t^{\sigma^{\mathcal{Z}}}$ is a second-moment shock that affects the shape of the distribution by widening the tails of the level shock and keeping its mean unchanged. Parameters $\rho^{\mathcal{Z}}$ and $\rho^{\sigma^{\mathcal{Z}}}$ drive the persistence associated to the level and volatility of productivity shocks respectively, and $\eta_{\sigma^{\mathcal{Z}}}$ drives the magnitude of the productivity uncertainty shock.

3.5 Monetary Policy

The monetary authority sets the nominal interest rate, R_t, to stabilize inflation and output growth. Monetary policy adjusts short term nominal interest rates in accordance with the following standard Taylor rule with interest rate smoothing and potential reaction to the deviations of output and inflation from their steady-state values

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_R} \left(\left(\frac{\pi_t}{\pi}\right)^{\rho_\pi} \left(\frac{y_t}{y}\right)^{\rho_y}\right)^{(1-\rho_R)} \tag{3.5.1}$$

where $\rho_R \in [0,1]$ is a smoothing parameter, ρ_π is the elasticity of R_t with respect to inflation deviations and ρ_{y_t} is the elasticity of R_t with respect to output gap, R is the steady-state gross nominal interest rate and y is the steady-state output.

3.6 Fiscal Policy

The government collects lump-sum taxes and runs a balanced budget in every period. The government budget constraint (3.6.1) equates current income (bond issues and tax revenues) with general expenditures and maturing government bonds. The government's budget constraint is thus given by

[33] I use the stochastic volatility approach proposed by Fernandez-Villaverde et al. (2011).

$$t_t + B_t = g_t + \frac{R_{t-1}B_{t-1}}{\pi_t} \tag{3.6.1}$$

where g_t is real general government spending, and B_t is the total amount of aggregate nominal government bonds held by the households ($B_t = \sum_i \pi^i B_t^i$ for $i \in (s,u,e)$). The distribution of lump-sum taxes is assumed to be equal across households such that $t_t = \sum_i \pi^i t_t^i$ for $i \in (s,u,e)$. The real amount of lump-sum taxes is adjusted according to the fiscal rule

$$\frac{t_t}{t} = \left(\frac{B_{t-1}}{B}\right)^{(\phi_D)} \left(\frac{y_t}{y}\right)^{(\phi_Y)} \tag{3.6.2}$$

Finally, government spending follows a standard AR-(1) process:

$$\log\left(\frac{g_t}{\bar{g}}\right) = \rho^g \log\left(\frac{g_{t-1}}{\bar{g}}\right) + \varepsilon_t^g \tag{3.6.3}$$

3.7 Closing the Model

Combining the budget constraints of the households and the government the final good market clearing condition is obtained. Final output is used for private consumption, investment, government expenditures. Total demand is thus given by

$$y_t = c_t + i_t + g_t \tag{3.7.1}$$

where aggregate consumption is $c_t = \sum_i \pi^i c_t^i$ for $i \in (s,u,e)$, and aggregate investment is $i_t = \pi^e i_t^e$.

4 Impact of Uncertainty Shocks: Dissecting the Mechanism

In this Section, I provide an insight into the transmission of uncertainty shocks onto skilled and unskilled labor markets. While the existing transmission channels do not distinguish between relative effects of uncertainty on segmented labor markets with respect to skills, I demonstrate that capital-skill complementarity gives rise to an additional propagation channel of aggregate uncertainty on relative skilled-to-unskilled wages and employment.

The revealed stylized facts relevant to this paper in Section 2 are (i) the skill premium decreases after a rise in the macroeconomic uncertainty, and (ii) the relative employment of skilled to unskilled labor increases as a response to a rise in the macroeconomic uncertainty. I illustrate the mechanism behind the responses of relative wages and employment by looking at the interaction of *relative* skilled-to-unskilled (precautionary) labor supply and firms' *relative* skilled-to-unskilled labor demand. Firms' relative labor demand is affected by the degree of complementarity/ substitutability of capital and skilled labor in production[34]. Households' labor supply and firms' labor demand read as

For skilled agents:	For unskilled agents:
$\lambda_t^s w_t^i = mrs^s(c_t^s, h_t^s, X_t^s)$	$\lambda_t^u w_t^u = mrs^u(c_t^u, h_t^u, X_t^u)$
$w_t^s = x_t mpl^s(\mathcal{Z}_t, k_t, n_t^s, n_t^u)$	$w_t^u = x_t mpl^u(\mathcal{Z}_t, k_t, n_t^s, n_t^u)$

Labor supply is characterized by the condition that the marginal rate of substitution (mrs_t^i) is equal to the household-i wage w_t^i times the household-i discount factor λ_t^i, while the labor demand curve is characterized by the marginal product of labor (mpl_t^i) being equal to the labor-i wage w_t^i times a marginal cost x_t, where the subscript $i \in (s, u)$ denotes either skilled or unskilled household.

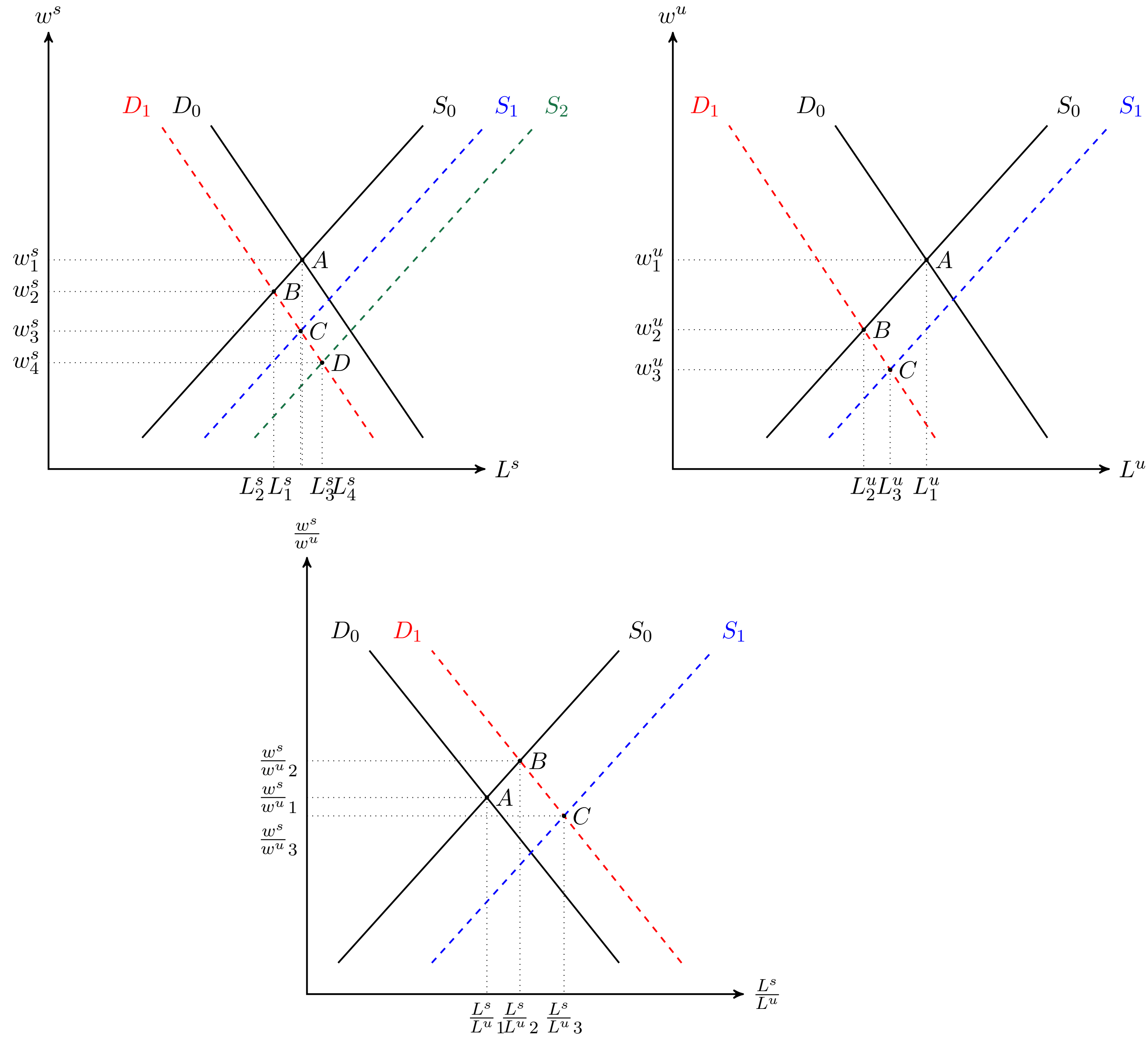
Figure 3 illustrates what happens after an unexpected rise in uncertainty. The panels at the top describe the skilled (left panel) and unskilled (right panel) labor market. The bottom panel describes the relative skilled to unskilled labor market. Below, I show how changes in the capital-to-skilled labor ratio, and the skilled-to-unskilled labor ratio (i.e. relative employment) affect the response of the skill premium given in Equation 3.2.2. Uncertainty induces precautionary behavior of households due to the presence of risk aversion in the households' preferences. Households increase savings and labor supply, and reduce demand for consumption goods. Skilled and unskilled labor supply curves shift upward (see top panels of Figure 3). Higher labor supply reduces firms' marginal costs. Both price and wage markups increase due to nominal rigidities (see Basu and Budnick (2017)). The rise in markups leads to a fall in labor demand (see top panels of Figure 3). However, labor demand and labor supply change in different magnitude in skilled and unskilled labor markets. In response to a rise in uncertainty capital-to-skilled labor ratio increases since capital adjusts slower than labor in response to the shock. Complementarity between capital and skilled labor reduces the decline in the marginal product of skilled labor from the shock and dampens the decrease in skilled labor demand. As a consequence, a decrease in the demand for skilled labor is smaller than for unskilled labor, which leads to an increase in the relative labor demand, and the relative labor demand curve shifts to the right from D_0 to D_1 (see bottom panel of Figure 3).

[34] In the model skilled and unskilled labor demands are given by equation 3.2.4 and 3.2.5 respectively, and labor supply conditions are given by equation 3.1.7.

Due to the wealth effect on labor supply, households react to lower labor income by increasing hours worked. This wealth effect controls the degree of precautionary labor supply. If wealth effect is asymmetric between skilled and unskilled households, shifts in skilled and unskilled labor supply curves will not be the same. Provided that skilled households have a stronger wealth effect on labor supply than unskilled households, skilled households increase labor supply more than unskilled households. The first panel of Figure 3 displays that if skilled households increase labor supply in the same magnitude as unskilled households, their labor supply curve shifts from S_0 to S_1. However, a larger shift of skilled labor supply curve to S_2, rather than to S_1, causes a sharper fall in the skilled wage to w_4^s. Corresponding equilibrium skilled employment is also higher at L_4^s. Larger precautionary labor supply by skilled households leads to an increase in relative skilled-to-unskilled labor supply and the relative labor supply curve shifts to the right from S_0 to S_1 (see bottom panel of the Figure 3). As a consequence, relative employment increases (see point C, bottom panel of the Figure 3). As a result of the changes is the supply and demand of skilled and unskilled labor, the skill premium falls (see third panel $\frac{w^s}{w^u}{}_3$).

Alternatively to asymmetric wealth effect, asymmetric wage rigidity also helps to rationalize the decline in the skill premium in response to heightened uncertainty. Large degree of rigidity attenuates shifts in wages. In response to a rise in uncertainty, very rigid wages decrease to a lesser extent. Provided that skilled wages are more flexible than unskilled wages, the skilled wage falls less than otherwise so that the relative wage ratio falls. In this instance the magnitude of the increases in skilled and unskilled labor supplies is the same: skilled labor supply curve shifts from S_0 to S_1 and unskilled labor supply curve shifts from S_0 to S_1 (see two top panels of Figure 3). However, the unskilled wage, being more sticky, cannot fall to w_3^u. Consequently, the magnitude of the decline in the skilled wage is larger and the skill premium goes down.

Figure 3: Labor demand & labor supply in skilled labor market (first panel to the left). Labor demand & labor supply in unskilled labor market (second panel to the right). Relative labor demand & relative labor supply (third centered panel). Impact of an uncertainty shock on wages and employment.



Notes for the third panel: D_0 is an initial relative labor demand curve and S_0 is an initial relative labor supply curve. The initial equilibrium wage differential between skilled workers (w^s) and unskilled workers (w^s) is denoted ($\frac{w^s}{w^u}{}_1$). It is determined by the intersection of the relative demand curve for skills (D_0) and the relative supply curve for skills (S_0). This equilibrium is associated with an initial relative employment ratio of skilled to unskilled workers ($\frac{L^s}{L^u}{}_0$).

5 Solution and Calibration

5.1 Solution Method

I solve and simulate the model by a third-order perturbation method using the pruning algorithm by Andreasen et al. (2018)[35]. As explained in Fernandez-Villaverde et al. (2011), the third-order approximation of the policy function is necessary to analyze the effects of uncertainty shocks independently of the first moment shocks. The volatility shock plays an independent role and enters as an independent argument in the approximated policy function without interacting with any other variable function only in a third-order approximation.

I am interested in the effects of an increase in volatility or a positive shock to ${\sigma^{\mathcal{Z}}}_t$ in Equation 3.4.2, while the level shock to TFP is zero. I consider impulse response functions (IRFs) that isolate the pure uncertainty effect resulting from higher volatility in the spirit of Fernandez-Villaverde et al. (2011). I focus on the effect uncertainty has on expectations, and how expectations transmit to actual decisions, but ignore materialized shocks to the level of the exogenous processes. I compute impulse response functions of the respective variables in percentage deviation from the ergodic mean of the simulated data by the model in the absence of shocks. In linear models IRFs are usually computed using the deterministic steady state as an initial condition. In these models, IRFs do not depend on the state of the economy when the shock occurs, nor on the sign and size of the shock. In a higher order approximation to the solution of the model, impulse responses computed from the deterministic steady state do not converge as they are just one of the many IRFs of the non–linear model since in a third order approximation, the expected value of the variable will also depend on the variance of the shocks in the economy[36]. Therefore, it is more informative to compute impulse responses as percentage deviations from their mean, rather than their steady state.

[35]The model is solved using Dynare 4.4.3 (MATLAB R2017b). In order to obtain a non-explosive behavior of the simulations, Dynare relies on the pruning algorithm described in Andreasen et al. (2018). The version of Dynare used allows pruning also for third order perturbation algorithms.

[36]Schmitt-Grohe and Uribe (2004) show that in a first-order approximation of the model, the expected value of any variable coincides with its value in the non-stochastic steady state, while in a second-order approximation of the model, the expected value of any variable differs from its deterministic steady-state value only by a constant.

5.2 Calibrated Parameters

The model is calibrated so that its steady-state is consistent with the quarterly US data. Parametrization is based on values commonly found in the literature or on making the steady-state model replicate some empirical targets, that I base on the quarterly US data employed in Section 2. Variables without a time subscript denote the steady-state values and an index $i \in \{s, u, e\}$ corresponds to skilled, unskilled and entrepreneur households respectively. The proportion of entrepreneurs in the population, π^e, is set equal to 10% as in Dolado et al. (2020). The proportion of skilled workers, π^s, is 21%, which is equal to the average share of workers in the CPS MORG dataset with college education, and the rest 69% are unskilled workers. The time discount factor is $\beta = 0.99$ and the relative risk aversion parameter os skilled and unskilled households is set to $\sigma_u^s = 1$ and $\sigma_u^u = 1$ respectively, the value commonly employed in the literature[37], with a moderate degree of consumption habit persistence $b_c = 0.5$ (as estimated in Born and Pfeifer (2014)) and the parameter governing taste for leisure, κ_h^i, is chosen so that households work h^i=1/3 of their time in steady state (as is commonly assumed in the macro literature). I set $\phi^s = 1.4$ and $\phi^u = 1.4$ which corresponds to the skilled and unskilled Frisch elasticities of 2.5 as the benchmark and will examine the quantitative implications of the model with higher Frisch elasticity. Likewise, I set the parameters governing the wealth effect to $\sigma_X^s = 0.2$ and $\sigma_X^u = 0.2$ as the benchmark and will examine the quantitative implications of the model with a lower wealth effect, absence of wealth effect and asymmetric wealth effect. Degree of real wage rigidity is high – $\rho_w^u = 0.8$ and $\rho_w^s = 0.8$, consistent with the analysis of Krause and Lubik (2007) and Leduc and Liu (2016). I also examine the case when wage rigidity is asymmetric with unskilled wages being more sticky $\rho_w^u = 0.8 > \rho_w^s = 0.65$.

The depreciation rate of capital equipment is $\delta = 0.25$. I set the parameters governing the elasticities of substitution between skilled labor and capital and between unskilled labor and capital (or skilled labor) $\rho = -0.495$ and $\sigma = 0.401$, which are the estimates by Krusell et al. (2000) frequently used in the literature (see Lindquist (2004), Pourpourides (2011), Angelopoulos et al. (2014), Dolado et al. (2020)). This results in the elasticity of capital to skilled labor of $\frac{1}{1-\rho} = 0.67$ and the elasticity of capital to unskilled labor $\frac{1}{1-\sigma} = 1.67$. The remaining parameters in the production function are calibrated to ensure the steady-state predictions of the model are consistent with the data. I calibrate $\mu = 0.62$ to obtain the labor share in income of 69% and I choose share of capital to composite

[37] see Schmitt-Grohe and Uribe (2007) and the references reported in their paper.

input $\lambda = 0.8$ to target the skill premium of 1.67[38]. Both of these targets are consistent with the US data for the period 1979–2018 used in Section 2. Government spending-to-output ratio is set equal to 20% and public debt is calibrated at 67% of annual output. An interest rate smoothing parameter ρ_r is set to 0.7, the elasticity of r_t with respect to inflation deviations ρ_π is 1.5, and the elasticity of r_t with respect to output gap ρ_{y_t} is 0.2. The parameters of the tax feedback rule are $\phi_D = 0.3$ and $\phi_Y = 0.34$.

The quantitative impact of uncertainty on the macroeconomy depends on the calibration of the size and persistence of the uncertainty shock process. For the exogenous process of technology I use the value of persistence $\rho^{\mathcal{Z}}$ of 0.8 and the average standard deviation $\sigma_{\mathcal{Z}}$ is set to 0.01. The persistence of the volatility process is generally assumed to be quite high (Basu and Budnick (2017) and Gilchrist et al. (2014)). SVAR evidence shows that my measure of macroeconomic uncertainty falls gradually to about 30% of its peak in 4 quarters. If I approximate the SVAR uncertainty shock by an AR(1) process in the DSGE model, the persistence parameter should be approximately $\rho^{\sigma^{\mathcal{Z}}}$ equal to 0.7 at quarterly frequencies. There is no general consensus regarding the value of the standard deviation of the volatility shock. I thus calibrate it at 0.03 to match the empirical standard deviation of my uncertainty indicator in the SVAR. The calibrated values of the model parameters are summarized in Table 1.

[38]Krusell et al. (2000) do not report their estimates of unskilled labor weight in composite input share μ and capital weight in the composite input share λ.

Table 1: Benchmark parameter calibration

Preferences		
β	0.99	Discount factor equivalent to 4% average annualized risk-free real interest rate p.a.
ϕ^s	1.4	Parameter for skilled Frisch elasticity of labor supply (skilled Frisch elasticity equals to 2.5)
ϕ^u	1.4	Parameter for unskilled Frisch elasticity of labor supply (unskilled Frisch elasticity equals to 2.5)
σ_u^s	1	Relative risk aversion parameter of skilled
σ_u^u	1	Relative risk aversion parameter of unskilled
b_c	0.5	Habit in consumption parameter
σ_X^s	0.2	Skilled wealth effect on labor supply
σ_X^u	0.2	Unskilled wealth effect on labor supply
Production		
δ	0.025	Capital depreciation rate; 10% depreciation rate p.a.
ϕ_i	5	Investment adjustment cost
σ	0.401	Substitutability btw skilled (or capital) and unskilled labor
ρ	-0.495	Capital-skill complementarity
π^s	0.21	Share of skilled labor in population
π^u	0.69	Share of unskilled labor in population
π^e	0.10	Share of entrepreneurs in population
Calvo Price rigidity		
θ_p	11	Elasticity of substitution of goods equivalent to 10% price markup
κ_p	0.85	Nominal price rigidity
χ	1	Price indexation
Monetary and fiscal policy		
ρ_r	0.7	Interest rate smoothing
ρ_π	1.5	Taylor-coefficient on inflation
ρ_y	0.2	Taylor-coefficient on output
ϕ_D	0.3	Tax feedback to debt
ϕ_Y	0.34	Tax feedback to output
$\frac{g}{y}$	0.2	Steady-state government spending to GDP
Shocks		
ρ^z	0.8	Technology autoregressive parameter
σ^z	0.01	Steady state TFP volatility
ρ^{σ^z}	0.7	Persistence of volatility of TFP shocks
η_{σ^z}	0.0338	Magnitude of the productivity uncertainty shock

6 Theoretical Results: Impulse Response Analysis

First, I discuss the impact of an uncertainty shock on the economy. Then, I analyze in more detail the transmission of the uncertainty shock as well as the underlying amplification mechanisms.

6.1 Effects of Productivity Uncertainty Shocks

Figure 4 displays impulse responses of aggregate variables to a one standard deviation shock in technology uncertainty. The solid blue line shows the responses of the model with capital-skill complementarity as described in Section 3. The dashed red line shows the responses of the corresponding model without capital-skill complementarity. First, I investigate the effects of an increase in aggregate uncertainty in the model with capital-skill complementarity. Consistent with the SVAR evidence presented in Section 2, a one standard deviation shock to the volatility of productivity causes a persistent downturn in aggregate economic activity (see blue solid lines in Figure 4). An uncertainty shock generates a reduction in aggregate demand, which leads to a contraction in output, consumption and investment. It leads to a rapid decrease in output of 0.47%, before output returns to its initial level after 10 quarters. Reacting to weaker consumer demand, firms decrease their demand for production inputs. Investment and employment fall, together with wages and capital rents.

Figure 4 displays impulse responses of the relative variables of interest to a one standard deviation productivity uncertainty shock. Due to capital-skill complementarity skilled and unskilled workers have different roles in production. This implies that skilled and unskilled workers do not endure the same decrease in labor income. Skilled workers experience a steeper fall in their wages than unskilled workers leading to a fall in the skill premium of about -0.1%. On the other hand, employment ratio of skilled-to-unskilled workers increases by 0.15% (see blue solid lines in Figure 5).

6.2 Inspecting the Transmission Channels of Uncertainty

When analyzing how uncertainty shocks affect economic activity in a general equilibrium framework, many channels play a role in determining the responses to these shocks. The responses of the endogenous variables depend on the interplay of precautionary household behavior, nominal rigidities and the capital-skill complementarity channels. The drop in aggregate output is caused by the interaction of precautionary households' behavior and nominal price rigidity. Risk-averse households are driven by precautionary motives and respond to higher uncertainty by adjusting consumption downward and increasing savings. As uncertainty about future income increases and the marginal utility of wealth goes up, households adjust their labor supply upward. From the production side, firms respond to the fall in demand by lowering demand for production inputs. Higher labor supply of both skilled and unskilled workers lowers firms' marginal costs. Due to the presence of nominal price rigidities, prices cannot adjust instantly to changing conditions, leading to an increase in firms' mark-ups. The wedge between markup and marginal cost increases resulting in a decrease in labor demand. When the degree of price stickiness is sufficiently high, uncertainty generates a downward shift in labor demand, which is large enough to translate in a fall in investment, labor hours, and output. The marginal products of capital, skilled and unskilled labor fall because of this demand-driven fall in output. This is the aggregate demand channel, which relies on the presence of price stickiness (see Basu and Budnick (2017))[39]. The response of inflation depends on the interaction of aggregate demand channel and upward nominal pricing bias channel[40], which both rely on nominal price rigidities. The nominal pricing bias channel leads firms to increase their prices due to the asymmetry of the profit function – with price rigidities firms find it less costly to set a price that is too high relative to the competitors, rather than setting it too low. In the model the cumulative effect of these two channels produces an increase in inflation, which means that the effect of upward pricing by firms dominates the increase in households' precautionary savings. I find therefore that an increase in uncertainty leads to a rise in inflation due to the stronger upward nominal pricing bias channel, consistent with Born and Pfeifer (2014) and Fernandez-Villaverde et al. (2015).

While the price stickiness channel plays an important role in driving aggregate consumption and output down, ***capital-skill complementarity*** plays an equally important role in understanding the effects of uncertainty on macroeconomic variables and is key to generate responses of relative wages and employment in line with the data. Figure 4 and Figure 5 display impulse responses in the the model with (solid blue lines) and without capital-skill complementarity (red dashed lines) for aggregate and relative variables respectively. The difference between the two models comes from the production function. In the benchmark model, the production function is given by Equation

[39]The price stickiness channel is used by Basu and Budnick (2017) to produce positive co-movement between consumption, investment, and output.

[40]The nominal pricing bias arises in the Phillips curve due to the presence of nominal rigidities that make firms more prudent when setting nominal prices of goods (see Fernandez-Villaverde et al. (2015)).

3.2.1 and the model without capital-skill complementarity is described in Appendix A. The presence of capital-skill complementarity in production amplifies the responses of aggregate economy. The capital-skill complementarity channel acts on top of the aggregate demand and precautionary labor supply channels. Importantly, consistent with Dolado et al. (2020), capital-skill complementarity gives rise to a feedback loop between employment and capital investment: following aggregate uncertainty shocks that lower demand, capital investment is discouraged making complementary skilled workers less productive, which further reduces capital investment. This further fall in investment creates additional demand pressures leading to a sharper fall in aggregate output compared to the standard production function. In the absence of capital-skill complementarity, i.e. when skilled and unskilled labor are perfect substitutes, the wage of skilled workers declines in the same magnitude as the wage of unskilled workers due to the equality of marginal products of the two types of labor, and the skill premium does not move. Labor ratio stays constant as well since skilled and unskilled workers are perfect substitutes.

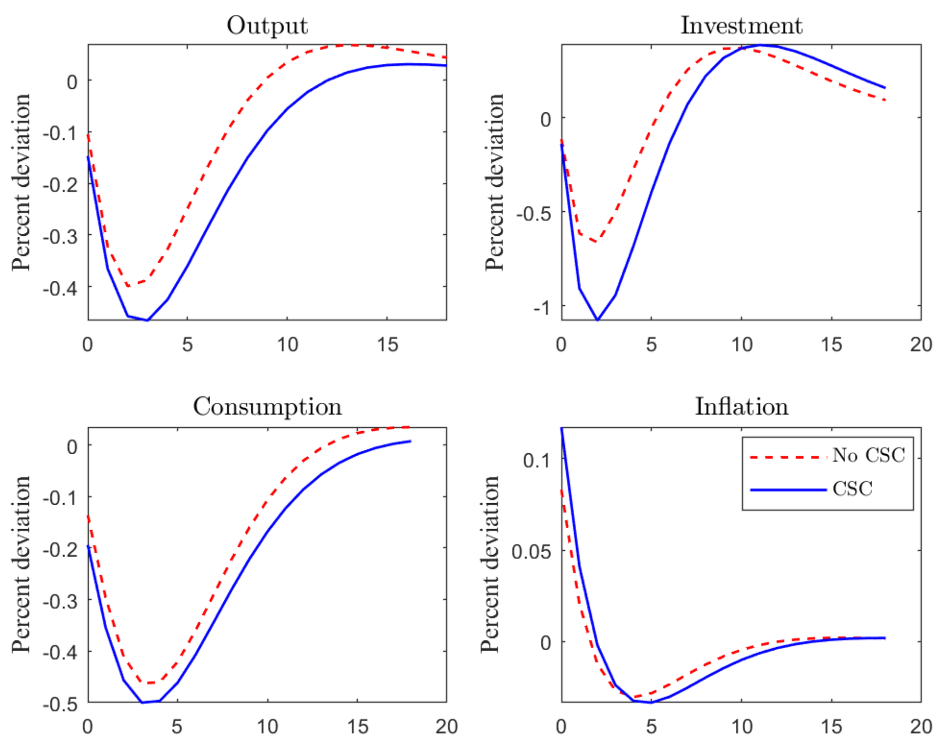


Figure 4: Impulse response functions to TFP uncertainty shock in the benchmark model with and without CSC – aggregate variables.

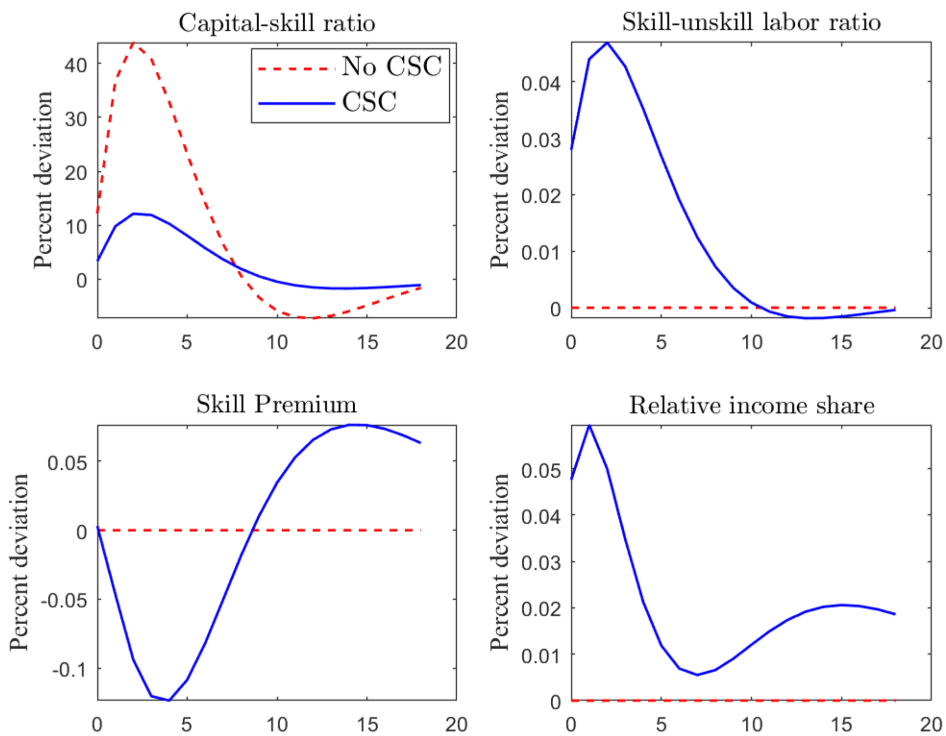


Figure 5: Impulse response functions to TFP uncertainty shock in the benchmark model with and without CSC – relative variables.

As shown in Section 4, the response of the skill premium depends on the changes in capital-to-skilled labor ratio and relative labor ratio. In the model both capital-to-skilled labor ratio and relative skilled-to-unskilled labor ratio increase following the uncertainty shock (see blue solid lines in Figure 5). Capital adjusts slower than labor in response to an increase in uncertainty. Higher capital-to-skilled labor ratio dampens the decline in skilled labor demand and productivity of skilled labor. Thus, the relative labor ratio and the skill premium tend upward. Provided the relative labor ratio increases sufficiently enough, the skill premium falls in line with the empirical evidence from Section 2. Asymmetric wealth effect in preferences and asymmetric wage rigidity allow to generate movements in the relative labor supply curve in response to uncertainty as detailed in Section 4. These features represent additional transmission channels and it is worth inspecting how both of them affect the relative labor ratio and the skill premium. The benchmark impulse responses of the model (Figure 4 and 5) consider the latter option, asymmetric wage rigidity, but both cases are arguably reasonable. Theoretical model presented in Section 3 is able to replicate the rise in the skill-to-unskilled labor ratio as well as the reduction in the skill premium by relying on the interaction of complementarity of capital and skilled labor with motives for precautionary labor supply and wage rigidity.

Asymmetric Wage Rigidity I consider asymmetric wage rigidity with $\rho^{w,s} = 0.65$ and $\rho^{w,u} = 0.8$. Asymmetric wage rigidity between skilled and less skilled individuals is supported by recent empirical work on the US labor market, which finds that low-skilled wages are more sticky than skilled wages. The Wage Rigidity Meter at the San Francisco Fed uses the same data source as I do in this paper and reports that nominal wage rigidities decrease with educational attainment[41]. Additionally, Doniger (2019) provides evidence for the United States in support of wages of workers with a bachelor's degree or more being less rigid and pro-cyclical than wages of high school dropouts. Parker and Vissing-Jorgensen (2010) documents the same finding that high-skilled earnings are more cyclical than lower-skilled ones. Assumption that skilled wages are easier to adjust than unskilled wages allows to dampen the capital-skill complementarity effect and obtain the fall in the skill premium in line with the empirical results in Section 2. Rigidity attenuates wage movements. Thus, stronger wage rigidity is associated with a weaker decline of the wage. Since skilled wages are more

[41]The Wage Rigidity Meter at the San Francisco Fed shows that the fraction of workers receiving an annual wage change of zero is much higher among the U.S. workers who completed only high school than among those who obtained a college degree. The data for these statistics were drawn from a matched Current Population Survey dataset.

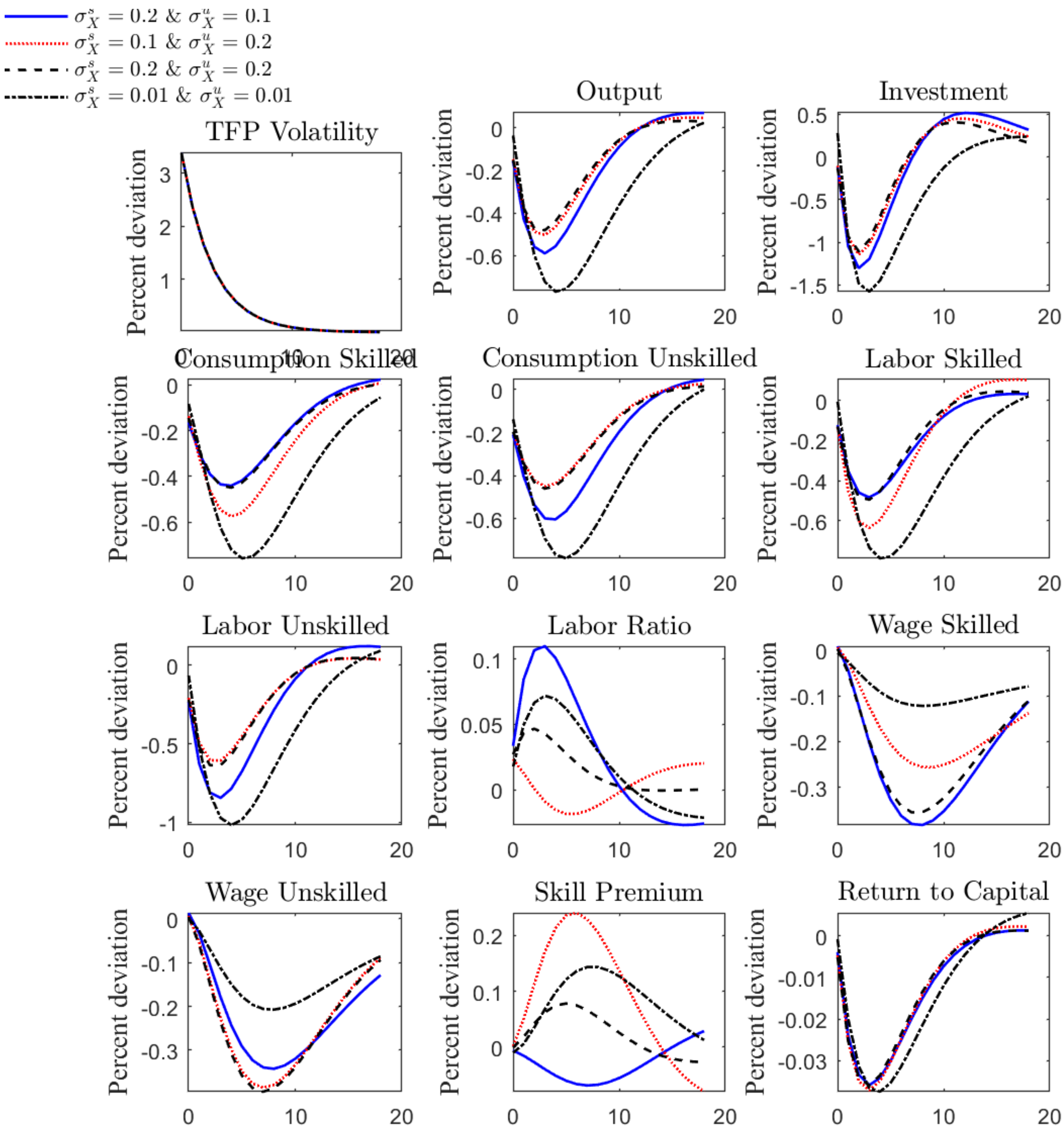
flexible, firms find it relatively easier to adjust more skilled wages, whereas unskilled wages are more constrained by the rigidity and can be adjusted to a lower degree. As a result, firms decrease more skilled wages, which in turn attenuates the fall in the relative demand for skilled labor (see Figure 4 and Figure 5). Consequently, the relative labor ratio increases more than when wage rigidity is symmetric so that the skill premium falls.

Asymmetric Wealth Effect The impact of wage movements on hours worked is captured by the wealth effect on labor supply. According to the wealth effect, when consumption decreases, leisure becomes relatively less attractive and labor supply increases. Wealth effect represents an additional channel of how negative shocks, which affect consumption, influence households' labor supply. Since it is an important feature in the model, I investigate its role in more detail. I vary the values of the parameters that control the strength of the wealth elasticity of labor supply σ_X^s for skilled workers and σ_X^u for unskilled workers while I keep wage rigidity symmetric at $\rho^{w,s} = \rho^{w,u} = 0.8$. First, I set both $\sigma_X^s = 0$ and $\sigma_X^u = 0$ so that the benchmark preferences of the form à la Jaimovich and Rebelo (2009) collapse to the Greenwood et al. (1988) (GHH) preference specification. The results are displayed by orange solid line in Figure 9. The preferences of the GHH form amplify the negative impact of uncertainty relative to the benchmark case (blue solid line in Figure 9). With GHH preferences wealth effect is zero and the labor supply becomes more elastic since it depends only on the current real wage, and, importantly, is independent of the marginal utility of income. Zero-wealth effect implies that (i) labor supply depends only on the real wage and not consumption, and (ii) expected consumption growth depends on the real interest rate and on the growth rate of expected labor. Therefore, movements in consumption do not affect labor supply. The difference with the benchmark case is that, in the benchmark labor supply Equation 3.1.7, variations in consumption do affect labor supply.

Figure 6 shows impulse response functions when wealth effect is lower than the benchmark value, symmetric and asymmetric. First, when the degree of wealth effect is higher for both types of workers, an increase in labor supply in response to negative changes in consumption is larger, which attenuates the fall in employment and output (see black dashed lines in Figure 6). On the other hand, lower symmetric wealth effect attenuates precautionary labor supply and leads to a steeper fall in employment, which is needed to equilibrate the market (see black dash-dot lines in Figure

6). Now, I turn to the case of asymmetric wealth effect. I assume that skilled households have a stronger degree of a wealth effect than unskilled households by setting $\sigma_X^s > \sigma_X^u$ with $\sigma_X^s = 0.2$ and $\sigma_X^u = 0.1$ (see blue solid lines in Figure 6). The evidence suggests that individuals with more skilled jobs and higher education tend to spend like households with higher income (Calvet and Comon (2003)) and, thus, have higher wealth elasticity of labor supply. This asymmetricity increases the extent of precautionary labor supply by skilled households compared to unskilled households. As a result of an uncertainty shock, more skilled (wealthier) agents experience a smaller increase in marginal utility of wealth than less skilled individuals, and hence choose to cut consumption by less, increasing the degree of their labor supply. Larger skilled labor supply attenuates the fall in skilled employment and puts a downward pressure on the skilled wage. Consequently, the relative employment increases and the skill premium falls.

Figure 6: Model IRFs: Asymmetric wealth effect.



Effects on labor income shares Both income shares of skilled and unskilled labor decrease. The cumulative changes, i.e. the fall in relative wages and the increase in relative employment, generate a rise in the relative skilled-to-unskilled labor share $\frac{w_t^s n_t^s}{w_t^u n_t^u}$ (see blue solid lines in Figure 5, bottom right panel). This implies that the aggregate effect of the uncertainty shock is more harmful for workers with lower skills – even though both types are worse off in absolute terms. Macroeconomic uncertainty shocks increase labor income inequality by raising the relative income share of skilled workers. Although firms cut wages of skilled workers more than of unskilled workers, the more skilled are more likely to preserve their employment. The rise in the relative skilled-to-unskilled income share is mainly driven by the increase in the relative employment of skilled workers. As explained above, capital-skill complementarity increases the relative demand for skilled labor, which contributes to an increase in the relative employment and in the relative skilled-to-unskilled income share.

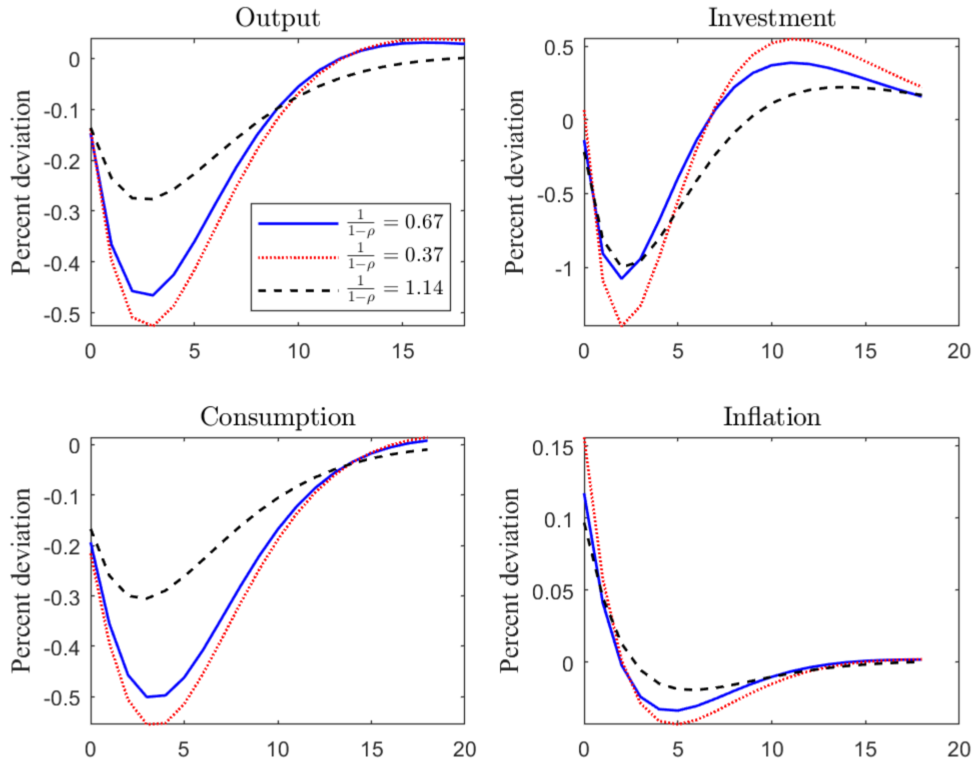
6.3 Sensitivity analysis

The previous analysis has shown that the response of the economy and, in particular relative labor market variables, to the volatility shock relies on the interaction of capital-skill complementarity with precautionary motives and aggregate demand. In this subsection I explore the sensitivity of the model to various its features, which allow to gain a deeper insight into the transmission mechanisms. In order to identify roles of these features of the model, I either vary or shut them off. In particular, I look at the degree of complementarity between production factors, risk aversion, and Frisch elasticity of labor supply.

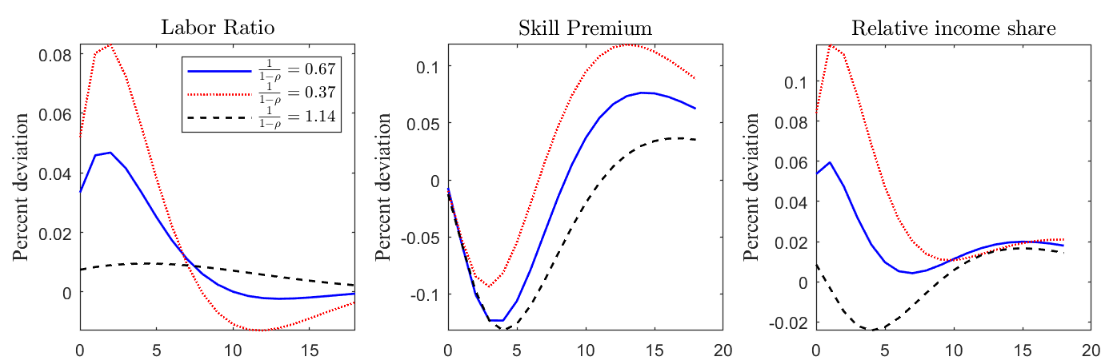
Capital-Skill Complementarity: Elasticity of Substitution Capital-skill complementarity is captured in the model through the elasticity of substitution between capital and skilled labor, $\frac{1}{1-\rho}$. Figure 7 depicts responses of the key variables of interest when we vary this elasticity. Benchmark calibration of the elasticity of capital and skilled labor is 0.67 and the elasticity of capital and low-skilled labor is $\frac{1}{1-\sigma} = 1.67$. I consider cases of strong complementarity (i.e. lower elasticity of substitution) $\frac{1}{1-\rho} = 0.37, \rho = -1.7$ (red dotted line) and of weak complementarity $\frac{1}{1-\rho} = 1.14, \rho = 0.12$ (black dashed line). In this case I still keep the elasticity of substitution between capital and skilled labor lower than the elasticity of substitution between capital and unskilled labor, even though capital and skilled labor are now substitutes, i.e. and $\frac{1}{1-\sigma} > \frac{1}{1-\rho}$. Figure 7 plots the corresponding impulse response functions of the two cases in comparison with the benchmark model.

Higher degree of complementarity, which corresponds to lower elasticity of substitution (see red dotted lines), increases the responsiveness of skilled wage to the fall in capital. In response to a contraction in aggregate demand, the fall in capital investment makes skilled employment less productive, inducing a further fall in skilled wages. Larger decreases in wages in turn amplify the drop in consumption via income effect leading to a sharper decline in output. Higher degree of complementarity disfavors labor income of skilled households even more than in the benchmark case, further decreasing the skill premium (see Figure 7b). Imposing substitutability between capital and skilled labor (see black dashed line in Figure 7) dampens responses to an uncertainty shock. When capital and skilled labor are substitutes, firms will not decrease their demand for skilled labor as much as when they are complements.

As the next exercise, I change the elasticity of substitution between the skill-capital composite and unskilled labor, $\frac{1}{1-\sigma}$ while keeping the elasticity of substitution between capital and skilled labor, $\frac{1}{1-\rho}$ constant. In addition to the benchmark calibration with $\sigma = 0.401$, I consider an alternative values of σ used in the literature. One is estimated by Duffy et al. (2004), which gives $\sigma = 0.7899$ that implies higher elasticity of substitution ($\frac{1}{1-\sigma} = 4.76$) than in the benchmark case. Figure 8 shows that, as σ becomes smaller, the effects of an increase in uncertainty become more muted. Higher elasticity of substitution between the capital-skill composite and unskilled labor makes firms more flexible. Degree of substitutability of production inputs presents a type of real rigidity. Larger σ decreases this real rigidity, which tends to dampen the recessionary effects of uncertainty. A Larger value of σ implies weaker capital-skill complementarity, so that the fall in investment induced by uncertainty is associated with a smaller decline in the skill premium and a weaker incentive for reducing skilled employment.

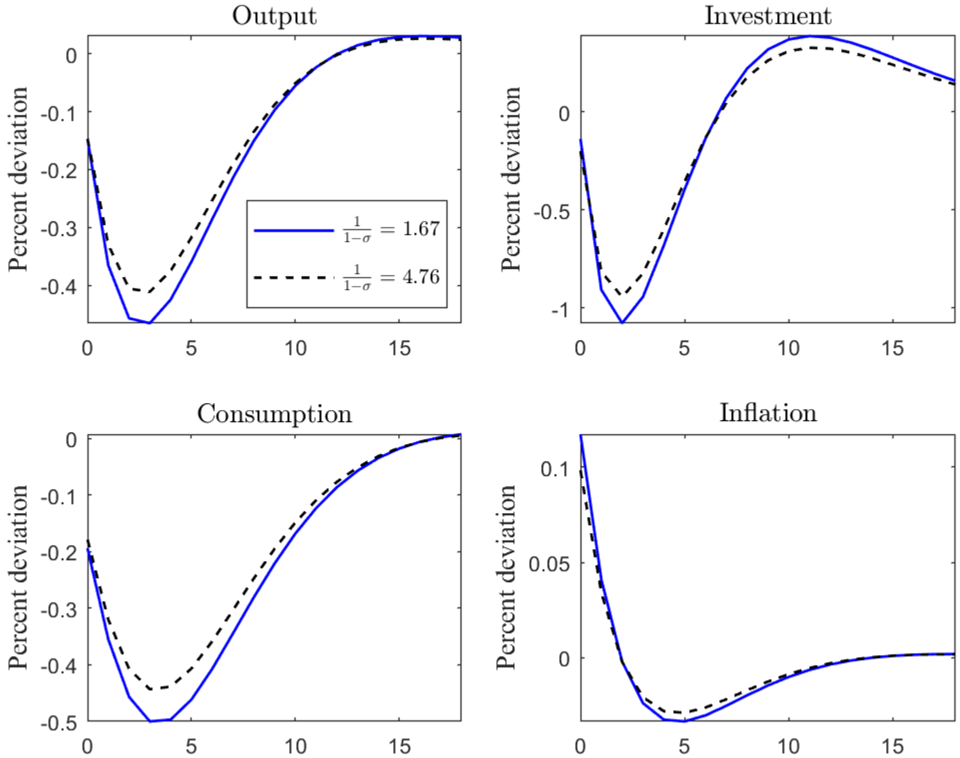


(a) Impulse response functions to TFP uncertainty shock in the benchmark model – aggregate variables.

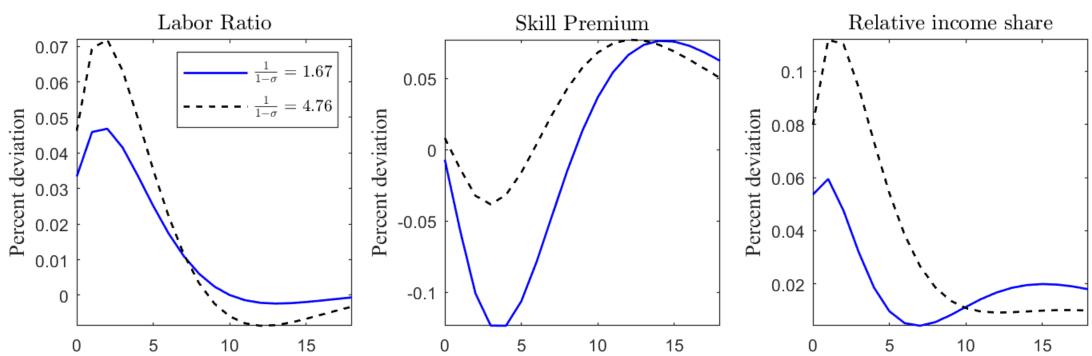


(b) Impulse response functions to TFP uncertainty shock in the benchmark model – relative variables.

Figure 7: Impulse response functions to TFP uncertainty shock – elasticity of substitution btw capital and skilled labor.



(a) Impulse response functions to TFP uncertainty shock in the benchmark model – aggregate variables.



(b) Impulse response functions to TFP uncertainty shock in the benchmark model – relative variables.

Figure 8: Impulse response functions to TFP uncertainty shock – elasticity of substitution btw capital and skilled labor composite and unskilled labor.

Risk Aversion The degree of households' precautionary behavior depends on the value of relative risk aversion. The effect of varying increasing the risk aversion parameter σ_u is shown in rose dash-dotted line. When I increase this parameter from the benchmark value 1 to 2, the agents' precautionary motive becomes more pronounced and consumption drops by 0.33 percentage points more than in the benchmark calibration (see Figure 9, pink dot-dash lines).

Frisch Elasticity of Labor Supply Frisch elasticity indicates the extent to which people change their labor supply in response to changes in the wage. First, I discuss symmetric Frisch elasticity. In the model, the implications of different values of Frisch elasticity are illustrated with Equation 3.1.5 a first order condition for marginal utility of consumption. For convenience, I consider no habit formation with $b_c = 0$. Marginal utility of consumption in Equation 3.1.5 with $b_c = 0$ writes as

$$\lambda_t^i = \left(c_t^i - \kappa_h X_t^i \left(h_t^i\right)^{\phi}\right)^{-\sigma_u} + \sigma_X \upsilon_t^i (c_t^i)^{\sigma_X - 1} (X_{t-1}^i)^{1-\sigma_X} \tag{6.3.1}$$

A positive shock to the volatility of productivity leads to an increase in the marginal utility of consumption, as detailed in the preceding analysis of impulse responses. $\left(h_t^i\right)^{\phi}$ is increasing in the value of the Frisch elasticity of labor supply $\frac{1}{\phi-1}$ provided $h_t^i \in (0,1)$. Equation 6.3.1 shows that a fixed amount of drop in current consumption translates into a larger increase in the marginal utility of wealth λ_t^i when the Frisch elasticity is high, holding everything else constant. Consequently, higher λ_t^i encourages households to supply more labor, which dampens the fall in aggregate employment, leading to a smaller contraction in output than that with a lower Frisch elasticity. Figure **??** displays impulse responses for cases of low (green dotted lines) and benchmark (blue solid lines) Frisch elasticity. The impulse responses confirm the intuitions - a negative impact of a 1-sd productivity uncertainty shock is larger when Frisch elasticity of labor supply is low. Lower Frisch elasticity, magnifies negative impact of the uncertainty shocks on the economy (see Figure 9, green dotted lines). Lower Frisch elasticity decreases the willingness of agents to work if the wage decreases. Thus, it attenuates precautionary labor supply motives and produces a stronger response of hours worked to changes in the wage. Consequently, an uncertainty shock produces a stronger recession when labor supply elasticity is low. On the other hand, benchmark value of Frisch elasticity, which is higher, attenuates the negative impact of the uncertainty shock (see Figure 9, blue solid lines).

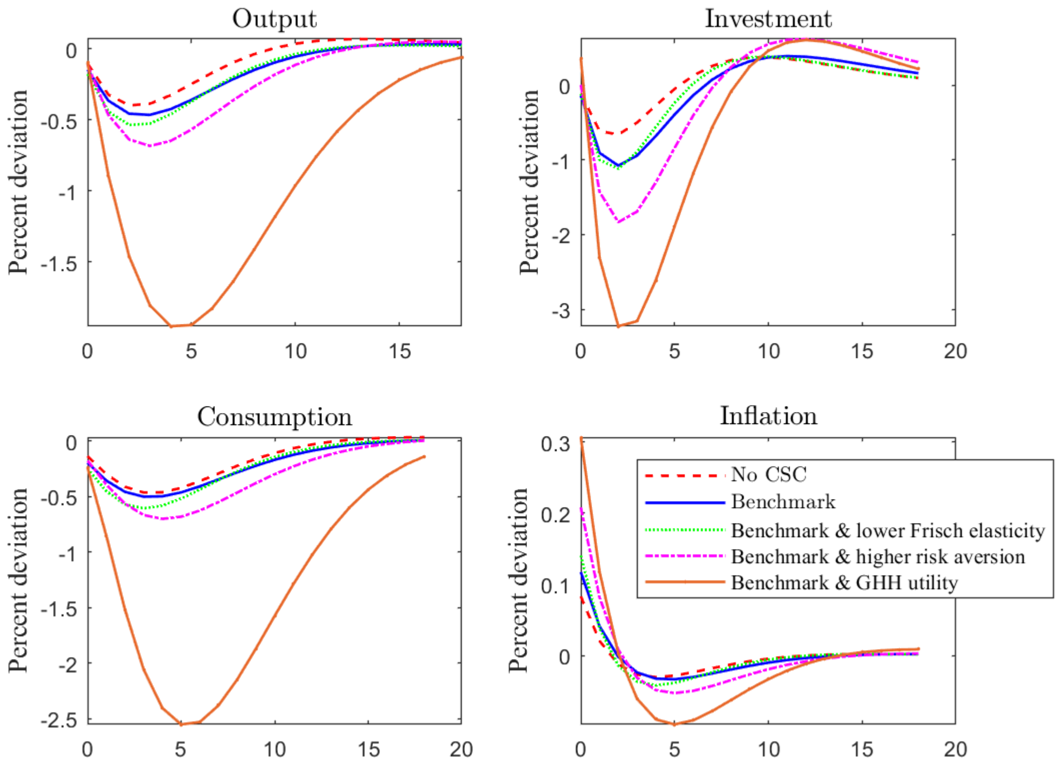


Figure 9: Impulse response functions to TFP uncertainty shock – aggregate variables.

7 Conclusion

In this paper I showed that aggregate uncertainty has a heterogeneous impact on employment and wages of skilled relative to unskilled workers. On the empirical side, I documented that while generating a contraction in aggregate economic activity, heightened macroeconomic uncertainty induces a fall in relative wages and a rise in relative employment of skilled to unskilled labor. Heterogeneity of workers in skills is an important feature of the data that should not be overlooked when studying the propagation of uncertainty shocks and disentangling mechanisms through which uncertainty affects the economy. On the theoretical side, I showed that considering differences across skill levels of labor inputs and their different degrees of complementarities and (or) substitutabilities with physical capital in a New-Keynesian model allows to better understand the transmission mechanism of elevated uncertainty to the real economy. A macroeconomic uncertainty shock increases disparities in labor earnings of skilled to unskilled workers since it generates a decline in the relative wage but raises relative employment of skilled workers. I find that the interaction of capital-skill complemetarity and precautionary labor supply is crucial in delivering this result. The presence of capital-skill complementarity amplifies the responses of relative labor demand and relative labor supply. As such, it is important to highlight this mechanism in addition to existing propagation channels of uncertainty shocks, namely aggregate demand and precautionary motives, in order to have a deeper understanding of the implications of macroeconomic uncertainty shocks.

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Appendices

A Production Function without Capital-Skill Complementarity

In the benchmark model the form of the production function is a nested CES composite of production factors in Equation 3.2.1, and in the counterfactual model without capital-skill complementarity the form of production function is given by Equation A.1. In the case without capital-skill complementarity I assume a production function, the structure of which allows to impose perfect substitutability between skilled and unskilled labor inputs. For this purpose, I generalize a constant returns to scale Cobb-Douglas form of production function with aggregate capital (k_t) and aggregate labor (n_t) services, i.e. $y = \mathcal{Z}_t k_t^{\iota} n_t^{1-\iota}$, where capital and aggregate labor are neither complements nor substitutes. In doing so I let labor input, n_t, be a constant elasticity of substitution (CES) function of composite skilled and unskilled labor, i.e. $n_t = (\omega(n_t^s)^{\nu} + (1-\omega)(n_t^u)^{\nu})^{\frac{1}{\nu}}$. I assume that skilled and unskilled hours are perfect substitutes by setting the elasticity of substitution between skilled and unskilled labor equal to one. The production function becomes

$$y = \mathcal{Z}_t k_t^{\iota}(\omega(n_t^s)^{\nu} + (1-\omega)(n_t^u)^{\nu})^{\frac{(1-\iota)}{\nu}} \tag{A.1}$$

with $\omega = 0.5$, $\nu = 1$ (governs substitution between 2 labor types with $\nu = 1$ perfect substitutes), and the income share of capital ι is calibrated to obtain a labor income share of 69%.

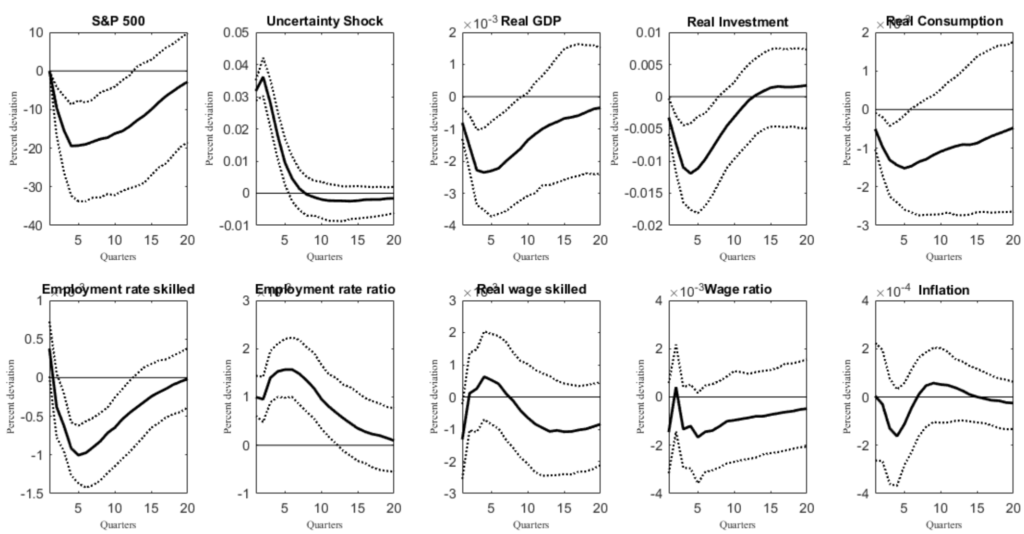
B Empirical Robustness

The benchmark SVAR presented in Section 2 revealed two stylized facts – a 1-sd uncertainty shock diminishes the skill premium as well as it raises the employment rate ratio. In this section, I examine the robustness of the benchmark empirical model along several dimensions. I show that the main results regarding the behavior of the aggregate variables, the skill premium and employment rate ratio hold, if I include stock prices in the SVAR, order uncertainty last in the SVAR, use higher frequency estimation, restrict analysis to the pre-2007 financial crisis sample period.

B.1 Control for the Stock Market

I re-estimate the benchmark specification of the SVAR and include the Standard & Poor's 500 Stock Price Index ordering it first, which allows to control for the movements in the stock market[42]. Ordering $S\&P500$ index first implies that the uncertainty measure is contemporaneously affected by shocks to the $S\&P500$ index, but not by the other variables. In the following periods, uncertainty responds to all shocks through its relation with the lags of the variables included in the model. This identification strategy is in line with that in Bloom (2009), Basu and Budnick (2017), Bonciani and Oh (2020). Figure 10 shows that skill premium declines and employment ratio increases after an uncertainty shock, which is consistent with the baseline results. Including stock prices in the SVAR produces a slightly larger decline in investment, consumption and skilled employment, and a slightly smaller increase in employment rate ratio and a steeper decline in the skill premium. Overall, the results are very similar to the baseline specification.

Figure 10: Empirical impulse response functions to 1-sd uncertainty shock when including stock prices in the baseline specification.



Note: Solid lines correspond to the median IRFs while the dashed lines are the 14^{th} and 86^{th} percentiles. Horizontal axes indicate quarters. I take logs of the uncertainty measure, to interpret the IRFs in percentage terms. Output, consumption, capital investment, and skilled wage are expressed in logs. Variables enter with two lags, selected according to the Akaike criterion.

[42] It is common practice to include stock prices in such empirical specifications, see other studies, for example, Bloom (2009), Basu and Budnick (2017), Bonciani and Oh (2020)

B.2 Monthly Frequency

Baseline results are robust to using higher frequency estimation. In the benchmark SVAR, I aggregate monthly labor market data – wages and employment rates – to quarterly frequency, which comes at the disadvantage of not making full use of high-frequency information. In order to exploit higher-frequency series as well as to ensure the results are robust to the aggregation of labor market series, I estimate a version of the SVAR model with monthly frequency data. The estimated period ranges from to 1979M1 to 2018M12. The monthly SVAR-(p) model reads as follows:

$$AY_t = B\sum_{p=1}^{P} B_p Y_{t-1} + \epsilon_t$$

where p is the number of lags, B_p is the coefficient matrix for the $p-th$ lag of Y_t, ϵ_t is the vector of reduced form zero-mean innovations, and $Y_t = [\sigma_t^z \quad y_t \quad i_t \quad c_t \quad n_t^s \quad \left(\frac{n^s}{n^u}\right)_t \quad w_t^s \quad \left(\frac{w^s}{w^u}\right)_t \quad \pi_t]'$ is a vector comprising the following variables: σ_t^z the macroeconomic uncertainty measure – JLN index from Jurado et al. (2015), y_t – Industrial Production (IP) Index, i_t – real gross private domestic investment[43], c_t – personal consumption expenditures, n_t^s the skilled employment rate defined as the share of skilled employed workers in the skilled labor force, $\frac{n_t^s}{n_t^u}$ the employment rate ratio[44], w_t^s weighted average of real hourly wage of employed in the skilled category[45], $\frac{w_t^s}{w_t^u}$ is the wage ratio (the skill premium), π_t is chain-type price index for personal consumption expenditures. Monthly macroeconomics series are retrieved from FRED, Federal Reserve Bank of St. Louis; https://fred.stlouisfed.org/series/. The monthly labor market time series are adjusted for seasonality using the X-13-ARIMA algorithm. I take logs of the uncertainty measure, to interpret the impulse response functions in percentage terms. IP index, real consumption, capital investment, and skilled wage enter the SVAR in log levels. I include six lags in the monthly SVAR, as suggested by the Akaike Information Criterion.

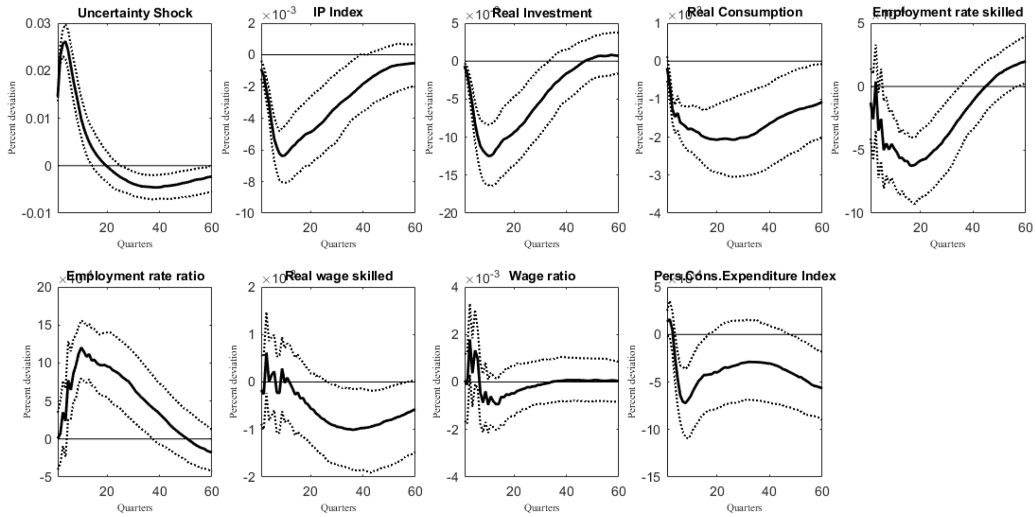
Figure 11a shows the results of the monthly SVAR. Figure 11b displays a specification controlling

[43]Since monthly series are not available, I temporally dissagregate quarterly time series of real gross private domestic investment into monthly series with Chow-Lin method using software JDemetra+ version 2.2.1. Figure 12 displays impulse responses without disaggregated private investment. The Figure 12 shows that not including private investment series does not change the results. JDemetra+ is a tool for seasonal adjustment (SA) developed by the National Bank of Belgium (NBB) in cooperation with the Deutsche Bundesbank and Eurostat in accordance with the Guidelines of the European Statistical System (ESS).

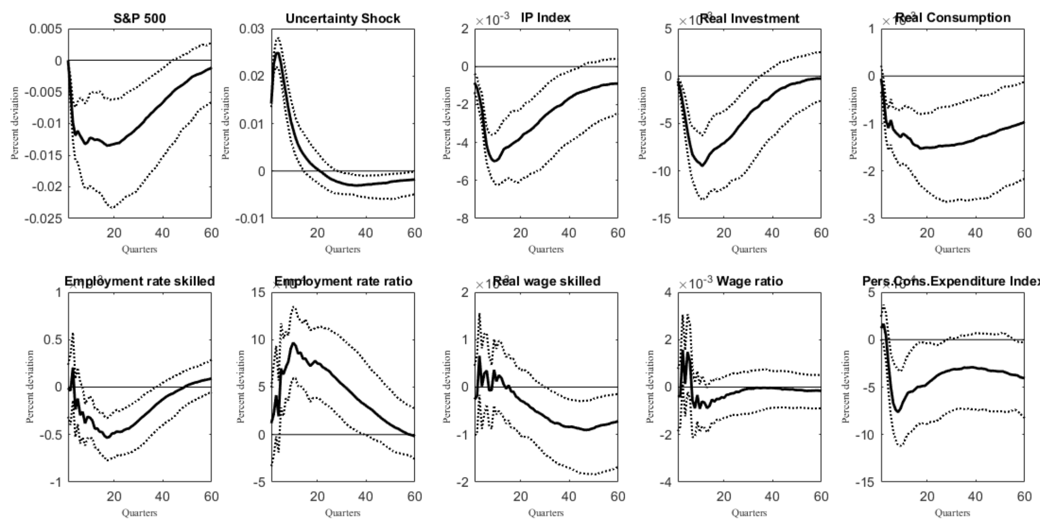
[44]I follow Dolado et al. (2020) and include in the SVAR the wage and employment gaps in addition to the individual variables for skilled workers since it allow to interpret the responses of the respective variables for unskilled workers.

[45]Aggregated real hourly wage of employed in skilled category combines the usual hourly earnings for hourly workers (excluding otc), and nonhourly workers (including otc) in the usual hourly earnings.

for the stock market with $S\&P500$ ordered first. The responses of aggregate variables as well as the wage ratio and employment rate ratio are in line with those obtained from the benchmark quarterly specification. In particular, in both of these specifications with and without $S\&P500$ a 1-sd shock to the uncertainty measure triggers a decline in real economic activity and a rise in the employment rate ratio and a fall in the wage ratio confirming the baseline intuition.



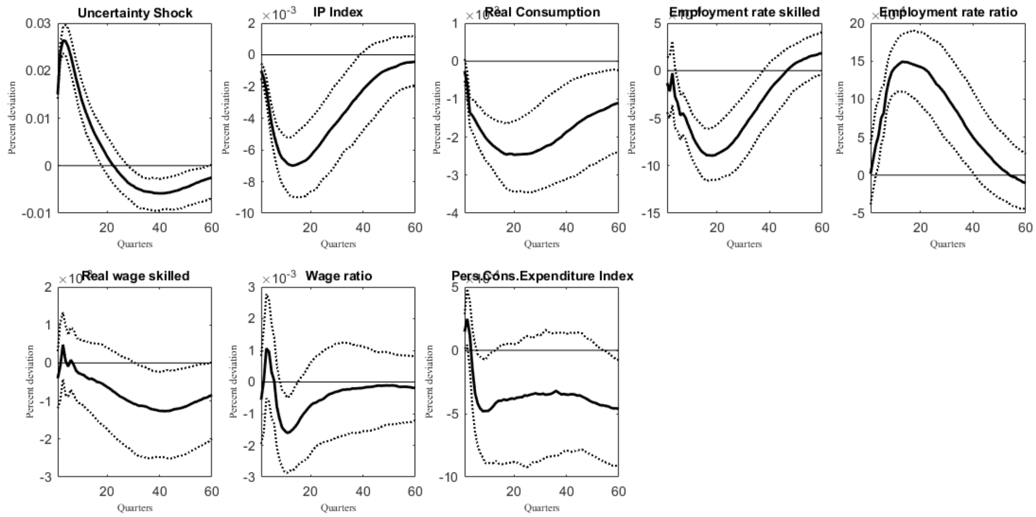
(a) Empirical impulse response functions to 1-sd uncertainty shock with monthly frequency of the data.



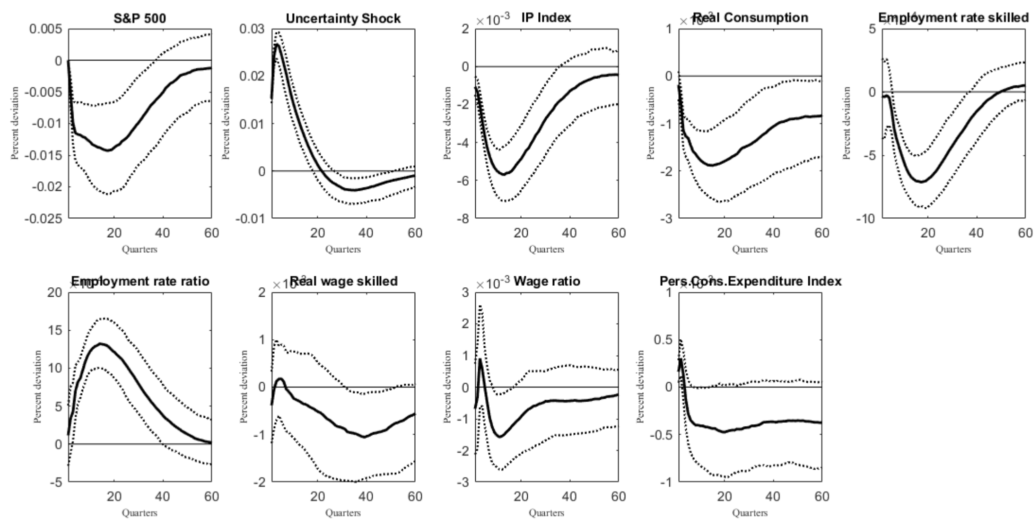
(b) Empirical impulse response functions to 1-sd uncertainty shock with monthly data frequency and controlling for the stock market.

Figure 11: Empirical impulse response functions to 1-sd uncertainty shock with monthly data frequency.

Note: Solid lines correspond to the median IRFs while the dashed lines are the 14^{th} and 86^{th} percentiles. Horizontal axes indicate quarters. Variables enter with six lags, selected according to the Akaike criterion.



(a) Empirical impulse response functions to 1-sd uncertainty shock with monthly data frequency.



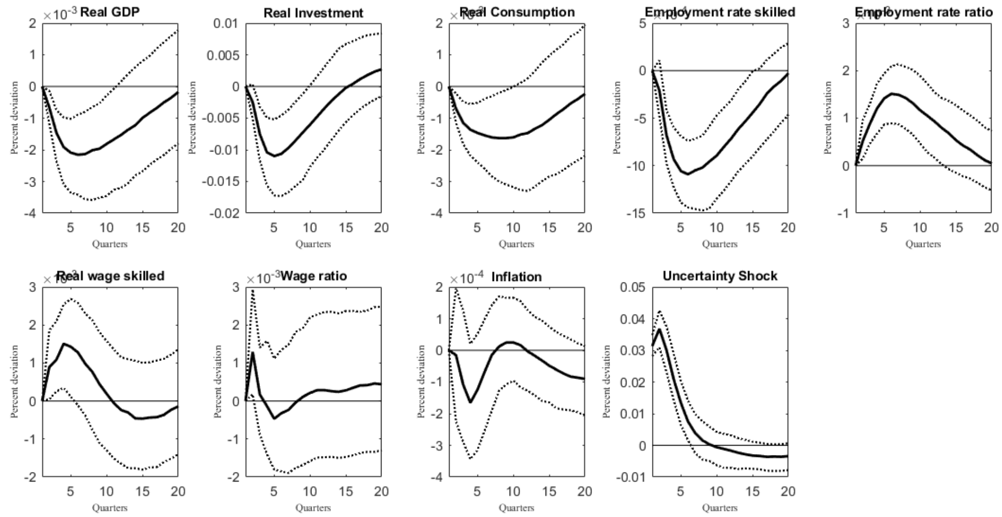
(b) Empirical impulse response functions to 1-sd uncertainty shock with monthly data frequency and controlling for the stock market.

Figure 12: Empirical impulse response functions to 1-sd uncertainty shock with monthly data frequency without private investment.

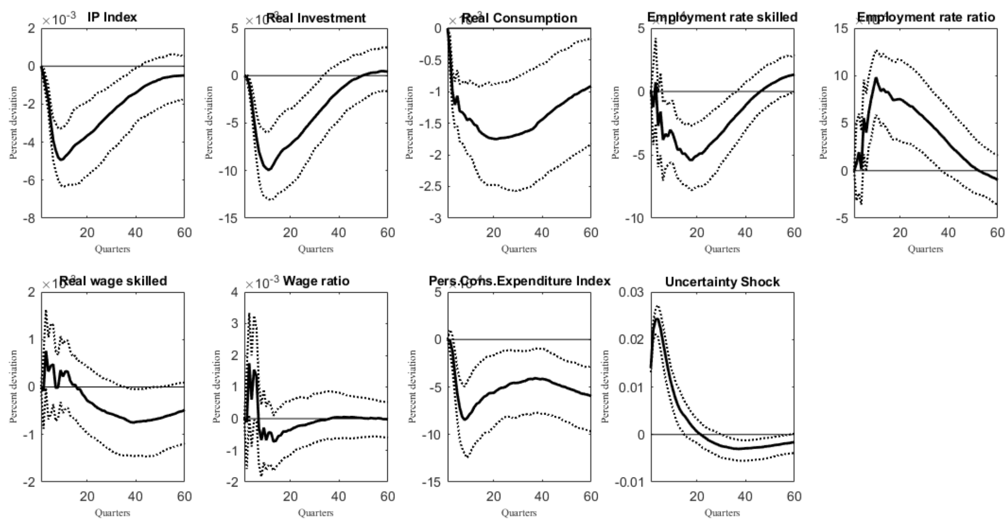
Note: Solid lines correspond to the median IRFs while the dashed lines are the 14^{th} and 86^{th} percentiles. Horizontal axes indicate quarters. Variables enter with six lags, selected according to the Akaike criterion.

B.3 Uncertainty Ordered Last

I check an alternative identification scheme by changing the Cholesky ordering assumed in the benchmark specification. Thus, I order uncertainty last, allowing the uncertainty measure to respond on impact to all the other variables in the model. The other variables will respond with a one-period lag to an uncertainty shock. Figure 13 also shows that the baseline results hold. I conduct this robustness check using both quarterly and monthly data in Figure 13a and Figure 13b respectively, both produce similar findings.



(a) Empirical impulse response functions to 1-sd uncertainty shock with uncertainty shock ordered last in the quarterly SVAR.



(b) Empirical impulse response functions to 1-sd uncertainty shock with uncertainty shock ordered last in the monthly SVAR.

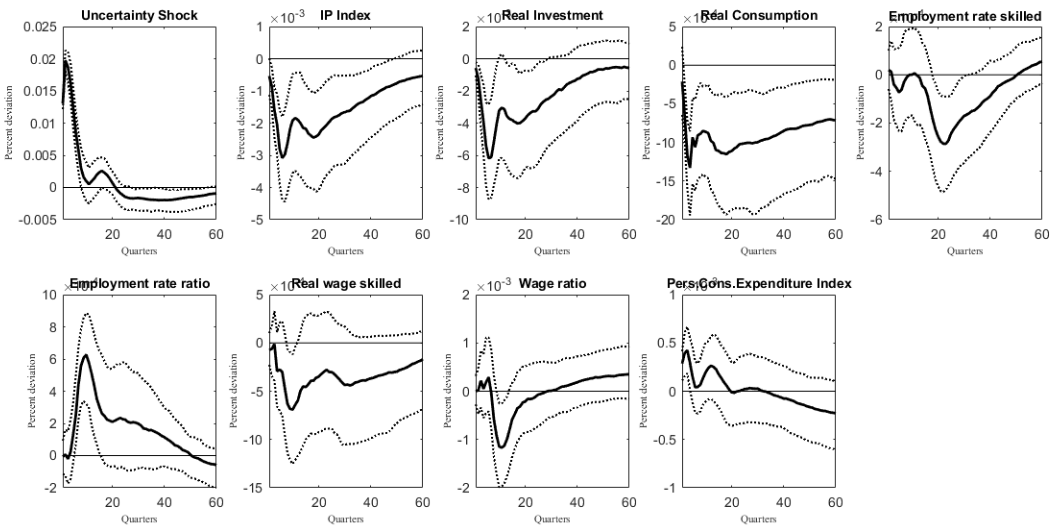
Figure 13: Empirical impulse response functions to 1-sd uncertainty shock with uncertainty ordered last.

Note: Solid lines correspond to the median IRFs while the dashed lines are the 14^{th} and 86^{th} percentiles. Horizontal axes indicate quarters. I take logs of the uncertainty measure, to interpret the IRFs in percentage terms. Output, consumption, capital investment, and skilled wage are expressed in logs.

B.4 Period Prior to 2007

I reduce the sample until 2007M12 in order to exclude the financial crisis. I conduct this robustness check using monthly data in order to preserve sufficient length of the model. Figure 14 shows that the results hold if I exclude the post-2007 financial crisis years.

Figure 14: Empirical impulse response functions to 1-sd uncertainty shock in the monthly specification of SVAR, period ranges from 1979M1 to 2007M12.



Note: Solid lines correspond to the median IRFs while the dashed lines are the 14^{th} and 86^{th} percentiles. Horizontal axes indicate quarters. Variables enter with six lags, selected according to the Akaike criterion.