Abstract

This paper investigates the role of uncertainty shocks in a two-sector, representative-agent sticky price model. We demonstrate that the presence of flexibly priced investment goods fundamentally changes the way uncertainty shocks affect the economy. If investment goods have flexible prices in a sticky price model, an increase in uncertainty lowers the relative price of investment goods and thereby boosts the demand for investment goods. More strikingly, while consumption drops due to precautionary saving in response to uncertainty shocks, the expansion in investment sector can be so strong as to dictate the behavior of aggregate hours and GDP. In other words, uncertainty shocks cause aggregate hours and GDP to increase. We demonstrate that incorporating frictions that inhibits inter-sectoral factor mobility can overcome the negative co-movement problem. The limited factor mobility raises the relative price of investment goods and thus decreases production of investment goods in response to uncertainty shocks. Finally, we present supporting evidence that an exogenous rise in the empirical uncertainty measure indeed not only increases the relative price of investment goods, but also causes co-movement among output, consumption, and investment.

Keywords: Uncertainty shocks, Sticky prices, Sticky Wages, Factor mobility, Relative price of investment goods

JEL Classification: E32
1 Introduction

The recent Great Recession has sparked an idea that an increase in uncertainty can be an important driver of economic fluctuations.\footnote{Following the literature, we use the term “uncertainty” as shorthand for what would more precisely be referred to as “objective uncertainty” or “risk” where the probabilities are well understood. There might be an alternative source of uncertainty, ambiguity, where the probabilities are not well understood.} For example, Bloom (2013) says, “The onset of the Great Recession was accompanied by a massive surge in uncertainty. The size of this uncertainty shock was so large it potentially accounted for around one third of the 9% drop in GDP versus trend during 2008-2009.” Recent empirical results by Alexopoulos and Cohen (2009), Bloom (2009), Leduc and Liu (2012), Bachmann, Elstner and Sims (2013), Baker, Bloom and Davis (2013), and Jurado, Ludvigson and Ng (2015) suggest that uncertainty shocks can produce an adverse effect on aggregate economic activity.

What is the propagation mechanism through which uncertainty shocks affect the key macroeconomic variables? Modern representative-agent DSGE models typically attribute central importance to nominal price rigidities. One-sector DSGE models with nominal price rigidities generate economic fluctuations in response to uncertainty shocks through countercyclical variations in price markups. For example, Basu and Bundick (2012) consider technology and demand uncertainty, and they show that an increase in uncertainty induces a countercyclical markup through sticky prices and creates macroeconomic fluctuations. The same propagation mechanism is shared with Fernandez-Villaverde, Guerron-Quintana, Kuester and Rubio-Ramirez (2011b), who analyze how uncertainty regarding future fiscal policy is transmitted to the macroeconomy.

The reason why higher uncertainty raises firms’ price markup in the presence of nominal rigidities is related to households’ precautionary saving and precautionary labor supply. An increase in uncertainty induces households to lower consumption and supply more labor for a given level of real wages, which in turn reduces firms’ marginal costs. Combined with rigid nominal prices, this precautionary labor supply increases firm’s price markup over nominal marginal costs. A higher markup reduces the demand for consumption, and especially, investment goods. Since output is determined by demand in sticky-price models, output and employment must fall when consumption and investment both decline. In contrast, in one-sector DSGE model with fully flexible prices, a higher uncertainty only induces precautionary saving and labor supply, leaving a firm’s markup unchanged. Thus, higher uncertainty reduces consumption but raises output, investment,
and hours worked in the flexible price model.

However, much of our understanding about the mechanism through which uncertainty shocks affect the economy in a representative-agent DSGE model has come from one-sector sticky price models with symmetric firms using identical price-setting rules. In contrast, we seek to investigate the role of uncertainty shocks in a two-sector (consumption and investment sectors), sticky price model that allows each sector to have a different degree of price rigidity. We demonstrate that our two-sector, sticky price model has strong and unexpected implications for the propagation of uncertainty shocks. In particular, the presence of flexibly priced investment goods fundamentally changes the way uncertainty shocks affect the economy. Flexibly priced investment goods can undo the implications of standard sticky price models with symmetric price rigidity across sectors.

To be more specific, if the prices of consumption goods are sticky, but investment goods have flexible prices, there is a strong tendency that higher uncertainty reduces the production of consumption sector but raises the production of investment sector. This lack of co-movement is inconsistent with business cycle observations. More strikingly, the expansion in the flexible-price investment sector can dominate the contraction in the sticky-price consumption sector, so that higher uncertainty results in an expansion in aggregate output and hours worked. Even though the bulk of GDP consists of sticky-price consumption goods, the presence of flexible-price investment goods makes sticky-price models behave qualitatively similar to the flexible-price model. This scenario contrasts sharply with that of standard sticky-price models with symmetric price rigidity. Furthermore, the presence of flexible-price investment goods also has an impact on the extent to which the production of sticky-price consumption goods contracts in response to uncertainty shocks. Compared to the sticky-price models with identical price rigidity, higher uncertainty entails a much smaller reduction in consumption in the model with flexibly-priced investment goods. Therefore, the presence of flexible-price investment sector significantly undermines the importance of uncertainty shocks as a driver of business cycles in sticky-price DSGE models.

The assumption of the asymmetric sectoral price rigidity is not just a matter of purely theoretical possibility, but seems to be rather a reasonable description of the reality. The consumption sector producing nondurable goods and services, the lion’s share of GDP, has sticky prices. In contrast, the pricing of the investment sector producing durable goods can be better characterized as flexible rather than as sticky. As Barsky, House and Kimball (2003) argue, we often bargain over durable
goods. Other large durables often require considerable customization; this necessitates negotiations, and the discussions about the exact nature of the good are likely to be accompanied by negotiations about prices. This suggests that the transaction prices of many durable goods be effectively flexible. In addition to these conceptual reasons, several empirical findings (e.g., Bouakez, Cardia and Ruge-Murcia (2009) and Bils, Klenow and Malin (2012)) show that construction, residential housing and structure, and durable-goods sector have flexible-price.²

Why does then allowing for the flexible-price investment sector in sticky price model change the propagation mechanism of uncertainty shocks? As mentioned above, higher uncertainty induces a ‘precautionary labor supply’, so that the period after the uncertainty shock is a less expensive time to produce. While the price markups on goods with sticky prices rise above their desired levels, for producers in flexible price sector, the decline in factor prices is merely a beneficial cost shock. If producers in the investment-sector can fully adjust their prices, therefore, the relative price of investment goods becomes temporally cheaper following the increase in uncertainty. In this case, uncertainty shocks, to a certain extent, look like positive investment-specific technology shocks in the Real Business Cycle models. For the investment goods with a low depreciation rate, as Barsky, House and Kimball (2007) emphasize, the intertemporal elasticity of substitution for purchases of such goods is high. Hence, even modest decline in the intertemporal relative price of investment goods can trigger a large shift of expenditure toward that sector and thereby can cause pronounced expansion in production of that sector. Because of the significant increased production of investment sector, aggregate hours worked and GDP rise in response to uncertainty shocks. The expansion in investment sector in turn partially offsets the fall in factor prices induced by the precautionary labor supply. Thus, the rise in price markups on consumption goods is more moderate in the model with flexibly-priced investment goods. As a result, higher uncertainty causes a smaller decline in consumption in the model with flexible-price investment goods than in the model with symmetric price rigidity.

We consider possible several modifications to our baseline two-sector, sticky price model that might help to regain the importance of uncertainty shocks. The introduction of sticky wages to the baseline model only delivers a partial success. While adding sticky wages to the baseline

²For example, Bouakez, Cardia and Ruge-Murcia (2009) find that construction and durable-goods sector have flexible-price by estimating a multi-sector DSGE model. Bils, Klenow and Malin (2012) estimate the frequency of price adjustment using micro-data and find that residential housing and structure are flexibly-priced.
model does cause uncertainty shocks to decrease aggregate hours worked and GDP, production of investment still rises, so that the negative co-movement between consumption and investment prevails. We show that allowing for imperfect factor mobility can lead to a decline in production of investment, successfully generating the co-movement between consumption and investment. The key to the success is that if factors of production cannot freely flow across sectors, the relative price of investment goods can increase in response to the uncertainty shock. When the uncertainty shock causes production of sticky-price consumption goods to fall due to the precautionary saving, capital and labor used for production of consumption goods cannot be immediately refurbished and retrained to that of investment goods, whereas they can in the baseline model. Hence, additional new capital and labor suited to producing investment goods are needed, which raises the marginal costs of investment sector relative to those of consumption sector. If this effect is strong enough to dominate that of precautionary labor, the relative price of investment goods can increase, which in turn causes production of investment goods to fall. In contrast to the baseline model, therefore, uncertainty shocks look like negative investment-specific technology shocks when factors cannot flow freely across sectors.

Finally, we present empirical evidence that the relative price of investment goods significantly increases following an exogenous increase in the empirical measure of uncertainty. This is consistent with the theoretical prediction of our modified sticky price model with inflexible factor mobility. We document that three big episodes of uncertainty displayed by the empirical measure of uncertainty, i.e., the 1973-74 and the 1981-82 recessions and the Great recession of 2007-09, are associated with the increase in the relative price. This observation might suggest that uncertainty shocks cause the relative price of investment goods to rise. We then conduct a VAR analysis to formally examine the dynamic relationship between uncertainty shocks and the relative price of investment goods. A positive innovation to the uncertainty measure leads to a significant increase in the relative price of investment goods. We also find that the exogenous increase in the uncertainty yields co-movement among output, consumption, and investment.

The rest of this paper is organized as follows. Section 2 presents our baseline two-sector, sticky price model. Section 3 shows that the presence of flexible-price investment sector lowers the relative price of investment goods in response to uncertainty shocks, causing the negative co-movement between consumption and investment and resulting in an increase in output and aggregate hours.
Section 4 offers possible resolution to the co-movement problem. In particular, we demonstrate that the imperfect factor mobility leads to an increase in the relative price following uncertainty shocks, so that the co-movement can be restored. Section 5 performs an empirical analysis and shows that a positive innovation to empirical uncertainty measure leads to an increase in the relative price. Section 6 concludes.

2 Model

The economy is populated an infinitely-lived representative household, continua of firms in the two sectors that respectively produce differentiated consumption and investment goods, perfectly competitive final goods firms in the two sectors, and a monetary authority.

2.1 Households

The representative household receives utility from consumption and incurs disutility from allocating labor hours to the consumption and investment goods sectors. Let $C_t$ and $N_t$ respectively denote period $t$ consumption and an aggregate labor. Households maximize expected lifetime utility, given by

$$U_0 = E_0 \left[ \sum_{t=0}^{\infty} \beta^t U(C_t, N_t) \right],$$

where $\beta \in (0, 1)$ is the subjective discount factor.


$$U(C_t, N_t) = \frac{C_t^{1-\eta} \left( 1 + \left( \frac{1}{\gamma} - 1 \right) v(N_t) \right)^{\frac{1}{\gamma}} - 1}{1 - \frac{1}{\gamma}},$$

where $\eta$ is the Frisch elasticity of aggregate labor supply when preference is separable. Labor can flow freely across sectors. Hence, $N_t = N_{c,t} + N_{i,t}$, where $N_{c,t}$ and $N_{i,t}$ denote labor hours devoted to the consumption and the investment sector, respectively.

The household enters period $t$ with the stock of private one-period nominal bonds $B_{t-1}$. During
this period, the household receives wages, rental rates, dividends paid by firms, and interest payments on bond holdings. These resources are used to purchase consumption and investment, and to acquire assets to be carried over to the next period. Then, the household’s budget constraint is

\[ C_t + \left( \frac{P_{t,j}}{P_{c,t}} \right) I_t + \frac{B_t}{P_{c,t}} \leq R_{t-1} - \sum_{j=c,i} \left( \frac{W_{j,t}}{P_{c,t}} \right) N_{j,t} + \sum_{j=c,i} \left( \frac{R_{j,t}}{P_{c,t}} \right) K_{j,t} + \sum_{j=c,i} D_{j,t}, \]

where the subscript \( c \) and \( i \) denote variables specific to the consumption and investment sector, respectively, \( P_{j,t} \) is the nominal prices in sector \( j \), \( I_t = I_{c,t} + I_{i,t} \), where \( I_{j,t} \) represents newly purchased capital in sector \( j \), and \( W_{j,t} \) is the nominal wage rate paid by firms in sector \( j \). In addition, \( K_{j,t} \) is a productive capital stock in sector \( j \) and \( R_{j,t} \) is the rental rates of capital services in sector \( j \). \( R_t \) is gross nominal interest rate and \( D_{j,t} \) is real dividend from profit.

The capital stock for the case of perfect mobility evolves according to:

\[ K_{t+1} = I_t \left[ 1 - \phi \left( \frac{I_t}{I_{t-1}} \right) \right] + (1 - \delta) K_t, \]

where

\[ K_t = K_{c,t} + K_{i,t}. \]

Here, \( \delta \) is a depreciation rate and \( \phi(\cdot) \) represents adjustment costs that are occurred when the level of investment changes over time. We assume a quadratic adjustment cost:

\[ \phi \left( \frac{I_t}{I_{t-1}} \right) = \frac{\kappa}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2. \]

Since capital also can flow freely across sectors, we assume that while aggregate capital stock, \( K_t \), is predetermined, sectoral capital, \( K_{j,t} \), is a control variable.

### 2.2 Firms

We assume the existence of a continuum of monopolistically competitive firms, indexed by \( s \in [0,1] \), which produce differentiated intermediate goods in each sector. A final good in each sector is produced by a perfectly competitive representative firm. The firm produces the final good by combining a continuum of intermediate goods.
2.2.1 Final goods firms

The final good in each sector, $Y_{jt}$, is aggregated by the constant elasticity of substitution (CES) technology:

$$Y_{jt} = \left( \int_0^1 Y_{jt}(s)^{\frac{\epsilon_j - 1}{\epsilon_j}} ds \right)^{\frac{1}{1 - \epsilon_j}} \quad (7)$$

Here, the parameter $\epsilon_j$ represents the elasticity of substitution of intermediate goods in sector $j$.

A cost minimization problem for the final good producer in each sector implies that the demand for intermediate goods is given by

$$Y_{jt}(s) = \left( \frac{P_{jt}(s)}{P_{jt}} \right)^{-\epsilon_j} Y_{jt}, \quad (8)$$

where $P_{jt}(s)$ is the price of intermediate good $s$ in sector $j = c, i$ and $P_{jt}$ is the aggregate price level in sector $j = c, i$. Finally, the zero-profit condition implies that the sectoral price index is expressed as

$$P_{jt} = \left( \int_0^1 P_{jt}(s)^{1-\epsilon_j} ds \right)^{\frac{1}{1-\epsilon_j}}. \quad (9)$$

2.2.2 Intermediate goods firms

Intermediate good producers in each sector are monopolistically competitive. Each intermediate goods firm produces its differentiated goods using the following production function:

$$Y_{jt}(s) = A_t K_{jt}(s)^{\alpha} N_{jt}(s)^{1-\alpha} - F_j, \quad (10)$$

where $F_j$ denote the fixed cost of production and $A_t$ is the level of aggregate total factor productivity (TFP).

The intermediate good firms in each sector are subject to nominal rigidities. Given the demand function, the monopolistic intermediate good firms maximize profits by setting prices subject to
adjustment costs as in Rotemberg (1982). Thus, the firms, $s$, in sector $j$ solve:

$$E_t \sum_{v=0}^{\infty} \beta^v \Lambda_{t+v} \left\{ \frac{P_{j,t+v}(s)}{P_{j,t+v}} Y_{j,t+v}(s) - \frac{\Psi_{j,t+v}}{\Pi_{j,t+v}} Y_{j,t+v}(s) - \frac{\phi_{p_j}}{2} \left( \frac{P_{j,t+v}(s)}{\Pi_{j,t+v}} - 1 \right)^2 Y_{j,t+v} \right\}$$

(11)

s.t.  

$$Y_{j,t}(s) = \left( \frac{P_{j,t}(s)}{P_{j,t}} \right)^{-\epsilon_j} Y_{j,t},$$

(12)

where $\beta^v \Lambda_{t+v} / \Lambda_t$, is a stochastic discount factor for the firms, $\Psi_{j,t}$ is a nominal marginal cost in sector $j$, and $\phi_{p_j}$ is a parameter measuring the degree of price rigidity in sector $j$.

2.3 Equilibrium

The Rotemberg-style pricing allows us to assume a symmetric equilibrium. In a symmetric equilibrium, each firm makes an identical decision so that $N_{j,t}(s) = N_{j,t}$, $K_{j,t}(s) = K_{j,t}$, $Y_{j,t}(s) = Y_{j,t}$, and $P_{j,t}(s) = P_{j,t}$.

In the equilibrium, the net private debt $B_t = 0$ and goods market equilibrium requires:

$$Y_{c,t} = C_t + \frac{\phi_{p_c}}{2} \left( \frac{\Pi_{c,t}}{\Pi_c} - 1 \right)^2 Y_{c,t},$$

(13)

$$Y_{i,t} = I_t + \frac{\phi_{p_i}}{2} \left( \frac{\Pi_{i,t}}{\Pi_i} - 1 \right)^2 Y_{i,t},$$

(14)

2.4 Monetary authority

The monetary authority conducts monetary policy using the short-term nominal interest rate as the policy instrument. The gross nominal interest rate $R_t$ follows a Taylor rule of the following type:

$$\frac{R_t}{\rho} = \left( \frac{R_{t-1}}{\rho} \right)^{\rho_p} \left( \frac{\Pi_t}{\Pi} \right)^{\rho_n(1-\rho_p)} \left( \frac{Y_t}{Y_{t-1}} \right)^{\rho_y(1-\rho_p)} \exp(\xi_{R,t}),$$

(15)

where $\xi_{R,t}$ is a monetary policy shock, $\Pi_t$ is an economy-wide inflation rate, and $Y_t$ is a real GDP. The economy-wide total output (real GDP) $Y_t$ is given by

$$Y_t = Y_{c,t} + \frac{P_t}{P_c} Y_{i,t},$$

(16)
We define the aggregate price index $P_t$ as

$$P_t = P_{t,1}^{\omega_c} P_{1,t}^{1-\omega_c},$$

(17)

where $\omega_c$ is the steady state output share of the consumption sector. This aggregate price index $P_t$ is used for calculating an economy-wide inflation, $\Pi_t \equiv \frac{P_t}{P_{t-1}}$.

### 2.5 Shock Process

For simplicity, we focus on the technology shock and assume that the only source of uncertainty is changes in the volatility of the technology shock. We model these changes in volatility as a stochastic volatility approach, recently used by Fernandez-Villaverde, Guerron-Quintana, Kuester and Rubio-Ramirez (2011b), Andreasen, Fernández-Villaverde and Rubio-Ramírez (2013), Basu and Bundick (2012). Hence, the technology shock process is parameterized as follows:

$$A_t = (1 - \rho_a)A + \rho_a A_{t-1} + \sigma_t \epsilon_t$$

(18)

$$\sigma_t = (1 - \rho_\sigma) \sigma + \rho_\sigma \sigma_{t-1} + \sigma_\nu \nu_t$$

(19)

Here, $\epsilon_t$ is a standard first moment shock that captures innovations to the level of the stochastic process for technology. We refer to $\nu_t$ as a second moment or “uncertainty” shock since it captures innovation to the volatility of the exogenous process of the model. An increase in the volatility of the shock process increases the uncertainty about the future time path of the stochastic process. All two stochastic shocks are independent, standard normal random variables.

### 3 Impact of Uncertainty Shocks

In this section, we demonstrate how the propagation mechanism of a sticky price model with flexibly priced investment goods can differ from that of the model with symmetric price rigidity. We begin with presenting an analytical discussion to gain intuition. We then numerically solve our two-sector sticky price model to show our main results.
3.1 Analytical Discussion

To organize discussion, it is useful to note that because factors can flow freely across sectors, with the production function (10), the capital-to-labor ratios will equalize across all sectors, regardless of which ones have sticky prices and which have flexible prices:

\[
\frac{K_{c,t}}{N_{c,t}} = \frac{K_{i,t}}{N_{i,t}} = \frac{K_t}{N_t},
\]

(20)

where \( K_t = K_{c,t} + K_{i,t} \) is predetermined in period \( t \) and \( N_t = N_{c,t} + N_{i,t} \). Thus, the marginal product of labor \((MPL)\) in each sector will be the same and can be expressed as:

\[
MPL_{jt} = (1 - \alpha)A_t \left( \frac{K_{jt}}{N_{jt}} \right)^\alpha = (1 - \alpha)A_t \left( \frac{K_t}{N_t} \right)^\alpha, \quad j = c, i.
\]

(21)

In addition, since factors can flow freely across sectors, nominal wages and rental rates will equalize across sectors. This implies that firms in each sector will have the same nominal marginal cost, \( MC_t \):

\[
MC_t = MC_{c,t} = MC_{i,t}.
\]

(22)

Combining the fact that the marginal product of labor and nominal marginal cost will be the same across sectors, the labor market equilibrium in each sector (i.e., equating labor demand and supply in each sector) can be reduced to

\[
\frac{\psi'(N_t)}{\lambda_t} = \psi_t(1 - \alpha)A_t \left( \frac{K_t}{N_t} \right)^\alpha,
\]

(23)

where \( \psi_t = \frac{MC}{P_{c,t}} \) is a real marginal cost in terms of consumption goods. For the sake of simplicity, it is assumed that momentary utility function is separable between consumption and labor (i.e., \( \sigma = 1 \)).

This equation is instructive to understand how uncertainty shocks propagate in sticky price models. Basu and Bundick (2012) also derive the equation analogous to (23) from the one-sector sticky price model. Several comments are deserved. First, note that when all prices are flexible, firms in each sector charge \( P_{jt} = \mu MC_t \), where \( \mu \) is a desired markup in each sector. Hence, \( \psi_t = \psi \). An increase in uncertainty induces wealth effects on the representative household through the forward-looking marginal utility of wealth denoted by \( \lambda_t \). Thus, an increase in uncertainty
induces precautionary labor supply of the representative household and leads to a rise in aggregate hours worked. In this case, capital and labor utilized in the consumption sector move toward the investment sector, causing the negative co-movement problem in a two-sector setup.

In contrast, if all prices are equally sticky, an increase in uncertainty can be contractionary. An increase in uncertainty induces precautionary labor supply of the representative household, which reduces firms’ marginal costs of production. Falling marginal costs with slowly-adjusting prices imply an increase in firms’ markups over nominal marginal cost (i.e., a decrease in $\psi_t$). If firms’ markups increase enough to dominate the increase in $\lambda_t$, (23) shows that hours worked can decrease in response to an increase in uncertainty. Note that if all prices are equally sticky in the two-sector sticky price model, the model virtually collapses to a standard one-sector sticky price model. This implies that firms charge the same prices across sectors, leaving the relative price unchanged.

As in the model with fully flexible prices, however, higher uncertainty can be expansionary in sticky price models if the prices of investment goods are flexible. Compared to the sticky price model with identical rigidity, the extent to which the price markups rise in response to uncertainty shocks can significantly reduced in the model with flexibly-priced investment goods. If firms’ markups does not increase sufficiently to offset the increase in $\lambda_t$, (23) shows that uncertainty shocks might increase aggregate hours worked.

The different behavior of price markups is attributable to the fact that the presence of the flexible-price investment sector induces a change in the relative price of investment goods in response to uncertainty shocks, which is absent in the symmetric price rigidity case. When heightened uncertainty decreases nominal marginal costs due to the precautionary labor supply, its impact on sectoral prices is not uniform, if investment goods have flexible prices. While producers in the sticky-price consumption sector do not reduce their prices much, those in the flexible-price investment sector lower their prices by the same amount as the marginal costs fall. Hence, uncertainty shocks decrease the relative price of investment goods and act like positive investment-specific technology shocks in sticky price model with the flexible-price investment sector. The lower relative price of investment goods entails an intertemporal substitution of these goods and causes production of that sector to expand, which in turn mitigates the decrease in firms’ real marginal costs, $\psi_t$. Because of this change in the intertemporal relative price of investment goods, the price markups does not increase as much as those in the model with symmetric price rigidity.
In numerical simulations below, we demonstrate that whether the precautionary labor supply effect dominates the price markups effect or not depends on the depreciation rate of capital. As emphasized by Barsky, House and Kimball (2007), if productive capital is long-lived (i.e., a productive durable with a low depreciation rate), the intertemporal elasticity of substitution of purchases of these goods is high. Thus, the temporary lower relative price of investment goods induces a significant increase in production of the investment sector, so that the precautionary labor supply effect dominates the price markups effect. As a result, uncertainty shocks cause aggregate hours worked and GDP to rise.

3.2 Simulations

We solve the model by using the third-order perturbation method with pruning, implemented in Dynare. As discussed in Fernández-Villaverde et al. (2011a), the third-order approximation is necessary because changes in uncertainty start to play an independent role in the policy function without any interactions with other terms from the third order. As in Basu and Bundick (2012) and Fernández-Villaverde et al. (2011a), we present impulse responses as percentage deviations from the ergodic mean of each model variable.

To set parameter values, we basically follow the specification in Basu and Bundick (2012). There are two parameters that are unique in our model. We set the Frisch elasticity of labor supply $\eta$ to be 1.25 and the investment adjustment cost parameter $\kappa$ to be 1.43. These values are based on the estimates in the two-sector model of Katayama and Kim (2015).

Figure 1 presents responses of model variables under two different scenario: the model with symmetric price rigidity in both sectors and the model with sticky prices in only the consumption sector.

**Symmetric Price Rigidity** We begin by considering the model in which all prices are equally sticky throughout the economy. The equilibrium reaction of the model to a technology uncertainty shock in this case is indicated with dashed lines in Figure 1. In the case of symmetric price rigidity, an increase in uncertainty generates simultaneous drops in consumption, investment, aggregate hours, and GDP. This result essentially replicates the key result of Basu and Bundick (2012), which is obtained in one-sector sticky price model. The intuition behind this result is well explained
Figure 1: Responses to Technology Uncertainty Shock

Note: Dashed lines represent percentage deviations from the ergodic means with symmetric price rigidity ($\phi_{Pc} = \phi_{Pi} = 160$). Solid lines show those with the flexible-price investment sector ($\phi_{Pi} = 160, \phi_{Pi} = 0$).
Table 1: Baseline Parameter Values

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>α</td>
<td>Capital share parameter</td>
<td>0.33</td>
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<tr>
<td>β</td>
<td>Discount factor</td>
<td>0.9987</td>
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<td>δ</td>
<td>Depreciation rate</td>
<td>0.025</td>
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<td>γ</td>
<td>Intertemporal elasticity of substitution</td>
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</tr>
<tr>
<td>η</td>
<td>Frisch elasticity of labor supply</td>
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</tr>
<tr>
<td>κ</td>
<td>Investment adjustment cost</td>
<td>1.43</td>
</tr>
<tr>
<td>φp,c</td>
<td>Consumption sector price adjustment cost</td>
<td>160</td>
</tr>
<tr>
<td>φp,i</td>
<td>Investment sector price adjustment cost</td>
<td>0 or 160</td>
</tr>
<tr>
<td>ρR</td>
<td>Interest rate smoothing in the Taylor rule</td>
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</tr>
<tr>
<td>ρπ</td>
<td>Reaction coefficient on inflation in the Taylor rule</td>
<td>1.5</td>
</tr>
<tr>
<td>ργ</td>
<td>Reaction coefficient on output growth in the Taylor rule</td>
<td>0.5</td>
</tr>
<tr>
<td>Π</td>
<td>Steady-state inflation rate</td>
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</tr>
<tr>
<td>ε</td>
<td>Elasticity of substitution for intermediate goods</td>
<td>6</td>
</tr>
<tr>
<td>ρa</td>
<td>First moment technology shock persistence</td>
<td>0.99</td>
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<tr>
<td>ρσ</td>
<td>Second moment technology shock persistence</td>
<td>0.83</td>
</tr>
<tr>
<td>σ</td>
<td>Steady-state volatility of technology</td>
<td>0.01</td>
</tr>
<tr>
<td>σν</td>
<td>Volatility of second moment technology shock</td>
<td>0.0037</td>
</tr>
</tbody>
</table>

by Basu and Bundick (2012). Households want to consume less and save more when uncertainty increases in the economy. On impact, households increase their labor supply (i.e., the precautionary behavior of labor supply) to accumulate more capital, which lowers nominal marginal costs in both consumption and investment sectors (MCjt). A reduction in marginal costs with slow-adjusting prices increases firm’s markups (µpipj) and thus decreases the demand for labor in both sectors. In equilibrium, the mark-up effect dominates the precautionary labor supply effect, so that uncertainty shocks produce significant falls in consumption, investment, aggregate hours worked, and GDP.

**Asymmetric Price Rigidity**  Now we assume that the investment goods have flexible prices while the consumption goods have sticky prices. The solid lines in Figure 1 depict the reaction of the model to the uncertainty shock in this case. The presence of flexible-price investment sector fundamentally changes the way uncertainty shock affects the economy. In response to the uncertainty shock, the model exhibits a lack of business cycle co-movement: consumption declines, but investment rises. More interestingly, aggregate hours worked and GDP rise and the production of sticky-price consumption sector drops by a significantly smaller amount. To a certain extent, the behavior of the model with flexible-price investment goods is unexpected. Because the sticky-price consumption sector is such a large part of the economy, it is natural to think that aggregate hours will drop in
response to the uncertainty shock and production of sticky-price consumption sector will not be
affected. Yet, Figure 1 clearly shows that sticky price models have surprising implications when
investment goods have flexible prices. This is reminiscent of the result of Barsky et al. (2007) that
flexibly-priced durable goods alter the impact of the monetary policy shock.

As discussed above, all of these results can be accounted for by the behavior of the relative price
of investment goods, denoted by $p$. As shown in Figure 1, while it is barely unchanged in the model
with symmetric price rigidity, the relative price of investment goods drops temporarily in the model
with flexible-price investment goods. Because of the decline in the relative price of investment
goods, production of investment sector rises. As investment sector expands, marginal costs start
to increase, which counteracts the effects of precautionary labor supply on the marginal costs. As
shown in the figure, therefore, the drop in marginal costs of the model with flexible-price investment
sector is much smaller than that of the model with symmetric price rigidity. As a result, the price
markups increase by a smaller amount in the model with flexible-price investment sector. In this
case, the precautionary labor supply effect dominates the price markups effect, so that aggregate
hours worked and GDP rise in response to the uncertainty shock. Furthermore, because the price
markups increase less in the model with flexible-price investment goods, production of sticky-price
consumption sector drops by a smaller amount.

Whether the precautionary labor supply effect dominates the price markups effect is in turn
governed by the depreciation rate of capital. To show this, Figure 2 plots the reaction of the model
to the uncertainty shock as we increase the rate of depreciation. Even though investment goods
have flexible prices, if capital has a high depreciation rate, the price markups increase enough to
dominate the precautionary labor supply effect, resulting in a rise in aggregate hours worked and
GDP. If capital has a higher rate of depreciation, the temporary reduction in the relative price of
investment goods exerts a smaller degree of intertemporal substitution and thus the production
of those goods increases by a smaller amount. As Figure 2 shows, this implies that the firms’
marginal costs fall more because a smaller increase in investment-sector production less moderates
the reduction of marginal costs due to precautionary labor supply. As a result, the price markups
rise more with a higher rate of depreciation, so that aggregate labor and GDP drop and consumption
decline more in response to the uncertainty shock. Therefore, a low depreciation rate of capital is
the key to the surprising result that uncertainty shocks are expansionary in sticky price model when
Figure 2: Responses to the Uncertainty Shock with Different Rates of Depreciation

Note: Above lines represent percentage deviations from the ergodic means with the different rates of depreciation and the flexible investment sector. Solid lines correspond to the base line case. Dashed lines are responses with $\delta = 0.25$ and dotted lines represent those with $\delta = 0.75$. 
investment goods have flexible prices.

Finally, we study the sensitivity of the results with the size of flexible-price investment sector and the degree of price rigidity in consumption sector. Figure 3 shows that as the share of the flexible-price investment sector, denoted by $\omega_i$, gets smaller, aggregate hours worked and GDP can decline on impact following the uncertainty shocks. However, aggregate labor and GDP drop for only a very short period of time and start to increase right away. Moreover, the negative co-movement of sectoral hours worked and outputs persists. We find that a quantitatively similar result emerges even if the prices of consumption goods are very rigid. Therefore, even a small flexible-price investment sector makes it difficult for uncertainty shocks to generate fluctuations that look like business cycles, though most of the economy consist of sticky-price consumption goods whose prices are very sticky.

4 Restoring the Importance of Uncertainty Shocks

Should we conclude that uncertainty shocks do not matter at all in accounting for business cycles, if investment goods are flexibly priced? Probably not. We consider some modifications to our baseline model to ask whether they can restore the importance of uncertainty shocks as a driver of business cycles.

4.1 Sticky Wages

The first modification we consider is to add nominal wage rigidity to our baseline model above. This is partly motivated by the fact that use sticky wages to resolve the negative co-movement puzzle with respect to the monetary shock, which is documented in Barsky et al. (2007).

We assume that there is a continuum of households, indexed by $h \in [0, 1]$. Households are identical except for the heterogeneity of labor. Each household $h$ is the supplier of its differentiated labor to the labor aggregator, and has monopoly power over its own labor. Hence, it sets a wage for its differentiated labor. Each household pays the costs of adjusting nominal wages for each sector,
Figure 3: Responses to the Uncertainty Shock with the Different Size of Flexible Investment Sector

Note: Above lines represent percentage deviations from the ergodic means with the different size of flexible investment sector. The size of the investment sector is determined endogenously. We change $\alpha$ from 0.33 to 0.2 and 0.1. The corresponding shares of the investment sector are 0.31 (solid lines), 0.29 (dashed lines), and 0.095 (dotted lines), respectively.
which is assumed to be quadratic. Hence, the household budget constraint, (3), is modified to:

\[
C_t(h) + \left( \frac{P_{c,t}}{P_{c,t}} \right) I_t(h) + \frac{B_t(h)}{P_{c,t}} + \sum_{j=\epsilon,\iota} \phi_{W_j} \left( \frac{W_{j,t}(h)}{P_{c,t}} \right)^2 \frac{W_{j,t}(h)}{P_{c,t}}
\]

\[
\leq R_{t-1} \frac{B_{t-1}(h)}{P_{c,t}} + \sum_{j=\epsilon,\iota} \left( \frac{W_{j,t}(h)}{P_{c,t}} \right) N_{j,t}(h) + \sum_{j=\epsilon,\iota} \left( \frac{R_{j,t}}{P_{c,t}} \right) K_{j,t}(h) + \sum_{j=\epsilon,\iota} D_{j,t}(h),
\]

(24)

where \( I_t(h) = I_{c,t}(h) + I_{i,t}(h) \), and \( \phi_{W_j} \) is the parameter measuring the degree of nominal wage rigidity in sector \( j \).

A perfectly competitive labor packer aggregates the different types of labor in sector \( j = \epsilon, \iota \), \( N_{j,t}(h) \), into homogeneous labor in sector \( j \), \( N_{j,t} \), with the production function:

\[
N_{j,t} = \left( \int_0^1 N_{j,t}(h) \frac{1}{\epsilon_{W_j}^W} \frac{1}{\epsilon_{W_j}^W} dh \right)^{\frac{1}{\epsilon_{W_j}^W}}, \quad j = \epsilon, \iota.
\]

(25)

Here the parameter \( \epsilon_{W_j}^W \) represents the elasticity of substitution among labor varieties in sector \( j \). The first-order condition for profit maximization yields the demand function of each household’s differentiated labor in sector \( j \):

\[
N_{j,t}(h) = \left( \frac{W_{j,t}(h)}{W_{j,t}} \right)^{-\epsilon_{W_j}^W} N_{j,t}.
\]

(26)

Finally, the zero-profit condition implies that the sectoral wage index is expressed as

\[
W_{j,t} = \left( \int_0^1 W_{j,t}(h)^{1-\epsilon_{j}^W} dh \right)^{-\frac{1}{1-\epsilon_{j}^W}}.
\]

(27)

When sticky prices coexist with sticky wages, (23) is modified to:

\[
\frac{v'(N_t)}{\lambda_t} = \psi_t \psi_{t}^{W}(1 - \alpha)A_t \left( \frac{K_t}{N_t} \right)^{\alpha} \psi_{t}^{W}. \]

(28)

where \( \psi_{t}^{W} \) is the inverse of wage markup. Recall that the presence of flexible-price investment sector substantially reduces the extent to which price markups rise, so that uncertainty shocks might increase aggregate hours worked. The addition of sticky wages leads to another shifter in (28). If the wage markups increase significantly in response to uncertainty shocks, aggregate hours worked
can decrease even though the price markups do not increase that much.

Figure 4 plots the responses of endogenous variables to the uncertainty shock as we vary the values of the wage rigidity parameter, $\phi_W$. An increase in uncertainty now does reduce aggregate hours worked and GDP due to the rise in the wage markups ($\mu_{w,j}$). However, the negative co-movement of consumption and investment still prevails. Introducing more rigid wages does not help resolve the problem. Consumption declines, whereas investment rises in response to the uncertainty shock. Hence, while adding sticky wages to the baseline model does cause uncertainty shocks to decrease aggregate hours worked and GDP, it does not eliminate the negative co-movement.

4.2 Imperfect Factor Mobility

Previously we assumed that hours worked in each sector are perfect substitutes for the representative household, so that labor can move freely across sectors. That is, the disutility of work was assumed to take the form of $v(N_{c,t} + N_{i,t})$. Also, capital is assumed to be perfectly mobile across sectors. We relax the assumption of perfect factor mobility and allows for some degree of factor immobility. We show that allowing for factor immobility can eliminate the negative co-movement between consumption and investment and thereby leads to the co-movement among key aggregate macroeconomic variables in response to the uncertainty shock.

We model imperfect labor mobility by introducing some degree of sector specificity to labor, which inhibits labor from moving across sectors. In order to parsimoniously capture some degree of sector specificity to labor while not deviating from the representative household assumption, we use the following aggregate labor index:

$$N_t = \left[ N_{c,t}^{\theta+1} + N_{i,t}^{\theta+1} \right]^{\theta/(\theta+1)}, \quad \theta \geq 0. \quad (29)$$

This specification is considered by Huffman and Wynne (1999), Horvath (2000), Katayama and Kim (2015) and is similar to the production frontier possibility. To better understand the implications of the specification, (29), it is useful to note that the marginal rate of transformation (MRT) between

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3In this exercise, we set the elasticity of substitution between differentiated workers, $\epsilon^W$, to 6.
Figure 4: Responses to the Uncertainty Shock with Flexible Investment Sector and Sticky Wages

Note: Above lines represent percentage deviations from the ergodic means with the different degrees of wage stickiness. Solid lines correspond to $\phi_w = \phi_i = 160$, dashed lines are with $\phi_w = \phi_i = 347$, and dotted lines assume $\phi_w = \phi_i = 510$. 
consumption-sector labor \((N_{c,t})\) and investment-sector labor \((N_{i,t})\) is given by

\[
MRT \equiv \left( \frac{N_{c,t}}{N_{i,t}} \right)^{\frac{1}{\theta}} = \frac{W_{c,t}}{W_{i,t}},
\]

where \(W_{j,t}\) is the nominal wage in sector \(j\). If \(\theta = \infty\), then there is an infinite intra-elasticity substitution between \(N_{c,t}\) and \(N_{i,t}\) and \(MRT\) is unity, the feature of the baseline model. Specifically, by reducing the labor used for producing consumption goods by one unit, it is possible to increase the labor that can be used for producing investment goods by one unit without any need to increase aggregate labor. This implies that it is very easy to reallocate labor from one sector to the other sector, so that each sector will pay the same wages. When \(\theta < \infty\), the \(MRT\) gets smaller as the households increase the composition labor more toward investment sector (i.e., the larger value of \(\frac{N_{i,t}}{N_{c,t}}\)). This might capture an aspect of labor market that workers cannot immediately be retrained so as to produce computers and structures instead of foods and entertainment services. In this case, the households might be reluctant to switch from consumption-sector labor toward investment sector even though the latter pays higher wages than the former. Put differently, to induce a shift in the composition of labor toward investment sector, the relative wages, \(\frac{W_{i,t}}{W_{c,t}}\) must rise.

As \(\theta\) gets smaller, it becomes more difficult to change the composition of the labor. To see this, suppose that the current labor ratio, \(\frac{N_{i,t}}{N_{c,t}} < 1\), and the households wish to increase the ratio such that \(\frac{N_{i,t}}{N_{c,t}} > 1\). The smaller is the parameter \(\theta\), the more costly is to change the ratio. This is because lower values of \(\theta\) require \(\frac{W_{i,t}}{W_{c,t}}\) to rise so much to achieve that change of the composition of labor. That is, to shift labor more toward investment sector, firms in the investment sector need to pay significantly higher wages than those in the consumption sector when \(\theta\) gets smaller. At extreme, as \(\theta\) approaches 0, it becomes impossible to alter the composition of the labor.

We also assume that capital is immobile across sectors by specifying separate accumulation equations for the capital stocks in each sector. The capital accumulation equations corresponding to the perfect capital mobility, (4) and (5), becomes:

\[
K_{j,t+1}(h) = I_{j,t}(h) \left[ 1 - \phi \left( \frac{I_{j,t}(h)}{I_{j,t-1}(h)} \right) \right] + (1 - \delta)K_{j,t}(h), \quad j = c, i
\]

where \(\phi(\cdot) = \frac{\kappa_j}{2} \left( \frac{I_{j,t}}{I_{j,t-1}} - 1 \right)^2\) represents adjustment costs that are incurred when the level of investment
changes over time. In contrast to the case with perfect capital mobility, sectoral capital, \( K_{jt} \), is now a predetermined variable. Hence, capital used in the production of heavy industrial equipment cannot be used to produce food or entertainment.

Before simulating the modified model that introduces factor immobility, we present an analytical argument for why the limited factor mobility renders the co-movement between consumption and investment in response to the uncertainty shock. It is the key to understanding the success that imperfect factor mobility might lead to an increase in the relative price of investment goods in response to the uncertainty shock. In this case, uncertainty shocks affect the investment similarly to the way negative investment-specific technology shocks do. If the relative price increases in response to the uncertainty shocks, production of investment goods declines. This implies that consumption and investment go down together because consumption drops due to precautionary saving.

To facilitate discussion, it is useful to inspect how the relative price of investment goods is determined in the baseline model in which factors are perfectly mobile. Rearranging (23) yields the relative price of investment goods, \( p_t \), in the baseline model:

\[
p_t = \mu \frac{1}{\lambda_t} \frac{\varphi'(N_t)}{(1 - \alpha)A_t \left( \frac{K_t}{N_t} \right)^\alpha}.
\]

(32)

Here we use the fact that the price markup in the flexible-price investment sector is constant, so that \( \mu = \frac{MC_t}{P_i} \). As stressed out above, higher uncertainty exerts precautionary labor supply (i.e., higher \( \lambda_t \)), so that the relative price of investment goods drops if consumption goods have sticky prices but investment goods have flexible prices. There is another force, which has not been discussed, that reduces the relative price even more. Heightened uncertainty induces precautionary saving, resulting in a decline in production of sticky-price consumption sector. As \( N_{ct} \) goes down, (32) shows that given \( N_{it} \), the relative price decreases due to the decline in marginal disutility of work (\( \varphi' (\cdot) \)) and the increase in marginal product of labor ((1 - \( \alpha \))\( A_t \left( \frac{K_t}{N_t} \right)^\alpha \)).

The analogous equation to (32) in the model with imperfect factor mobility is given by:

\[
p_t = \mu \frac{1}{\lambda_t} \frac{\varphi'(N_t) \frac{\partial N_t}{\partial N_{it}}}{(1 - \alpha)A_t \left( \frac{K_t}{N_t} \right)^\alpha} = \mu \frac{1}{\lambda_t} \frac{\varphi'(N_t) \left( \frac{N_{it}}{N_t} \right) \delta}{(1 - \alpha)A_t \left( \frac{K_t}{N_t} \right)^\alpha},
\]

(33)
where \( \mu = \frac{MC_i}{T_i} \) and \( K_i,t \) is predetermined. As before, precautionary labor supply pushes the relative price of investment goods down. Given \( N_{i,t} \), the reduction in \( N_{c,t} \) also lowers the marginal disutility of work, so that it decreases the relative price, captured by \( N_t^{1/\eta} \).

In contrast to the baseline model, there are offsetting forces that mitigate the downward pressure of the relative price and can even raise the relative price. When labor in consumption sector declines due to the precautionary saving effect, not all the workers used to work in consumption sector can be reallocated to produce investment goods. Additional new workers suited to producing investment goods are required to increase production of investment goods. This will increase the disutility of working in investment sector, since \( \frac{\partial}{\partial N_{c,t}} \left( \frac{\partial N_t}{\partial N_{c,t}} \right) = \frac{\partial}{\partial N_t} \left( \frac{N_{i,t}}{N_t} \right)^{1/\theta} < 0 \). In terms of wages, the decline in \( N_{c,t} \) will increase the investment-sector wage relative to consumption-sector, \( W_{i,t}/W_{c,t} \). To see this, we express \( \left( \frac{N_{i,t}}{N_t} \right)^{1/\theta} \) in terms of \( W_{i,t}/W_{c,t} \). Combining (29) and (30) yields:

\[
\left( \frac{N_{i,t}}{N_t} \right)^{1/\theta} = \left( \frac{W_{i,t}}{W_{c,t}} \right)^{1+\theta}/1 + \left( \frac{W_{i,t}}{W_{c,t}} \right)^{1+\theta} \tag{34}
\]

This equation says that if \( \frac{\partial}{\partial N_{c,t}} \left( \frac{N_t}{N_i} \right)^{1/\theta} < 0 \), \( W_{i,t}/W_{c,t} \) rises. Hence, \( \left( \frac{N_t}{N_i} \right)^{1/\theta} \) captures the effect that a reduction of \( N_{c,t} \) makes investment-sector labor more expensive than consumption-sector labor because of intersectoral labor immobility. This will work to increase the relative price of investment goods. Therefore, if \( W_{i,t}/W_{c,t} \) rises sufficiently to dominate the forces pushing down the relative price, then the relative price of investment goods can increase in response to the uncertainty shock. Capital immobility also contributes to the rise in the relative price. Unlike the case of perfect capital mobility, (33) shows that a reduction in \( N_{c,t} \) has no impact on the marginal product of capital in the case of imperfect capital mobility, mitigating the downward pressure of the relative price.

We now simulate the modified model. Based on the two-sector estimates in Katayama and Kim (2015), we set \( \theta \) to be 0.3030. Figure 5 plots the responses of endogenous variables to the uncertainty shock when capital and labor are not perfectly mobile. Again, it is assumed that consumption goods have sticky prices but investment goods have flexible prices. Uncertainty shock now generates economic fluctuations that are consistent with the business cycles data, even in the presence of flexibly priced goods. Consumption, investment, aggregate hours worked, and GDP drop all together simultaneously in response to the uncertainty shock.
Figure 5: Responses to Technology Uncertainty Shock with Flexible Investment Sector under Imperfect Factor Mobility

Note: Above lines represent percentage deviations from the ergodic means with the different degrees of sticky wages.
As discussed above, the key to the success lies in the behavior of the relative price of investment goods. As the Figure 5 shows, the relative price of investment \( p \) rises in the modified model with limited factor mobility. This stems from the fact that investment-sector wages increases substantially relative to consumption-sector wages, which dominates the effect of precautionary labor supply. A temporary increase in the relative price of investment goods causes a shift of expenditure away from that sector and thereby reduces production of investment goods. In this case, uncertainty shocks act like negative investment-specific technology shocks.

Furthermore, production of sticky-price consumption sector falls more in the modified model with imperfect factor mobility than does in the baseline model. The limited factor mobility pushed down the nominal marginal costs of consumption sector more because it makes nominal wages in consumption sector stay lower. Hence, the price markups in consumption sector rise more in the modified model and so does production of consumption goods.

5 Empirical Evidence

The sharp prediction of our sticky-price model with limited factor mobility is that uncertainty shocks cause the relative price of investment goods to rise if investment goods have flexible prices. In this section, we examine whether this prediction is consistent with the data using an empirical measure of uncertainty shocks.

As a starting point, Figure 6 plots a measure of uncertainty and the inflation rate of the relative price of investment goods. We use the estimate of Jurado, Ludvigson and Ng (2015) as a measure of uncertainty because they show that much of variation of popular uncertainty proxies is not generated by a movement in genuine uncertainty across the broader economy. They demonstrate that popular uncertainty proxies might not capture the common variation in uncertainty across many economic indicators and they erroneously attribute forecastable fluctuations to a movement in uncertainty. Jurado, Ludvigson and Ng (2015) address these problems and construct new estimates of uncertainty.

Although they provide three monthly measures (1-month-, 3-month, 12-month-ahead uncertainty

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4One popular practice in the literature is to use an observable proxy for uncertainty. For example, Bloom (2009) uses the VIX index, the implied stock market volatility based on the S&P index, and Bloom, Floetotto, Jaimovich, Saporta-Eksten and Terry (2012) use the cross-sectional dispersion of productivity. Another popular proxy for uncertainty is the cross-sectional dispersion of individual forecasts, as in Bachmann et al. (2013).
Figure 6: Uncertainty Measure and the Relative Price of Investment Goods

Note: The upper panel presents the aggregate uncertainty measure from Jurado et al. (2015). We use the quarterly average of their monthly series with $h = 3$ (i.e., 3-month-ahead uncertainty). The bottom panel shows the inflation rate of the relative price of investment goods.

measures), we use the 3-month-ahead uncertainty measure to be consistent with out setup. We convert it to quarterly by taking the quarterly average.

Following Justiniano, Primiceri and Tambalotti (2011), we construct the relative price of investment goods as the ratio of the chain weighted deflator for investment to that of consumption. For the denominator we use National Income and Product Accounts (NIPA) deflators for personal consumption expenditures on non-durables and services and for the numerator we use NIPA deflators for durable consumption and gross private investment. Since there is a downward trend in the relative price of investment goods, the average inflation rate (quarter to quarter) from 1960:Q3 to 2014:Q4 is about $-0.4$ percent.

Interestingly, all major spikes in uncertainty are associated with increases in the relative price of investment goods. Furthermore, those spikes are related to severe recessions, such as 1973-75, 1981-82, and 2007-2009 recessions. This observation suggests that an increase in uncertainty might cause the relative price of investment goods to rise, and severe economic downturns. To confirm this visual impression, we formally examine the dynamic relationship between the empirical measure of

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5The updated version of the aggregate uncertainty series, covering up to the end of 2014, was obtained from the author’s web site, http://www.econ.nyu.edu/user/ludvigsons/MacroUncertainty_update.zip.
uncertainty and the relative price of investment goods using a standard recursively identified VAR.

We follow the specification of Christiano et al. (2005) and augment it by including the relative price of investment and the uncertainty measure. Our VAR system consists of the following 11 variables: per capita real GDP, per capita real consumption, GDP deflator, per capital real investment, real wage, labor productivity, the federal funds rate, per capita real profits, M2 growth rate, the relative price of investment, and the aggregate uncertainty measure. All variables are logged, except for the federal funds rate and M2 growth rate. As mentioned above consumption covers nondurable goods and services and investment consists of durable goods consumption and gross private investment. Real variables are deflated by the price of consumption. As in Christiano et al. (2005), we include four lags.

Our sample starts from 1960:Q3 and ends at 2014:Q4. This is when the aggregate uncertainty measure of Jurado et al. (2015) is available. Since the sample period contains when the federal funds rate hit the zero lower bound, we use the shadow federal funds rate constructed by Wu and Xia (2014), which is not bounded below by zero and is supposed to summarize the stance of monetary policy. From 2009:Q1 to 2014:Q4, we replace the effective federal funds rate by the Wu-Xia shadow rate.

We use a standard Cholesky decomposition. The ordering of the variables are the same as the above. As in Jurado et al. (2015), who estimated a similar specification at a monthly frequency, we include the uncertainty measure last. The ordering of variables does not affect qualitative results that will be presented below (unless otherwise mentioned).

The top panel of Figure 7 shows the estimated impulse responses of macroeconomic variables to a one-standard-deviation innovation to the federal funds rate. The responses to the contractionary

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6We retrieve the following variables from the FRED of St. Louis Fed. FRED series IDs are in parentheses. Civilian Noninstitutional Population (CNP16OV), Nonfarm Business Sector: Compensation Per Hour (COMPNFB), Corporate Profits After Tax (without inventory adjustment and capital consumption adjustment, CP), Personal consumption expenditures: Durable goods (chain-type price index, DURRG3Q086SBEA), Personal consumption expenditures: Nondurable goods (chain-type price index, DNDGRG3Q086SBEA), Personal consumption expenditures: Services (chain-type price index, DSERRG3Q086SBEA), Effective Federal Funds Rate (FEDFUNDS), Gross Domestic Product (GDP), Gross Domestic Product: Implicit Price Deflator (GDPDEF), Gross Private Domestic Investment (GPDI), Gross Private Domestic Investment: Chain-type Price Index (GPDICTPI), Nonfarm Business Sector: Hours of All Persons (HOANBS), M2 Money Stock (M2SL), Personal Consumption Expenditures: Durable Goods (PCDG), Personal Consumption Expenditures: Services (PCESV), Personal Consumption Expenditures: Nondurable Goods (PCND). We construct price indices for consumption and investment by using the Törnqvist index. Then we obtain the quantity indices by deflating the expenditures. Per capita variables are divided by the HP trend of the population data since it has a couple of jumps.

7We obtain the shadow federal funds rate series from https://www.frbatlanta.org/cqer/research/shadow_rate.aspx, which is maintained and updated by the Atlanta Fed.
(a) Responses to the Monetary Policy Shock

(b) Responses to the Uncertainty Shock

Figure 7: Empirical Responses from VAR

Note: The top panel shows the responses to the monetary policy shock. The bottom panel shows the responses to the uncertainty shock. Horizontal axes measure quarters. Vertical axes are percentage deviations from the unshocked path. Shaded areas represent 2-standard-error confidence bands, which are based on 1,000 bootstrap repetitions.
monetary policy shock are quite similar to those in Christiano et al. (2005). Even though the uncertainty measure is supposed to be exogenous, it responds positively and significantly to the contractionary monetary policy shock. Of course, we can resolve this by placing the uncertainty measure first (or before the federal funds rate). Once we place it first, the responses become insignificant. However, the other qualitative results not affected by the ordering of the uncertainty measures.

The bottom panel of Figure 7 presents the responses of macroeconomic variables to a one-standard-deviation innovation to the uncertainty measure. In response to the uncertainty shocks, the relative price of investment goods increases significantly for the first two quarters. This is consistent with the theoretical prediction above. Furthermore, the uncertainty shock yields co-movement among output, consumption, and investment. They decrease significantly up to 10 quarters. There is a significant and sharp drop in profits when the economy experiences an exogenous increase in uncertainty. We can see that the quantitative impact of the uncertainty shock is quite comparable to that of the monetary policy shock.

This empirical evidence is consistent with predictions from our model with limited factor mobility. This does not exclude other possibilities in two-sector models. However, the empirical results suggest that one-sector model may miss an important channel through which uncertainty shocks affect the economy.

6 Conclusion

Much of our understanding about how uncertainty shocks affect the behavior of sticky price models comes from one-sector sticky price models in which the degree of price rigidity is same across sectors. If all prices are equally sticky across sectors, uncertainty shocks cause a simultaneous drop in consumption, investment, aggregate hours, and GDP. However, empirical evidence suggests that the investment sector can be characterized as a flexible-price sector. In this paper, we investigated whether allowing for a flexible-price investment sector in sticky price models changes the propagation mechanism of uncertainty shocks.

If both capital and labor are perfectly mobile, the presence of flexibly priced investment goods exerts unexpected and surprising behavior of sticky price model to uncertainty shocks. In this case,
the relative price of investment goods declines following the uncertainty shocks, so that production of the investment sector increases. More strikingly, while consumption drops due to precautionary saving in response to the uncertainty shocks, the expansion in the investment sector can be so strong as to dictate the behavior of aggregate hours and GDP. Even though consumption goods, the lion’s share of GDP, have sticky prices, the uncertainty shocks can increase aggregate labor and output. Furthermore, allowing for flexibly-priced investment goods entails a much smaller response of sticky-price consumption goods to the uncertainty shocks.

In contrast, the perverse behavior of sticky price models with flexibly priced investment goods disappears if both capital and labor cannot freely flow across sectors. The limited factor mobility raises the relative price of investment goods and thus decreases production of investment goods in response to the uncertainty shocks. Therefore, the co-movement between consumption and investment is restored, so that the uncertainty shocks cause a decline in aggregate hours worked and GDP. Furthermore, the uncertainty shocks entail a more contraction of consumption-sector production in the model with imperfect factor mobility than perfect mobility.

We perform an empirical analysis to examine the dynamic relationship between uncertainty shocks and the relative price of investment goods. Interestingly, three major macro uncertainty episodes in the post-war period (i.e., the 1973-74 and 1981-82 recessions and the Great Recession of 2007-09) are associated with the increase in the relative price. Our VAR analysis shows that a positive innovation to the empirical uncertainty measure indeed results in a significant increase in the relative price as well as co-movement among output, consumption, investment.

Finally, while we investigate the role of uncertainty shocks in the context of a represent-agent, DSGE model with nominal rigidities, there is another strand of the literature that analyzes it in a heterogeneous-firm model with convex and non-convex adjustment costs. Recent work by Bloom (2009) and Bloom, Floetotto, Jaimovich, Saporta-Eksten and Terry (2012) are important contributions to that literature. These papers emphasize the role of the non-convex nature of adjustment costs in propagating uncertainty shocks. Facing higher uncertainty, firms become more cautious in responding to business condition due to non-convex adjustment costs. When uncertainty is higher, firms have incentives to postpone purchases of capital goods and delay hiring of workers, contributing to a slowdown in economic activity. It would be interesting to extend our two-sector sticky price model to incorporate the non-convex adjustment costs of investment and labor. However, it is technically
extremely difficult to combine nominal price rigidities with the non-convex adjustment costs in a two-sector setup. We leave it as future research.
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