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Firm entry, Search and Matching in a Small Open Economy Faced with Uncertainty Shocks: The case of Korea

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Abstract

This paper investigates the impact of uncertainty shocks in a small open economy with search and matching frictions, endogenous job separation and firm entry. We first develop our empirical analysis in the context of the Korean economy, as all dimensions of the model are relevant in this country. An increase in uncertainty lowers output, consumption, investment and job finding rate, while raising unemployment and job separations. We also supplement the existing empirical evidence by looking at firm dynamics, real exchange rate and current account behavior. Increased uncertainty generates current account surplus, real exchange rate depreciation and reduces the number of firms in the economy. In our theoretical framework, we illustrate new transmissions mechanism that are ignored in the literature. The interaction of search frictions, firm entry and open economy leads to sizable macroeconomic effects of heightened uncertainty. Moreover, the model's predictions are consistent with empirical findings.
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1 Introduction

This paper investigates the impact of uncertainty shocks in a small open economy with search and matching frictions, endogenous job separation and firm entry. We combine these elements to highlight important transmission mechanisms that have not been analyzed in the existing work. We develop our analysis in the context of the Korean economy, as all dimensions of the model are relevant in this country: Korea is a globalized economy with heavily regulated labor and product markets, in which the job separation margin explains a large share of unemployment fluctuations.

We first provide original empirical evidence on the effects of fluctuating uncertainty on macroeconomic aggregates, labor market adjustments, firm dynamics, real exchange rate and current account. Using survey data, we compute the job finding and job separation rates. Following Shimer (2012)'s variance decomposition, unemployment inflows appears to be the main driver of unemployment cyclical behavior, which stresses the need for endogenous separation in the model. We then investigate the macroeconomic impact of time-varying volatility in a structural VAR. In doing so, we extend the literature along several dimensions. First, to our knowledge, we are the first to provide empirical evidence on labor market flows, firm dynamics *and* open-economy variables. Previous studies either investigate labor market flows or open-economy dimension. None look at firm dynamics. We look at all dimensions in Korean data. Secondly, the papers that analyze the effect of uncertainty shocks on the labor market (Leduc & Liu (2016), Guglielminetti (2016), Riegler (2015)) focus on US data. However, gross labor market flows are large in the US, suggesting that search and matching frictions may be too low to create large irreversibilities. The macroeconomic effects of uncertainty may be larger in more regulated labor and product markets, such as in Korea. With the exception of Miyamoto (2016) on Japanese data, to our knowledge, there is no empirical study on labor market flows in other countries in uncertain times. We fill this gap. We find that an increase in uncertainty lowers output, consumption, investment and job finding rates, while raising job separations and unemployment. We also find that increased uncertainty generates current account surplus, real exchange rate depreciation and reduces the number of firms in the economy.

We next develop a small open economy with search and matching frictions, endogenous job separation and firm entry. Uncertainty shocks are defined as unexpected exogenous variations in the volatility of the technological process. We consider only this uncertainty shock in order to compare our results to the literature (that mainly focuses on the macroeconomic impact of this shock). The model predicts that an increase in uncertainty raises unemployment, job separation rates, and lowers output, consumption, investment, the number of firms and job finding rates. The economy is also characterized by a current account surplus and real exchange rate depreciation. These effects are consistent with the VAR evidence.

The economic mechanisms are the following. In the standard real business cycle (RBC) model, uncertainty creates a precautionary saving motive: Domestic households cut consumption spending to invest in physical capital, job creation, firm entry or Foreign bonds. In a search and matching model, a job match is an irreversible long-term employment relation, which creates an option-value channel. When uncertainty increases, the value of a job match declines as the option value of waiting increases. Under the benchmark calibration, the option-value channel dominates the precautionary motive effects such that the increase in uncertainty reduces vacancies. Firms also use the separation margin to lay off the least productive workers. Unemployment goes up, making it harder for unemployed workers to find jobs. The decline in employment drives the marginal product of capital downward, which triggers fall in capital investment. The real option channel also applies to firm entry. As firm entry is costly, the option value of waiting increases. The expected value of a firm falls, which drives firm entry down. The number of producers declines. At the aggregate level, the reduction in the number of firms is equivalent to a drop in the capital stock. This amplifies the initial fall in output. The recessionary effects of increased uncertainty make investment in capital, job creation and firms unattractive. Households are then attracted by foreign bonds, which creates a current account surplus. Real exchange rate depreciates in response to increased uncertainty because of the fall in domestic relative prices, induced by the reduction in the number of producers. Real exchange rate depreciation makes Foreign bonds attractive as an hedging device against domestic shocks.

Economic mechanisms go beyond the simple addition of each feature. Search frictions, firm entry and the open economy dimension actually strongly interact to amplify the effects of uncertainty shocks and make the model consistent with the empirical evidence. Several elements illustrate these interactions. First, in a search and matching model with firm entry, firm entry interacts with labor frictions as the number of competitors affect the firm's relative price, hence the marginal value of a match. In turn, as firm entry involves vacancy opening, labor market tightness affects firm entry costs (Cacciatore & Fiori (2016)). Secondly, firm entry affects relative prices, hence consumer price index. The real exchange rate is therefore responsive to changes in the competitive environment. Furthermore, real exchange rate depreciation makes Foreign bonds attractive as an insurance device against domestic shocks.

Households then strongly reduce consumption and investment in domestic smoothing tools (jobs, firms or capital), thereby amplifying the recession in uncertain times.

Our work relates to the literature that documents the relationship between uncertainty and the business cycle. Basu & Bundick (2017) argue that the fall in output, consumption, investment, and employment can be obtained after an uncertainty shock in a demand-driven economy, with price rigidity. In Basu & Bundick (2017)'s model, increased uncertainty leads to an endogenous rise in markups, which is crucial in driving down employment in uncertain times. In this paper, as heightened uncertainty lowers firm entry, markups also endogenously increase. With respect to Basu & Bundick (2017), we investigate the macroeconomic effects of uncertainty shocks on labor market flows in an open economy setting. Other existing works analyze the macroeconomic effect of uncertainty shocks using either search and matching models, or in an open economy setting. To the best of our knowledge, none has used firm entry model. In our paper, we combine all elements and show how they interact and magnify recessionary effects of uncertainty shocks.

With respect to the literature on uncertainty shock in an open economy setting (Fernandez-Villaverde et al. (2011), Fogli & Perri (2015), Kollmann (2016)), our originality lies in investigating the consequences of time-varying volatility on labor market adjustments and firm entry. All models, including our own, correctly predict that heightened uncertainty is associated with a current account surplus. However, Kollmann (2016)'s model predicts that heightened uncertainty leads to higher domestic consumption and real exchange rate appreciation, which is not consistent with Korean data. Fernandez-Villaverde et al. (2011) and Fogli & Perri (2015)'s models generate a large precautionary savings that entices domestic households to work more, which is also inconsistent with Korean data. With respect to the literature in a search and matching environment (Leduc & Liu (2016), Guglielminetti (2016), Miyamoto (2016)), we lay stress on the endogenous separation and study the interaction between search and matching frictions and firm entry in an open economy setting. In particular, with endogenous separation, job finding rate increases in uncertain times, which is not consistent with the data (Miyamoto (2016)). Schaal (2017)'s search model also predicts an increase in the job finding rate during the Great recession [1]. Riegler (2015)'s search and matching model correctly predicts a fall in the job finding rate in response to increased uncertainty. With respect to his paper, we investigate the impact of uncertainty in aggregate shocks, rather than idiosyncratic volatility shock. Furthermore, Riegler (2015) introduces

[1] Schaal (2017) also get sizable effects from idiosyncratic volatility shocks partly by assuming a negative correlation between the volatility shocks and the level of aggregate productivity. We do not follow this route.

costly job creation (in addition to the usual hiring cost) to obtain the desired fall in job finding rate after an increase in uncertainty. We do not follow this route. Finally, we take into account the feedback effect of firm dynamics on relative prices, hence real exchange rate, which in turn affects precautionary motives and investment. Schaal (2017) and Riegler (2015) propose interesting insight in labor market dynamics. However, they say nothing about consumption and investment dynamics. As pointed out by Basu & Bundick (2017), papers experience difficulty in generating business-cycle comovements among output, consumption, investment, and employment from changes in uncertainty. Our paper succeeds in doing so, in addition to generating data-consistent a fall in the number of firms, current account surplus and real exchange rate depreciation. Finally, we relate to the literature using search and matching models with firm dynamics. Cacciatore & Fiori (2016) and Cacciatore et al. (2016) focus on structural reforms. We extend this work by investigating the macroeconomic effects of uncertainty shocks.

The paper is organized as follows. We investigate the macroeconomic effects of uncertainty shocks in Korean data in Section 2. We develop a small open economy model with search and matching, endogenous separation and firm entry in Section 3. We explore the macroeconomic effects of uncertainty shocks in Section 4. Section 5 concludes.

2 Effects of uncertainty shocks: empirical evidence

2.1 Measuring uncertainty

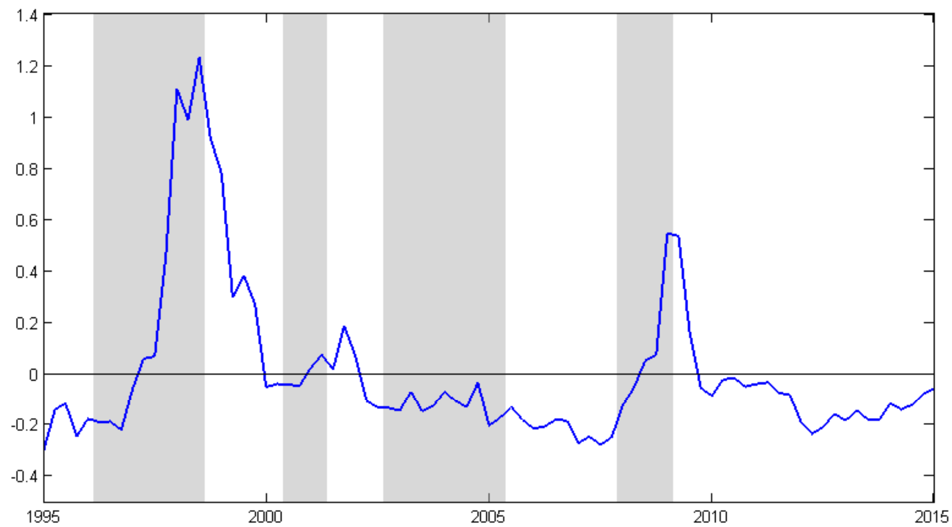
Our measure of uncertainty is forecast dispersion computed from the Korean economy forecasts. Periods when forecasters hold more diverse opinions are likely to reflect greater uncertainty. Survey-based measures of uncertainty have been commonly used in the empirical literature (Bachmann et al. (2013), Leduc & Liu (2016), Guglielminetti (2016) among others). Since January 1995, Consensus Economics has surveyed over prominent financial and economic forecasters for their estimates of a range of Korean macroeconomic variables, including GDP, inflation, unemployment and interest rates over a 2 year forecast horizon. Among them, we use the cross-sectional standard deviation of GDP forecasts.[2] The monthly

[2]To construct the series, we compute the average of cross-sectional standard deviations of GDP forecasts over a 2 year horizon. Bloom (2014) also checks that forecast dispersion provides a good proxy for perceived uncertainty. In the US Survey of Professional Forecasters, in 1992, forecasters provide probabilities for GDP growth (in percent) falling into ten different bins. Using the subjective uncertainty calculated using these probabilities, Bloom shows that disagreement across forecasters indeed captures changes in subjective

time series are seasonally adjusted using X-13-ARIMA-SEATS method and we quarterly average the series from 1995Q1 to 2015Q4.

Since we study the effects of a domestic uncertainty shock, however, our measure needs to be orthogonal to foreign uncertainty shocks. Therefore, we regress our forecast dispersion on US uncertainty measure[3] and use the residual from this regression as our uncertainty measure. Figure 1 displays our measure of uncertainty. In particular, our measure spikes in recession. This counter-cyclical behavior is consistent with empirical findings on US data.

Figure 1: Uncertainty measure



Note: Shaded areas indicate recessions by Statistics Korea.

2.2 Measuring worker flows

As in Shimer (2012), we measure the probability that an employed worker becomes unemployed and the probability that an unemployed worker finds a job, using EAPS survey data, between 1995Q1 and 2015Q4 [4]. Job finding and employment exit probabilities are

uncertainty.

[3]As US uncertainty indicator, we use a measure of disagreement drawn by the Survey of Professional Forecasters (SPF) administered by the Philadelphia FED. Professional forecasters are asked to disclose their best predictions about several macroeconomics indicators at different horizons. The Philadelphia FED itself computes a measure of forecast dispersion, which consists of the difference between the 75th and the 25th percentiles of the forecasts. We use this measure computed for the forecast on nominal GDP.

[4]See Appendix A.1.2 for a full description of the microdata and the methodology.

reported in Figure 6 in Appendix A.1.2. The job finding probability falls in recession, while employment exit probability rises in economic slumps. These cyclical features are also found in other OECD countries (Elsby et al. (2008), Shimer (2012)). The salient stylized fact in Korean data lies in the leading role of job separations in unemployment fluctuations. Based on Shimer (2012)'s variance decomposition, exit from employment accounts for nearly 80% of unemployment fluctuations (versus an upper bound of 50%-60% on US and French data (Fujita & Ramey (2009), Hairault et al. (2015)).[5] As a result, the model developed in this paper includes endogenous separation.

2.3 VAR evidence

The structural VAR consists of six time-series; in the following order, a measure of uncertainty, one of the labor market variables (the unemployment rate, the job finding rate or the job separation rate), the number of firms [6], real GDP (or one of GDP components such as real consumption or real private investment), a measure related to the open economy dimension (current account, as percent of GDP, or real exchange rate defined as the relative price of US consumption basket with respect to the Korean one[7]) and US real GDP. We include US output to ensure the identified shock is not correlated with any foreign shock. It is estimated with 2 lags according to Akaike's information criterion. All quarterly variables are in log (except a measure of uncertainty and current account), seasonally adjusted, and HP-filtered with smoothing parameter 1600. The sample ranges from 1995Q1 to 2015Q4.

As in Basu & Bundick (2017) and Leduc & Liu (2016), we assume that uncertainty does not respond to the state of the economy on impact, but labor variables, real GDP, and current account are allowed to react instantaneously to uncertainty. As in Leduc & Liu (2016), our identification strategy exploits the fact that, when answering questions at time t about their expectations, survey participants do not have complete information about the time t realizations of variables in our VAR model because the macroeconomic data have not yet been made public. Thus, the measure of uncertainty comes first in the Cholesky ordering.

Figure 2 plots the effects of the relevant variables to one-standard deviation shock to

[5] See Appendix A.1.3 for details on the computation of Shimer (2012)'s variance decomposition.

[6] Korean firm data are available on a semi-annual basis. Thus, semi-annual stock of firms is turned into quarterly data using spline. Furthermore, for want of data, we could not include vacancies in the VAR.

[7] In the model as in the data, real exchange rate is the US CPI expressed in South Korean wons relative to Korean CPI. An increase in the real exchange rate captures a depreciation of the Korean currency.

uncertainty with the 68% confidence bands. The responses of all macroeconomic variables appear statistically significant. First of all, a surge in uncertainty reduces output, consumption, and investment. Specifically, an increase in uncertainty produces a peak decline in output of about 0.6 percent, which falls within the range found in the literature (0.2 percent in Basu & Bundick (2017), 2.5 percent in Bloom et al. (2012)). The peak decline in investment is twice larger as the decline in output, as in US data (Basu & Bundick (2017)).

Figure 2: Structural VAR : The effects of one-standard deviation increase in uncertainty

Note: Quarterly data. 68% confidence band. The units of the horizontal axes are quarters. The units of the vertical axes are % change. Example : following a 1 standard deviation shock, the maximum fall in investment is -1.5%. Current account is % of GDP, IRF is then in percentage points.

Heightened uncertainty lowers GDP, consumption and investment, as well as the job finding rate while job separation increases. Both effects on the job finding and separation rates contribute to an increase in unemployment. In particular, a one-standard-deviation increase in uncertainty leads to a peak increase of unemployment rate of about 5.1 percent relative to the sample average. The negative effects of higher uncertainty on labor variables are in line with the recent empirical studies on US flows (Leduc & Liu (2016), Riegler (2015) and Guglielminetti (2016)). The number of firms significantly drops following an uncertainty shock. Increased uncertainty is also associated with current account surplus. This is consistent with the empirical result that heightened uncertainty reduces domestic absorption (consumption and investment fall, Fogli & Perri (2015), Fernandez-Villaverde et al. (2011)). Korean real exchange depreciates. This is consistent with current account surplus as real depreciation makes imports more expensive. In Appendix A.3, we also show that the results are robust to alternative identification, volatility measure, and specification.

3 Small open economy with labor market frictions, endogenous job separation and firm entry

In this section, we develop a small open economy with labor market frictions, endogenous job separation and firm entry as in Cacciatore & Fiori (2016) and Cacciatore et al. (2016). Foreign variables are denoted with a superscript star. The subscript d refers to quantities and prices of a country's own goods consumed domestically. x refers to quantities and prices of exports.

3.1 Household's preference

The economy is populated by a unit mass of households, where each household is an extended family. In each family, some members are employed, others are employed. This assumption is made to avoid heterogeneity across households, as in Andolfatto (1996). The representative household maximizes the expected intertemporal utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma_c}}{1-\sigma_c} \right]$$

where $\beta \in (0,1)$ is the discount factor, and $\sigma_c > 0$ risk aversion. C_t represents consumption of market and home-produced goods: $C_t = C_t^M + (1-L_t)h_p$, where C_t^M is consumption of market goods, h_p is home production, and L_t is the number of employed workers. The aggregate market-consumption basket C_t^M is a CES aggregate of domestic ($C_{d,t}$) and foreign

$(C^*_{x,t})$ goods with elasticity of substitution $\phi > 0$:

$$C^M_t = \left((1-\gamma)^{\frac{1}{\phi}} C_{d,t}^{\frac{\phi-1}{\phi}} + \gamma^{\frac{1}{\phi}} (C^*_{x,t})^{\frac{\phi-1}{\phi}}\right)^{\frac{\phi}{\phi-1}}$$

with $0 < \gamma < 1$ the share of foreign goods in the consumption basket and ϕ the elasticity of substitution between Home and Foreign goods. The corresponding composite price index is:

$$P_t = \left((1-\gamma)P_{d,t}^{1-\phi} + \gamma(\varepsilon_t P^*_{x,t})^{1-\phi}\right)^{\frac{1}{\phi-1}}$$

with ε_t the nominal exchange rate. The domestic consumption basket $C_{d,t}$ is defined over a set Ω_t of available consumption goods. As in Bilbiie et al. (2012), we assume that $C_{d,t}$ and $C^*_{x,t}$ take a translog form as in Feenstra (2003) such that the elasticity of substitution across varieties ω in the subset $C_{d,t}$ increases with the number of available goods in the economy. The price index associated with translog preferences is

$$\begin{aligned} \ln P_{d,t} &= \frac{1}{2\sigma}\left(\frac{1}{N_t} - \frac{1}{\tilde{N}_t}\right) + \frac{1}{N_t}\int_{\omega\subset\Omega_{d,t}} \ln p_{d,t}(\omega) d\omega \\ &+ \frac{\sigma}{2N_t}\int_{\omega\subset\Omega_{d,t}}\int_{\omega'\subset\Omega_{d,t}} \ln p_{d,t}(\omega)\left(\ln p_{d,t}(\omega) - \ln p_{d,t}(\omega')\right) d\omega d\omega' \end{aligned}$$

with $\sigma > 0$ the price elasticity of demand on an individual good, $p_{d,t}(\omega)$ the price of a variety ω produced and sold at Home, N_t the total number of Home producers (the mass of Ω_t), and $\tilde{N}_t$ the maximum number of varieties (the mass of Ω). In a small open economy setting, P^*_t and $P^*_{x,t}$ are exogenous.

3.2 Production

Producer of variety ω. There is a continuum of monopolistically competitive firms, each producing a different variety ω. As in Bilbiie et al. (2012), a firm is a producer of one product. The number of firms is endogenous, because of firm entry. Upon entry, firms pay a sunk entry cost $f_{E,t}$. Exit is exogenous, based on death shock $0 < \delta < 1$. Production uses labor and capital. Within each firm, there is a continuum of jobs, each job is executed by one worker. Capital is perfectly mobile across firms and jobs as in Den Haan & Watson (2000) and Cacciatore & Fiori (2016).

A filled job i at firm ω produces $Z_t z_{it} k^{\alpha}_{i\omega t}$ with Z_t aggregate productivity, z_{it} match-specific productivity, $k_{i\omega t}$ stock of capital allocated to the job. Within each firm, jobs with identical productivity z_{it} produce the same amount of output. As a result, i be can ignored. Each job is characterized by its match-specific productivity z_t. z_t is a per-period i.i.d. draw from a time-invariant distribution with c.d.f. $G(z)$, positive support, and density $g(z)$. When solving the model, we assume that $G(z)$ is lognormal with log-scale μ_z and shape σ_z. Total output for producer ω is

$$y_{\omega t} = Z_t l_{\omega t} \frac{1}{[1 - G(z_{\omega t}^c)]} \int_{z_{\omega t}^c}^{\infty} k_{\omega t}^{\alpha}(z) z g(z) dz$$

$z_{\omega t}^c$ endogenous threshold below which jobs that draw $z_t < z_{\omega t}^c$ are not profitable. As in Leduc & Liu (2016), the aggregate TFP shock Z_t follows the stochastic process

$$\ln Z_t = \rho_z \ln Z_{t-1} + \sigma_{zt} \epsilon_t^z \tag{1}$$

with $0 < \rho_Z < 1$. ϵ_t^z is an i.i.d.innovation to the technology shock and is a standard normal process, with mean zero and unit variance. The time-varying standard deviation of the innovation σ_{zt} captures technology uncertainty shock. σ_{zt} follows the stochastic process

$$\ln \sigma_{zt} = (1 - \rho_{\sigma_z}) \ln \sigma_z + \rho_{\sigma_z} \ln \sigma_{z,t-1} + \sigma_{\sigma_z} \epsilon_t^{\sigma_z} \tag{2}$$

with $0 < \rho_{\sigma_z} < 1$. $\epsilon_t^{\sigma_z}$ is an i.i.d.innovation to the technology uncertainty shock and is a standard normal process, with mean zero and unit variance. σ_{zt} and σ_{σ_z} respectively controls the degree of mean volatility and stochastic volatility in TFP. Firms sells at home and abroad. The demand faced by producer ω is

$$y_{\omega t} = y_{d,t}(\omega) + y_{x,t}(\omega)$$

with

$$y_{d,t}(\omega) = (1 - \gamma)\sigma \ln \left(\frac{\bar{p}_{d,t}}{p_{d,t}(\omega)} \right) \frac{P_{d,t}}{p_{d,t}(\omega)} \left(\frac{P_{d,t}}{P_t} \right)^{-\phi} Y_t^C$$

$$y_{x,t}(\omega) = \gamma\sigma \ln \left(\frac{\bar{p}_{x,t}}{p_{x,t}(\omega)} \right) \frac{P_{x,t}}{p_{x,t}(\omega)} \left(\frac{P_{x,t}}{\varepsilon_t P_t^*} \right)^{-\phi} Y_t^{C*}$$

where Y^C and Y_t^{C*} denote aggregate demand at Home and abroad. Notice that P_t^* expressed in Foreign currency, while P_x and $p_{x,t}(\omega)$ are in Home currency. The maximum prices that a domestic producer can charge is lower when faced with a larger number of competitors N_t

$$\begin{aligned}\ln \bar{p}_{d,t} &= \frac{1}{\sigma N_t} + \frac{1}{N_t}\int_{\omega \subset \Omega_{d,t}} \ln p_{d,t}(\omega) d\omega \\ \ln \bar{p}_{x,t} &= \frac{1}{\sigma N_t} + \frac{1}{N_t}\int_{\omega \subset \Omega_{x,t}} \ln p_{x,t}(\omega) d\omega\end{aligned}$$

Search and matching frictions Labor markets are characterized by search and matching frictions. Hirings are subject to costs of posting vacancy κ. The number of matched workers M_t are such that

$$M_t = \chi U_t^{\varepsilon} V_t^{1-\varepsilon}$$

with $\chi > 0$, $0 < \varepsilon < 1$, U_t the total number of unemployed workers in the economy and V_t the aggregate number of vacancies. The probability of filling a vacancy is $q_t = \frac{M_t}{V_t}$ and labor market tightness is $\theta_t = \frac{V_t}{U_t}$. Firms select capital after observing aggregate and idiosyncratic shocks. Let $v_{\omega t}$ denote the vacancies posted by producer ω. Total capital stock for firm ω is $k_{\omega t} = l_{\omega t}\tilde{k}_{\omega t}$ where

$$\tilde{k}_{\omega t} = \frac{1}{[1 - G(z_{\omega t}^c)]}\int_{z_{\omega t}^c}^{\infty} k_{\omega t}^{\alpha}(z) g(z) dz$$

The inflow of new workers and the outflow of workers due to separations jointly determine the evolution of firm level employment.

$$l_{\omega t} = (1 - \lambda_{\omega t})(l_{\omega t-1} + q_{t-1} v_{\omega t-1})$$

where $\lambda_{\omega t} = \lambda_t^x + (1 - \lambda_t^x) G(z_{\omega t}^c)$ denotes total separations within the firm ω. λ_t^x is the fraction of jobs that are exogenously separated in each firm.

Profit maximization Producer ω's production function can be written as

$$y_{\omega t} = Z_t \tilde{z}_{\omega t} k_{\omega t}^{\alpha} l_{\omega t}^{1-\alpha}$$

with $k_{\omega t} = l_{\omega t}\tilde{k}_{\omega t}$, $\tilde{z}_{\omega t} = \frac{1}{[1-G(z_{\omega t}^c)]}\left[\int_{z_{\omega t}^c}^{\infty} z^{\frac{1}{1-\alpha}} g(z) dz\right]^{1-\alpha}$ and $\tilde{k}_{\omega t} = \frac{1}{[1-G(z_{\omega t}^c)]}\int_{z_{\omega t}^c}^{\infty} k_{\omega t}^{\alpha}(z) g(z) dz$. Let $\rho_{\omega t} = \frac{p_{\omega t}}{P_t}$ denote the relative price of good ω with respect to the consumer price index. $\rho_{x\omega t} = \frac{p_{xt}}{P_t}$ as p_{xt} is the export price, expressed in Home consumption units. The firm per-period profit (in units of consumption) is

$$d_{\omega t} = \rho_{d\omega t} y_{d,t}(\omega) + \rho_{x\omega t} y_{x,t}(\omega) - \tilde{w}_{\omega t} l_{\omega t} - r_t k_{\omega t} - (1 - \lambda_t^x) G(z_{\omega t}^c)(l_{\omega t-1} + q_{t-1} v_{\omega t-1}) F - \kappa v_{\omega t}$$

where $\tilde{w}_{\omega t} = \frac{1}{[1-G(z^c_{\omega t})]} \int_{z^c_{\omega t}}^{\infty} w_{\omega t}(z) g(z) dz$ is the average wage paid by the firm. When terminating a job, each job incurs a real cost F. Firing costs are not a transfer to workers, they refer to pure administrative losses. The firm's program is

$$Max \quad \Pi_t = E_t \left[\sum_{s=t}^{\infty} \beta^t \left(1-\delta\right)^{s-t} \frac{\lambda_{t+s}}{\lambda_t} d_{\omega s} \right]$$

subject to

$$\begin{aligned}
l_{\omega t} &= \left(1-\lambda_{\omega t}\right)\left(l_{\omega t-1} + q_{t-1} v_{\omega t-1}\right) \qquad (\psi_{\omega t}) \\
y_{\omega t} &= y_{x,t}(\omega) + y_{d,t}(\omega) = Z_t l_{\omega t} \frac{1}{\left[1 - G\left(z^c_{\omega t}\right)\right]} \int_{z^c_{\omega t}}^{\infty} k^{\alpha}_{\omega t}(z) z g(z) dz \qquad (\varphi_{\omega t}) \\
y_{\omega t} &= y_{x,t}(\omega) + y_{d,t}(\omega) = \sigma \ln\left(\frac{\bar{p}_{d,t}}{p_{d,t}(\omega)}\right) \frac{P_{d,t}}{p_{d,t}(\omega)} \left(\frac{P_{d,t}}{P_t}\right)^{-\phi} \left[(1-\gamma) Y^C_t + Q^{\phi}_t \gamma Y^{C*}_t\right] \qquad (\mu_{\omega t}) \\
y_{x,t}(\omega) &= \gamma \sigma \ln\left(\frac{\bar{p}_{x,t}}{p_{x,t}(\omega)}\right) \frac{P_x}{p_{x,t}(\omega)} \left(\frac{P_{x,t}}{\varepsilon_t P^*_t}\right)^{-\phi} Y^{C*}_t \qquad (\mu_{x\omega t}) \\
y_{d,t}(\omega) &= (1-\gamma)\sigma \ln\left(\frac{\bar{p}_{d,t}}{p_{d,t}(\omega)}\right) \frac{P_{d,t}}{p_{d,t}(\omega)} \left(\frac{P_{d,t}}{P_t}\right)^{-\phi} Y^C_t \qquad (\mu_{d\omega t})
\end{aligned}$$

with the real exchange rate $Q_t \equiv \frac{\varepsilon_t P^*_t}{P_t}$. The Lagrange multiplier $\varphi_{\omega t}$ captures the marginal cost of a job. The FOC with respect to $k_{\omega t}$ equate the marginal productivity of capital to capital rental rate r_t.

Job creation Using the FOCs with respect to $v_{\omega t}$ and $l_{\omega t}$, we obtain the following job creation condition:

$$\frac{\kappa}{q_t} = \beta\left(1-\delta\right)\left(1-\lambda^x\right) E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \left(\begin{array}{c} \left(1 - G\left(z^c_{\omega t+1}\right)\right) \left(\frac{y_{\omega t+1}}{l_{\omega t+1}} \varphi_{\omega t+1} \left(1-\alpha\right) - \tilde{w}_{\omega t+1} + \frac{\kappa}{q_{t+1}} \right) \\ -G\left(z^c_{\omega t+1}\right) F \end{array} \right) \right] \tag{3}$$

The firm determines the optimal number of vacancies such that the cost of vacancy posting (κ incurred during an average number of periods of $\frac{1}{q_t}$) equal the expected return of a filled vacancy (which includes, if the job is not destroyed, future labor productivity and vacancy costs saved on next period's job, net of wage cost, and, for lost jobs, firing costs).

Job destruction The job destruction equation defines a productivity threshold $z_{\omega t}^{c}$ below which a job is destroyed

$$(1-\alpha)\,\varphi_{\omega t}\frac{y_{\omega t}}{l_{\omega t}}\left[\frac{z_{\omega t}^{c}}{\tilde{z}_{t}}\right]^{\frac{1}{1-\alpha}}-w_{\omega t}\left(z_{\omega t}^{c}\right)+\frac{\kappa}{q_{t}}=-F \tag{4}$$

The job destruction equation states that, at productivity level $z_{\omega t}^{c}$, the firm's outside option (firing the worker, thereby incurring the firing cost F) equals its profit (marginal product, net of labor costs) in addition to the recruitment costs the firm saves by keeping the worker.

Price setting The relative price of a variety ω is $\rho_{d\omega t}=\frac{p_{d\omega t}}{P_{t}}$ and $\rho_{x\omega t}=\frac{p_{x\omega t}}{P_{t}}$. Price setting is such that

$$\rho_{d\omega t}=\rho_{x\omega t}=\mu_{\omega t}\varphi_{\omega t} \tag{5}$$

Let $\theta_{\omega t}=\frac{-\partial lny_{\omega t}}{\partial lnp_{\omega t}}$ denote the price elasticity of total demand for variety ω. Then the firm's mark up over marginal cost $\mu_{\omega t}=\frac{\theta_{\omega t}}{\theta_{\omega t}-1}$.

3.2.1 Wage setting

The wage is the solution of the Nash bargaining process that splits the surplus of the match between the firm and the worker as in most of the labor search literature. At the symmetric equilibrium, all firms ω behave similarly. The average wage is then

$$\tilde{w}_{t}=\left(b+h_{p}\right)(1-\eta)+\eta\left[\begin{array}{c}(1-\alpha)\,\varphi_{t}\frac{y_{t}}{l_{t}}+\kappa\theta_{t}\\ +\Big(1-(1-\delta)\left(1-\lambda^{x}\right)\left(1-s_{t}\right)\beta E_{t}\left[\frac{\lambda_{t+1}}{\lambda_{t}}\right]\Big)\,F\end{array}\right]$$

with $s_{t}=\frac{M_{t}}{U_{t}}$ the job finding rate and η the worker's bargaining power. The wage is a weighted sum of the worker's outside option and the value of the match for the firm, which includes the expected marginal product of labor, the search costs saved by the firms because she kept the worker within the firm. Firing costs have two opposing effects on the current wage. On the one hand, the firm saves today the firing costs, which increases the current wage. On the other hand, the firm will pay future firing costs, in case of job separation in the next period, which lowers the current wage.

3.2.2 Firm entry

As in Cacciatore & Fiori (2016), prior to entry, firms pay a sunk entry cost

$$f_{Et} = f_{Rt} + f_{Tt} + \kappa v_t^e \tag{6}$$

The first two terms represent, respectively, the costs in terms of goods and services imposed by regulatory and administrative barriers to market entry (f_{Rt}) and technological requirements for business creation (f_{Tt}) such as research and development ($R\&D$), nonresidential structures, etc. $f_{Rt} + f_{Tt}$ are paid in terms of the final good Y_t. Upon entry, new entrants choose the same amount of labor as incumbent. They then post v_t^e vacancies such that $v_t^e = \frac{l_t + q_t v_t}{q_t}$. Prospective entrants compute their expected post-entry value, such that is the present discounted value of their expected profit stream

$$e_t = E_t \left[\sum_{s=t}^{\infty} \beta^t \left(1-\delta\right)^{s-t} \frac{\lambda_{t+s}}{\lambda_t} d_s \right] \tag{7}$$

The free entry condition is $e_t = f_{Et}$. As in Bilbiie et al. (2012), we introduce a one-period time-to-build lag. New and incumbent firms can be hit by a death shock with probability $\delta \in (0,1)$ at the end of the period. The law of motion is given by

$$N_t = \left(1-\delta\right)\left(N_{t-1} + N_{Et-1}\right)$$

Upon exit, the firm's workers join the unemployment pool.

3.3 Household budget constraint

Household accumulates physical capital and rent it to firms. Investment consists of domestic and foreign goods, in the same fashion as the consumption basket. Capital accumulation obeys a standard law of motion:

$$K_{t+1} = (1-\delta_K)K_t + I_t \left[1 - \frac{\nu}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] \tag{8}$$

with scale parameter $\nu > 0$ and $0 < \delta_K < 1$ capital depreciation rate. On the international financial market, households have access to foreign-currency risk-free bonds. Let us define $b_t^* = \frac{B_t^*}{P_t^*}$ real holdings of Foreign-currency bonds (in units of Foreign consumption). We assume a quadratic cost of adjusting Foreign bond holding, as in Benigno (2009). In addition, households hold shares in a mutual fund of firms. As in Ghironi & Melitz (2005), household savings are made available to prospective entrants to cover their entry costs through the mutual fund. x_t denotes the share in the mutual fund held by the household at the beginning of period t. The representative household receives each period, $N_t d_t$, the total profit of all firms that produce in that period (in units of consumption). Each period t, the household buys x_{t+1} shares in a mutual fund of $N_t + N_{Et}$ firms. Household's budget constraint (in units of consumption basket) is

$$\begin{aligned}
& C_t + b_t + Q_t b_t^* + \frac{\xi}{2} Q_t \left(b_t^*\right)^2 + \left(N_t + N_{E,t}\right) e_t x_{t+1} + I_t \\
= \; & r_t K_t + \mathcal{W}_t + Q_t b_{t-1}^* \left(1 + i^*\right) + N_t x_t \left(d_t + e_t\right) + \left(1 + i_{t-1}\right) \frac{P_{t-1}}{P_t} b_{t-1} \\
& + \left(b + h_p\right)\left(1 - L_t\right) + \Pi_t + T_t \quad (\lambda_t)
\end{aligned}$$

where T_t are lump-sum transfers, $\xi > 0$ the scale parameter on adjustment costs on Foreign bond holding. This is a small open economy. As a result, Foreign variables are considered as exogenous. In addition, as we focus on technological shocks, Foreign variables are assumed to be constant. λ_t is the Lagrange multiplier associated with the budget constraint. The first-order condition on Foreign holding is

$$1 + \xi b_t^* = \beta(1 + i^*) E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{Q_{t+1}}{Q_t} \right] \tag{9}$$

Choice of investment in firm entry is such that

$$e_t = \beta(1 - \delta) E_t \left[\frac{\lambda_{t+1}}{\lambda_t} (d_{t+1} + e_{t+1}) \right] \tag{10}$$

Household's choice on capital is such that

$$\zeta_t^K = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \left(\varphi_{t+1} \alpha \frac{Y_{t+1}}{K_{t+1}} \right) + \zeta_{t+1}^K (1 - \delta) \right] \tag{11}$$

$$\zeta_t^K \left[1 - \frac{\nu}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 - \nu \frac{I_t}{I_{t-1}} \left(\frac{I_t}{I_{t-1}} - 1 \right) \right] + \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \zeta_{t+1}^K \left(\frac{I_{t+1}}{I_t} \right)^2 \nu \left(\frac{I_{t+1}}{I_t} - 1 \right) \right] = 1 \tag{12}$$

with ζ_t^K is the multiplier associated with equation (8) and captures the shadow price of capital.

3.4 Equilibrium

In the symmetric equilibrium, the elasticity of substitution across varieties is $\theta_t = 1 + \sigma N_t$ and the mark-up

$$\mu_t = 1 + \frac{1}{\sigma N_t} = \frac{\theta_t}{\theta_t - 1} \tag{13}$$

As the number of producers N_t increases, the mark up decreases. As a result, the relative price

$$\rho_t = \exp\left[-\frac{1}{2}\frac{\tilde{N}_t - N_t}{\sigma \tilde{N}_t N_t}\right] \tag{14}$$

declines if N_t falls. Total employment is $L_t = N_t l_t$, the law of motion of employment is $L_t = (1 - \lambda_t)(1 - \delta)[L_{t-1} + q_{t-1}V_{t-1}]$ while the mass of unemployed workers is $U_t = 1 - L_t$. Total vacancies are $V_t = (N_t + N_{E,t})\, v_t + N_{E,t}\frac{l_t}{q_t}$ while aggregate capital is $K_t = N_t k_t$. Total output for all producing firms in terms of consumption units is $Y_t = \rho_t Z_t \tilde{z}_t K_t^{\alpha} L_t^{1-\alpha}$.[8] As pointed out by Ghironi & Melitz (2005), the number of firms behaves very much like a capital stock. Aggregate variables are directly affected by changes in the number of producers. Firm entry then potentially provides a potent magnification mechanism to uncertainty shocks. Current account dynamics is given by

$$Q_t b_t^* - Q_t b_{t-1}^* = Q_t b_{t-1}^* i^* + \rho_t N_t y_t - Y_t^C \tag{15}$$

with

$$Y^C = C^M + N_{E,t}\left(f_{Rt} + f_{Tt}\right) + \kappa V_t + I_t + F L_t \frac{G\left(z_t^c\right)}{\left[1 - G\left(z_t^c\right)\right]} + \frac{\xi}{2} Q_t \left(b_t^*\right)^2$$

Notice, in equation (15), that Home resources are scaled by the number of producers N_t and the relative price ρ_t (that comoves with N_t, equation (14)). A fall in the number of producers N_t then reduces Home aggregate production through these two channels.

[8] Because of the love for variety, measures in units of consumption are not data-consistent. The aggregate price index in the model takes into account changes in the number of available products, which is not the case in CPI data. Ghironi & Melitz (2005) suggest to solve this problem by deflating all variables using an average price index. When we assess the model's fit with the data, we make sure to consider data-consistent variables.

4 Effects of uncertainty shocks

4.1 Solution method and calibration

Solution method Uncertainty shocks, which are the second-moment shocks in our model only enter the model's policy functions independently from the level shocks at third order. Hence, the model is solved using a third-order approximation around the deterministic steady state. We then simulate the model and compute moments of endogenous variables using pruning[9]. The Dynare is used for that purpose (Adjemian et al. (2014)).

As argued in Fernandez-Villaverde et al. (2011), higher order approximation moves the economy away from its deterministic steady state. This implies responses as deviations of the deterministic steady state are not informative. To overcome this problem, we simulate the model for 4000 periods conditioning on future shocks by setting them to 0 and consider the values reached after the simulation as the "stochastic steady state"[10]. All IRFs are then computed as deviations from the stochastic steady state.

Calibration We calibrate the model at a quarterly frequency and choose parameter values from the literature to match features of the Korean economy. However, when data is not available for Korea, we use standard values in the literature. The benchmark calibration is summarized in Table 1 . We choose standard values for all the parameters that are conventional in the literature: the discount factor β, risk aversion σ_C, the capital share in the Cobb-Douglas production function α, and the capital depreciation rate δ_K ($\beta = 0.99$, $\sigma_C = 1$, $\alpha = 0.33$, and $\delta_K = 0.025$). Moreover, we set workers' bargaining power parameter η to 0.6 following Petrongolo & Pissarides (2001). Using Hosios (1990) condition, we set also the elasticity of matches to unemployment ε to 0.6. Adjustment costs on capital are set such that the model matches the relative volatility of investment (leading to $\nu = 0.5$).

Concerning the parameters related to the product market, we set regulation entry cost f_R following the procedure described in Ebell & Haefke (2009). Djankov et al. (2002)'s assessment of entry costs in Korea amounts to 27% of annual GDP per capita. We then infer the entry costs in terms of months of lost output. We add this measure to Pissarides

[9]To ensure stable sample paths, pruning discards higher order terms when iteratively computing simulations of the solution. At third order, Dynare 4.4.3 uses the pruning algorithm of Andreasen et al. (2013)

[10]Born & Pfeifer (2014) use the term EMAS (the ergodic mean in the absence of shocks). It is the point of the state space where, in absence of shocks in that period, agents would choose to remain although they are taking future volatility into account.

(2001)' index of entry costs (converted in the same unit of months of lost output).[11]

We set the technological entry cost f_T such that aggregate R&D expenditures are 1.7 percent of GDP as in Cacciatore & Fiori (2016). In order to get the calibrated value of f_T, we convert the empirical target in terms of quarterly output per capita. The calibrated value is a lower bound for the Korean economy as Korea is characterized by the largest growth in R&D expenditures over the recent years (OECD (2015)).

To pin down the firm exit rate δ, we target the portion of worker separation due to firm exit equal to 26 percent, within the range of estimates reported by Haltiwanger et al. (2006). We set the price elasticity of demand on an individual good, σ, such that the steady state markup is 10 percent, a benchmark value in the literature.

We now turn to the parameters that are specific to the search and matching framework. Unemployment benefit b, are equal to 61 percent of the steady state wage (OECD, Benefits and Wages Database, Korea)[12]. We choose the exogenous separation rate, λ^x, so that the percentage of jobs counted as destroyed in a given year that fail to reappear in the following year is 71 percent as in Cacciatore & Fiori (2016). We set home production, h_p, the matching efficiency parameter, χ, and firing costs, F, to match the total quarterly separation rate, λ, the unemployment rate, U, and the probability of filling a vacancy, q. We set $U = 11.2$, $q = 0.6$, and $\lambda = 0.027$, in line with the estimates in Appendix A.1.2. The resulting firing costs and home production appear to be, respectively, 3 percent of average wage and 31 percent of average wage, at the steady state. For the lognormal scale and shape parameters, μ_z and σ_z, we normalize μ_z to zero, and choose σ_z such that the model reproduces the variability of the job separation rate. Hiring costs as a fraction of steady-state average wage is $\frac{\kappa}{w} = 0.10$, close to the estimates by Abowd & Kramarz (1997) on French data. We consider France as a heavily regulated labor market, as in Korea.

As for the open economy dimension, as in Cacciatore et al. (2016), elasticity of substitution between domestic and foreign goods ϕ is 3.8, and adjustment costs on Foreign bonds $\xi = 0.0025$. The share of imports in total consumption γ is set to 0.3, which is consistent with OECD data on Korean imports. Foreign interest rate i^* is pinned down by the Euler equation on Foreign bonds.

[11] Korea does not appear in Pissarides (2001)' sample. However, according to Nicoletti & Scarpetta (2003)'s index of product market regulation, Korea's level of product market regulation is similar to Italy, Portugal and Spain. These countries appear in Pissarides (2001)' sample. We consider the Italian measure as a proxy for Korea. The implied regulation cost amount to 3.28 quarters of firm-level steady state output. Korea indeed ranks high in the OECD PMR index and in Djankov et al. (2002)'s listing of heavily regulated markets.

[12] We consider net replacement rates during the initial phase of unemployment

We calibrate the parameters in the first-moment shock. We set the persistence parameter to $\rho_z = 0.9$ and choose the average standard deviation, σ_z, to match the absolute standard deviation of GDP in the data. When it comes to the parameters in the second-moment shock, we set the standard deviation of the uncertainty shock to $\sigma_{\sigma z} = 0.17$ and the persistence parameter to $\rho_{\sigma z} = 0.70$, based on our VAR estimation from section 2. We check in Appendix B that the moments predicted by the model provides a satisfactory match of the data.

Table 1: Calibration

Parameter	Description	Value
β	Discount factor	0.99
σ_C	Risk aversion	1
α	Capital share	0.33
δ_K	Capital depreciation rate	0.025
σ	Variety elasticity	13.5
δ	Plant exit	0.007
f_R	Regulation entry cost	7.9
f_T	Technology entry cost	7.8
v	Investment adjustment costs	0.5
λ	Total quarterly separation rate	0.027
b/w	Unemployment benefit replacement ratio	0.61
F	Firing costs	0.0483
ε	Matching function elasticity	0.6
η	Worker's bargaining power	0.6
χ	Matching efficiency	0.32
κ	Vacancy cost	0.0966
σ_z	Lognormal shape	0.08
ρ_z	TFP, persistence	0.9
σ_z	TFP, standard deviation	0.0105
$\rho_{\sigma z}$	TFP uncertainty, persistence	0.70
$\sigma_{\sigma z}$	TFP uncertainty	0.17

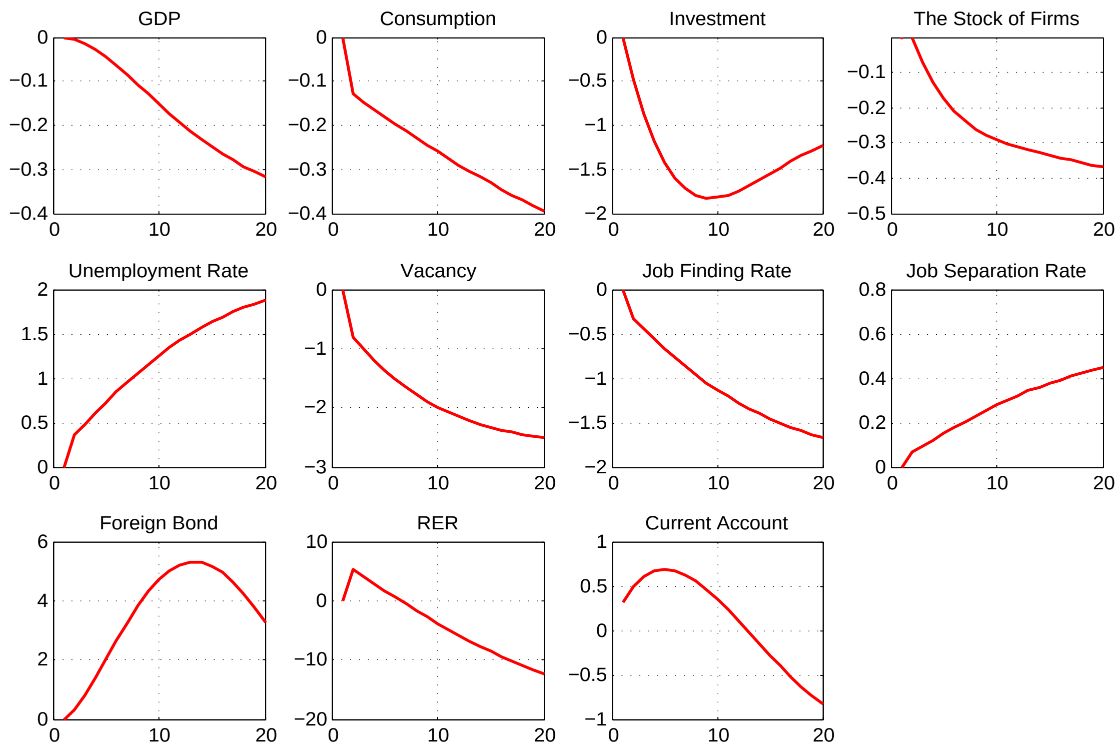
4.2 Impulse response functions

Figure 3 displays the impulse responses of macroeconomic variables to a one-standard deviation increase in technology uncertainty shock.

4.2.1 Mechanisms at work

Precautionary savings. As in the standard RBC model, uncertainty creates a precautionary saving motive: domestic households want to consume less and save more in order

Figure 3: Impulse responses of macroeconomic variables to a one-standard deviation technology uncertainty shock



The units of the vertical axes are % change from the stochastic steady state. Example: following a 1 standard deviation shock, the maximum fall in investment is -1.7%. Vacancy is aggregate vacancy. RER: real exchange rate Q. Job finding rate is $s_t = \frac{M_t}{U_t}$. Job separation is $\lambda_t^x + G(z_t^c)(1-\lambda_t^x) + \delta(1-\lambda_t^x)(1-G(z_t^c))$ total separation rate, including separations due to firm exit. Current account as % of GDP.

to insure themselves against future shocks. Since marginal utility is convex, the stochastic discount rate ($\beta\frac{\lambda_{t+1}}{\lambda_t}$) goes up following an uncertainty shock as in Fernandez-Villaverde et al. (2011), which raises the value of investing in job creation (equation (3)), firms entry (equation (10)), foreign bonds (equation (9)) and physical capital (equation (11)).

Real option value. Uncertainty also makes economic agents cautious about decisions like employment, which adjustment costs can make expensive to reverse. Thus, it gives rise to a contractionary real option-value effect. In our model, real options apply to key decisions: hirings, firing and firm entry.

As for hirings, unlike in a standard RBC model, employment cannot adjust each period due to search and matching frictions. Vacancy posting decisions are based on the expected value of a filled vacancy (equation (3)), which is determined by the stochastic discount rate times the expected surplus of a match. On the one hand, the stochastic discount rate increases, which raises the expected value of a filled vacancy. The present value of a job match goes up. On the other hand, a job match is an irreversible long-term employment relation. Therefore, the expected volatility of the economy affects the expected value of a filled vacancy (right hand-side of equation (3)), thereby introducing a real option effect. When uncertainty hits the economy, the option value of waiting rises, causing a drop in φ the marginal value of a match to the firm. The real-option effect dominates the precautionary savings effect. Hence, faced with a lower expected return on the match, firms post fewer vacancies.

Separations are also subject to an option value. As productivity can quickly revert, firms become more reluctant to separate from their workforce, all the more so as they pay firing costs. This could lead to less separations. However, conflicting forces are at work. As firms post lower vacancies, q the probability of filling a vacancy increases, thereby lowering the average hiring costs $\frac{\kappa}{q_t}$. This creates incentives to destroy more matches as rehiring is less costly. The combined effect on separations is ambiguous. In the benchmark calibration, job destruction rises. As a result, the decline in vacancy posting and the increase in separations push unemployment upward, making it harder for unemployed workers to find jobs. The decline in total employment drives the marginal product of capital downwards, which triggers a fall in capital investment. The interaction between capital and endogenous separation makes the propagation of the shock stronger, as in Den Haan & Watson (2000).

Let us have a look at firm dynamics. As firm entry entails sunk costs (equation (6)), real option channel also applies to firm entry. With higher uncertainty, e the expected value of a firm falls, which drives firm entry down. The number of producers eventually declines, raising mark-up (equation (13)).

Interaction between search frictions and firm entry Firm dynamics have an impact on job creation and separation decisions, and vice versa. First, firm entry condition (equation (6)) depends on labor market conditions. With lower vacancies and higher unemployment, labor market tightness declines, which drives firm entry cost down. Nonetheless, the number of firms still falls in response to higher uncertainty due to the option value channel. Secondly, firm entry also affects job creation and job destruction (in equations (3) and (4)) as φ, the marginal cost of a job, depends on the number of competitors. The fall in the number of firms N drives the relative price ρ downward (equation (14)) and raises the mark-up. The price-setting (equation (5)) implies that the real marginal benefit of a match φ goes down. Hence, the fall in the stock of firms amplifies the initial decline in vacancy posting, making expected future profits less. At the same time, it reinforces job destruction as existing matches become less valuable to the firm. Finally, with a reduced stock of firms, the total number of vacancy posting falls, making labor market tightness even lower. Overall, firm dynamics amplifies the deterioration in labor market conditions.

Open economy dimension and interaction with firm dynamics. We lay stress, in the previous paragraphs, on the fall of the Home relative price ρ. This effect drives consumer price index down, thereby generating a real exchange rate depreciation (Q rises). This is consistent with the empirical findings in section 2.

In addition, a rise in uncertainty induces households to save more and consume less. In the standard RBC closed economy model, this precautionary savings motive translates into higher investment, which is counterfactual. In our model, the domestic household has several investment opportunities to smooth consumption: jobs, capital, firms or foreign bonds. As pointed out in the previous paragraphs, the value of domestic physical capital, jobs, and firms fall. Households are then enticed to invest in Foreign bonds whose returns i^* are not affected by the local uncertainty shock. The rise in uncertainty generates a current account surplus. To further understand the current account dynamics, let us rewrite equation (9) as

$$1 + \xi b_t^* = \beta(1 + i^*) \left[E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \right) E_t \left(\frac{Q_{t+1}}{Q_t} \right) + cov \left(\frac{\lambda_{t+1}}{\lambda_t}, \frac{Q_{t+1}}{Q_t} \right) \right] \tag{16}$$

It is clear from equation (16) that the rise in $\beta \frac{\lambda_{t+1}}{\lambda_t}$ entices households to buy more Foreign bonds. The real exchange rate depreciation (rise in Q driven by relative prices and firm dynamics) amplifies this urge to invest in Foreign bonds. The covariance between changes in the discount rate and real exchange rate is also positive. In other words, consumers use foreign bonds to smooth consumption, all the more so as the Home currency depreciates (foreign currency appreciates in real terms). As the foreign bond is denominated in foreign currency, it provides an interesting hedging device against the fall in Home consumption purchasing power if Foreign currency appreciates when Home consumption falls.

In the description of the economic mechanisms we just provided, we lay stress on the link between the magnitude of real exchange rate depreciation and the current account surplus. As changes in the real exchange rate stem from firm dynamics (through changes in relative price ρ), the model display a strong interaction between the open economy dimension and firm dynamics.

4.2.2 Understanding the respective role of search and matching, open economy and firm entry

In order to provide further understanding of the respective role of search and matching, open economy and firm entry in the model, we display the response of the economy to a technology uncertainty shock in 3 different models. We start with the simple model with search and matching frictions and endogenous separations (no firm entry, closed economy) and analyze the effects of endogenous separation. We extend then this simple model along one dimension: either firm entry (a model with search and matching frictions in an closed economy, with firm entry) or the open economy dimension (a model with search and matching frictions in an open economy, no firm entry).[13] Table 2 summarizes our findings and contribution to the literature. Results of existing works are either incomplete or inconsistent with respect to Korean data. With search and matching frictions and endogenous separations (row 3. of Table 2), the model predicts an increase in investment and job finding rate. Firm entry (row 4. of Table 2) helps the model predict a fall in investment and job finding rate, which is consistent with empirical evidence. The stock of firms also falls, as in the data. The addition of the open economy dimension (row 5.) does not solve the counterfactual rise in the job finding rate but helps the model predict a fall in investment. Moreover, the behavior

[13]Each model is not an extreme calibration of the full model. We actually wrote separate models. In all models, all parameter values are kept at their benchmark values reported in Table 1, except the parameters whose value is derived at the steady state (home production, matching efficiency and firing costs) that are computed to match the same empirical targets: Unemployment, vacancy filling rate and total quarterly separation rate.

of open-economy variables match the data. The following subsections describe the economic mechanisms and underline the interaction between search and matching, open economy and firm entry.

Table 2: Responses of macroeconomic variables to increased uncertainty

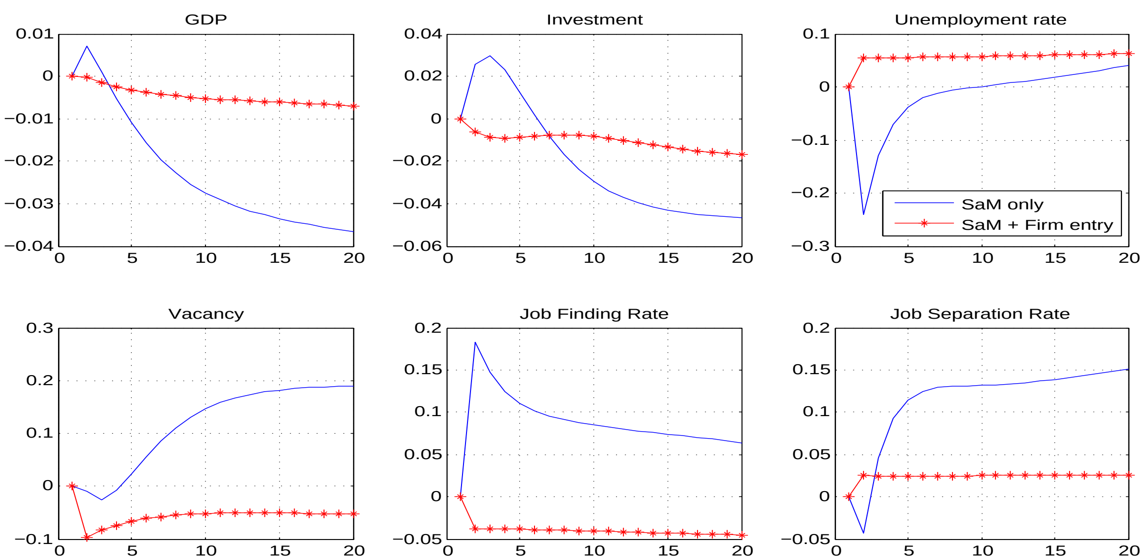
	C	I	E	U	JFR	JSR	N	CA	RER
1. Korean Data	-	-		+	-	+	-	+	+
Our paper									
2. Benchmark	-	-	-	+	-	+	-	+	+
3. SaM only (endo. sep.)	-	+*			+*				
4. SaM + Firm entry (closed economy)		-			-		-		
5. SaM + open economy (no firm entry)		-			+*			+	+
Neo Keynesian model (sticky p.)									
6. Basu & Bundick (2017)	-	-	-						
Search and matching (closed economy)									
7. Leduc & Liu (2016) , sticky p., exo. sep.	-			+					
8. Guglielminetti (2016), flex. p., exo. sep.	-	-		+	-				
9. Miyamoto (2016), flex. p., endo. sep.	-			+	+*	+			
Open economy (no search and matching)									
10. Kollmann (2016)	+*							+	-*
11. Fogli & Perri (2015)	-	+*	+*					+	
12. Fernandez-Villaverde et al. (2011)	-	-	+*					+	

C consumption, I investment, E employment, U unemployment, JFR Job Finding Rate, JSR Job Separation Rate, N number of firms, CA Current Account, RER Real Exchange Rate (+ means depreciation of national currency)
Following an increase in uncertainty, based on IRFs displayed in paper. "+": IRF displays an increase in the short-run. "-": based on IRFs displayed in paper, IRF displays a decrease in the short-run.
* : counterfactual IRF. Example: displays a "+", should be "-" to be consistent with the data. Or vice versa.
"sticky p.": sticky price; "flex. p": flexible price. "exo. sep." / "endo. sep.": exogenous / endogenous job separation.
Leduc & Liu (2016) develop a model without capital, hence without investment.

Search and matching with endogenous separation. With respect to Leduc & Liu (2016), our model includes endogenous separation and capital. Figure 4 shows that the addition of job separation and capital (SaM only) actually moves the model further away from the data. Indeed, the model predicts an counterfactual *increase* in investment and job finding rate (row 3. of Table 2). Due to real option value, job creation and destruction both decrease. The combined effect lowers unemployment, making it easier to find jobs. The increase in employment leads to a rise in investment. Endogenous separation seems to be the key to the counterfactual results. With exogenous separation, lower vacancy would increase unemployment, leading to lower investment. Guglielminetti (2016) uses a search and matching model with exogenous separation and capital. Absent endogenous separation, she finds that the model is able to replicate the contemporaneous drop in output, consumption and investment and the negative impact on the labor market.

Firm entry. To illustrate the link between search frictions and firm dynamics, we add firm dynamics shutting off the open economy dimension (row 4. of Table 2). Figure 4 shows that the introduction of firm entry (SaM + Firm entry) generates a fall in job finding rate and investment, which is consistent with the data. As the option value channel also affects firm entry decision, the number of producers N_t goes down in uncertain times, which increases mark up (μ equation (13)) and reduce relative prices (ρ equation (14)). This means that the marginal gain from a match φ falls (equation (5)). Therefore, firms post less vacancies and separate from more matches. Unemployed workers face a lower probability of finding a job. Investment falls as the decrease in employment reduce the marginal product of capital.

Figure 4: Impulse responses to a one-standard deviation increase in technology uncertainty shock



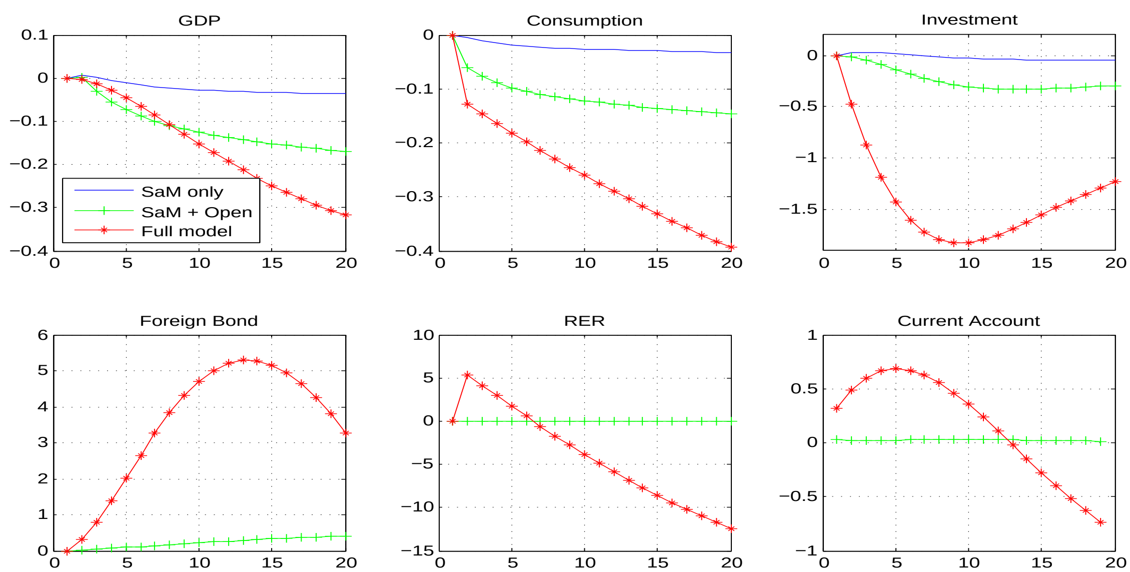
'SaM only' closed economy, no firm entry. 'SaM + Firm entry' closed economy, firm entry. The units of the vertical axes are % change from stochastic steady state. Example : Following a one-standard deviation shock in uncertainty, jog finding rate peaks at 0.17% in the model 'SaM only'.

Adding the open economy dimension. In a closed economy, the precautionary savings motive entices households to invest more, which is counterfactual. In an open economy, foreign assets provide an more interesting investment opportunity to build up a buffer stock against future shocks, as the return on Foreign assets i^* is exogenous (row 5. of Table 2). To highlight the interaction between search frictions and open economy dimension, we open the economy shutting off firm dynamics. In Figure 5, with open economy dimension (SaM

+ Open), the Home country runs a current account surplus and the fall in consumption is larger than in a closed economy setting. In a nutshell, the open economy dimension allows the model to generate a larger fall in consumption and a drop (rather than an increase) in investment. The latter further reduces the marginal product of labor, thereby leading to larger recessionary macroeconomic effects of the uncertainty shock.

Furthermore, firm entry and open economy dimension interact with each other. The fall in the stock of firms, that are associated with real options channel, reinforces the real exchange rate depreciation, thereby inducing more capital outflows (equation (16)). In Figure 5, with open economy and firm entry (the full model), real exchange rate depreciates more, leading to larger foreign bond holding and current account surplus. This outcome is consistent with larger reduction in consumption and investment. Moreover, comparing Figures 4 and 5 shows that a larger fall in GDP is obtained under the full model because of the interaction with the open economy dimension. [14]

Figure 5: Impulse responses to a one-standard deviation increase in uncertainty shock



'SaM only': closed economy, no firm entry. 'SaM + Open': open economy, no firm entry. 'Full model' : benchmark model. The units of the vertical axes are % change from stochastic steady state. Example : Following a one-standard deviation shock in uncertainty, the maximum fall in investment is -1.7% in the Full model.

Kollmann (2016) also finds that, following an unexpected rise in output volatility, Home

[14] The decline in output is persistent. It is also the case in Fernandez-Villaverde et al. (2011), Fogli & Perri (2015) and Kollmann (2016) as households gradually build-up a buffer stock of Foreign assets. Figure 4 suggest that firm dynamics also adds to the persistence of GDP response to increased uncertainty.

net foreign assets increase, which is consistent with our IRFs. However, in Kollmann (2016)'s 2-country model, under complete financial markets, the international risk sharing implies that the rise in Home output volatility triggers a wealth transfer from the rest of the world to the Home country, such that Home consumption rises, and the Home real exchange rate appreciates. These features are counterfactual on Korea data. Fogli & Perri (2015) show that, in a standard one-good 2-country RBC model, faced with increased domestic uncertainty, hence increased risk on domestic investment opportunities, agents buy more foreign assets. Our results show that these mechanisms are also at work in our model. However, in Fogli & Perri (2015)'s setting, as well as in Fernandez-Villaverde et al. (2011), the precautionary savings motive entices households to work more, which is counterfactual. Our model correctly predicts a fall in employment.

5 Conclusion

Using a VAR model, we show that an increase in uncertainty lowers output, consumption, investment and job finding rates, while raising job separations and unemployment. We also supplement the existing empirical evidence by looking at firm dynamics, real exchange rate and current account behavior. We find that increased uncertainty generates real exchange rate depreciation, current account surplus and reduces the stock of firms in the economy.

We then investigate the impact of uncertainty shocks in a small open economy with search and matching frictions, endogenous job separation and firm entry to illustrate new transmission mechanism. Basu & Bundick (2017) points out that papers experience difficulty in generating business-cycle co-movements among output, consumption, investment, and employment from changes in uncertainty. Our paper succeeds in doing so, in addition to generating data-consistent a fall in the number of firms, current account surplus and real exchange rate depreciation. The key mechanisms are real options channel and precautionary saving motive. The real options channel affects labor adjustment as well as firm entry. Precautionary saving motive gives rise to capital outflow and real exchange rate depreciation. The interaction of these channels in an open economy setting leads to sizable macroeconomic effects of heightened uncertainty, and helps reproduce data-consistent results.

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APPENDIX

A Data

A.1 Measuring worker flows

A.1.1 Economically Active Population Survey

We employ the Economically Active Population Survey (EAPS) conducted by Statistics Korea. It is cross-sectional monthly household survey, and the sample size consists of approximately 33,000 households per period (about 70,000 adult individuals). The main goal of EAPS is to reveal the characteristics of that population with regards to the labor market. In particular, based upon the main activities indicated for the reference week, Statistics Korea classifies respondents as follows: those working or absent from work as employed, those looking for work as unemployed, and all others as inactive. Among inactive, those who worked for the money more than 1 hour or worked more than 18 hours as non-paid family worker are classified as employed and those who searched for job during last 4 weeks are classified as unemployed.

A.1.2 Measuring transition rates

We use EAPS from January 1986 through December 2015 to construct the series of worker flows.[15] According to survey design, each household remains in the sample for 36 months, and 1/36 of total households is renewed each month.[16] EAPS's rotation scheme allows us to match individuals across two consecutive months, and obtain gross flows across labor market states.[17] Note that our analysis focuses on monthly transitions between employment (E) and unemployment (U), and never consider transition from and to inactivity (I). To calculate the transition rates, we first consider the gross flow N_t^{AB} of workers that transit from the state A to the state B over the month. Let $n_t^{EU}(n_t^{UE})$ denote the share of employed (unemployed) workers in period t-1 who are unemployed (employed) in period t:

[15] The EAPS has been in existence since 1963, but microdata in which information on individual characteristics is available have been collected since 1986.

[16] The survey was redesigned in 2005. Prior to 2005, EAPS maintained a fixed sample over 5 years.

[17] We match individuals by household ID, person ID, sex, and date of birth for the 1986-2004 period. Since 2005, however, Statistics Korea has not provided household ID and person ID. Thus, we use sex, date of birth, relation with the head of household, and level of education for the 2005-2015 period.

$$n_t^{EU} = \frac{N_t^{EU}}{N_t^{EE} + N_t^{EU}}$$

$$n_t^{UE} = \frac{N_t^{UE}}{N_t^{EE} + N_t^{EU}}$$

Then, we seasonally adjust the series using X-13-ARIMA-SEATS method, and corrects the time aggregation bias. We then compute quarterly averages of the monthly transition rates, as in Shimer (2012). Figure 6 displays the job finding (f_t) and separation (s_t) rates in Korea. The correlation of the corresponding steady-state unemployment $u = \frac{s_t}{s_t+f_t}$ with actual unemployment rate is very high (0.96), which tends to validate our method for measuring worker flows.

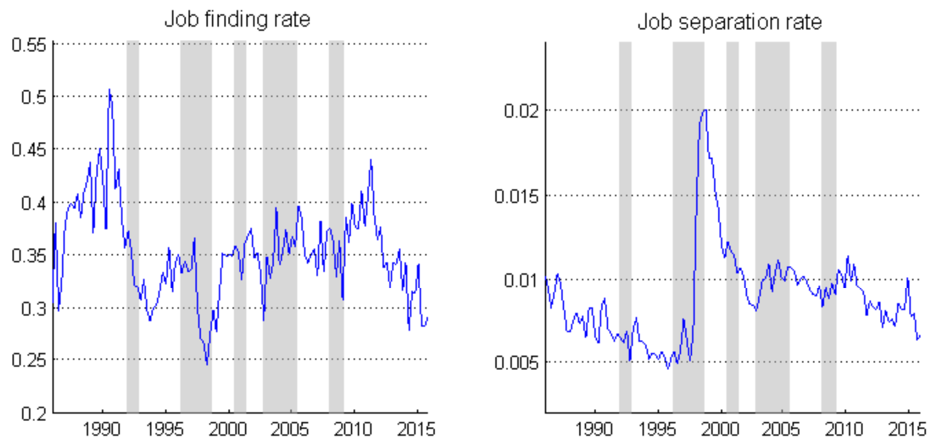
A.1.3 Contribution of the transition rates to unemployment

We next consider the cyclicality of the job finding and separation rates following Shimer (2012). If the economy were in steady state at some date t, the unemployment rate would be determined by the job finding and separation rates, $\frac{s_t}{s_t+f_t}$. In quarterly-averaged data, the correlation between this steady state measure and actual unemployment is 0.96. We use this strong relationship to calculate the contribution of changes in each of the two transition rates to fluctuations in unemployment rate.

Let $\bar{f}$ and $\bar{s}$ denote the average values of f_t and s_t during the sample period and compute the hypothetical unemployment rates $\frac{\bar{s}}{\bar{s}+f_t}$ and $\frac{s_t}{s_t+\bar{f}}$ as measures of the contribution of fluctuations in the job finding and separation rates to overall fluctuation in the unemployment rate. Figure 7 shows the contribution of fluctuations in the job finding and separation rates to the fluctuations in the unemployment rate. This exercise finds that the separation rate contributes much more to accounting for the fluctuation in the unemployment in Korea.

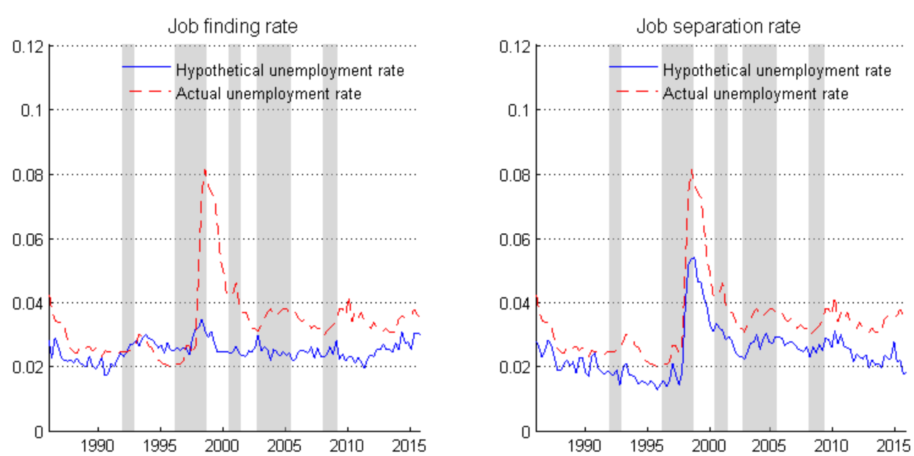
In order to quantify this, Shimer (2012) looks at the comovement of detrended data. Therefore, we use the Hodrick-Prescott filter for detrending with a smoothing parameter of 1600. Over the sample periods, the correlation of the cyclical components of unemployment and $\frac{\bar{s}}{\bar{s}+f_t}$ is 0.209, while the correlation of unemployment and $\frac{s_t}{s_t+\bar{f}}$ is 0.796. It shows that the job separation rate is the main driver of the fluctuation in the unemployment rate. These findings are consistent with Kim & Lee (2014) who show that inflows into unemployment contributes substantially to unemployment fluctuations in Korea.

Figure 6: The job finding and separation rates



Authors' calculations. Shaded areas indicate recessions by Statistics Korea.

Figure 7: Contribution of fluctuations in the job finding and separation rates to the fluctuations in the unemployment rate

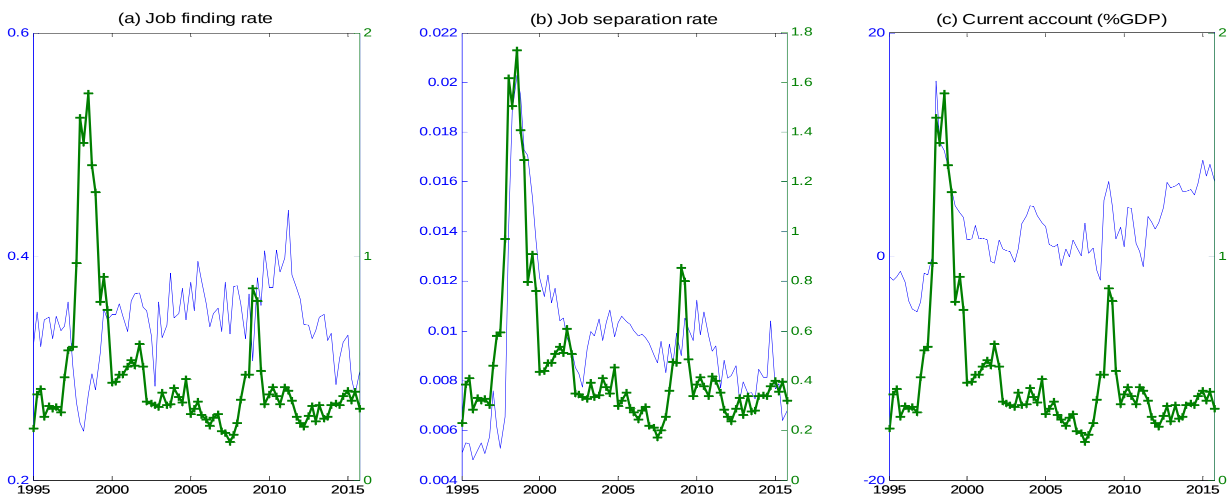


Authors' calculations. Shaded areas indicate recessions by Statistics Korea. "Hypothetical unemployment rate" in left panel : steady state unemployment predicted by time-varying job finding rate, separation rate constant. "Hypothetical unemployment rate" in right panel : steady state unemployment predicted by time-varying separation rate, job finding rate constant.

A.2 A first look at the data

Figure 8 displays our measure of uncertainty along with workers' flows and current account as % of GDP. Visual inspection suggests that increased uncertainty tends to be associated with lower job finding rate, higher separation and increases in current account. The correlation of the uncertainty measure with unemployment outflows, inflows and current account as % of GDP are respectively -0.52, 0.72 and 0.49. In section 2, we go beyond the descriptive statistics using a structural VAR to identify the causal effect of uncertainty on macroeconomic dynamics.

Figure 8: Job finding rate, separation rate, current account and uncertainty index



Source : Authors' calculations. See Appendix A. Solid line: the time series mentioned in the title of the graph. "+" line: Uncertainty measure

A.3 Structural VAR : Robustness checks

This section shows that the impulse response function in Figure 2 is robust to alternative identification, volatility measure, and specification. Our assumptions to identify uncertainty shocks imply that uncertainty does not respond to macroeconomic shocks in the impact period. To check the extent to which this assumption may affect our results, uncertainty is placed last in our vector. Uncertainty may reflect the forecasters' perceptions of bad economic times rather than an uncertain future. To control for potential effects from changes in consumer sentiment, we estimate a five-variable VAR that includes a consumer sentiment index as an additional variable. Our uncertainty measure is constructed to take a value 1 for each quarter that uncertainty exceeds the threshold and a 0 otherwise. This indicator function is used to ensure identification comes only from these large, and arguably exogenous, uncertainty shocks rather than the smaller ongoing fluctuations. The outcome of all robustness checks are reported in Figure 9. In all cases, the responses are comparable to the baseline.

A.4 Macroeconomic data

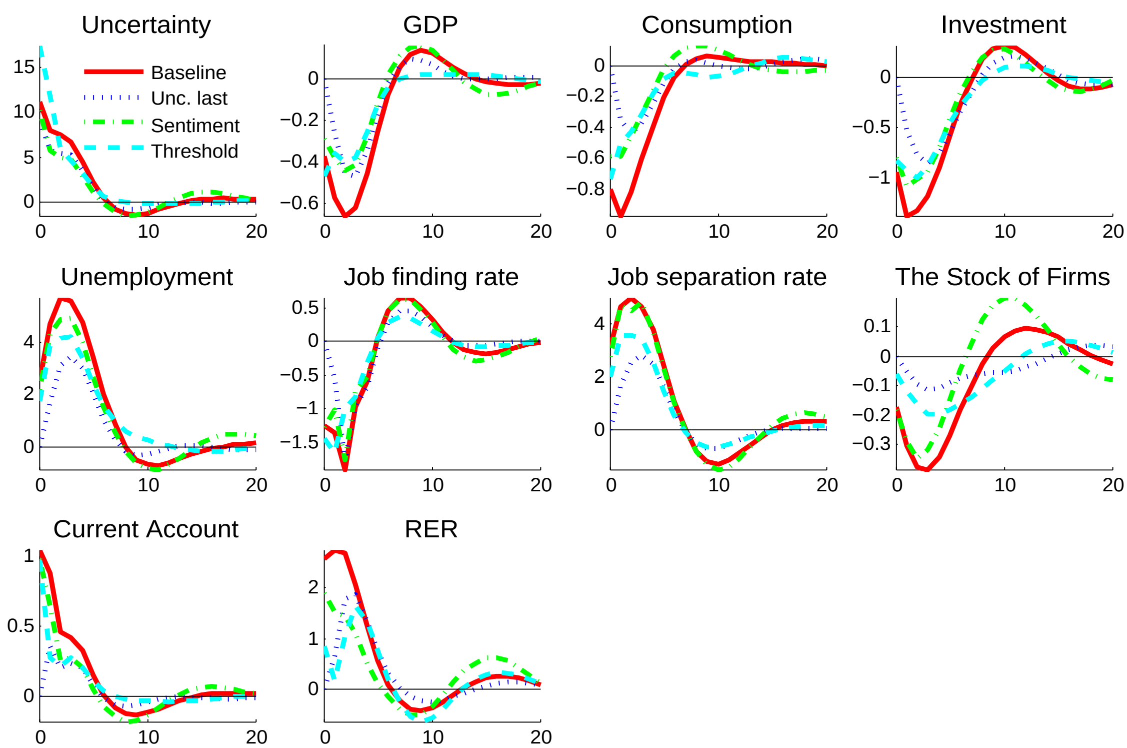
The data coverage is 1986Q1-2015Q4.

- Output: real gross domestic product, seasonally adjusted, 2010 reference year, Statistics Korea.
- Consumption: private consumption expenditure, seasonally adjusted, 2010 reference year, Statistics Korea.
- Investment: the sum of gross capital formation and changes in inventories, seasonally adjusted, 2010 reference year, Statistics Korea.
- Unemployment rate: official unemployment rate, job-search for 4 weeks standard, seasonally adjusted, Statistics Korea.
- Number of firms: the number of corporations in operation as of end of the relevant period, semi-annual frequency from 1995H1 to 2014H2, National Tax Statistics. We use a spline to transform semi-annual data into quarterly data.
- Current account as a % of GDP: seasonally adjusted, OECD Dataset.
- US GDP: real gross domestic product, billions of chained 2009 dollars, quarterly, seasonally adjusted annual rate, FRED

B Business cycle statistics: Model versus data

Finally, we check that the model provides a good fit of the data, with respect to business cycle statistics. Table 3 displays the simulated moments and the moments computed from Korean data from 1986Q4 to 2015Q4. All quarterly data are seasonally adjusted, logged,

Figure 9: The effects of one-standard deviation shock to uncertainty: robustness checks



Baseline: baseline VAR. Unc. last: uncertainty placed last in the otherwise baseline VAR. Sentiment: consumer sentiment index placed on top of the baseline VAR to control for potential effects from movement in consumers' perception of bad economic times. Threshold: uncertainty measure constructed to take a value 1 for each quarter that uncertainty exceeds the threshold and a 0 otherwise.

and HP-filtered with smoothing parameter 1600. See Appendix A.4 for a description of data sources. As mentioned in the calibration section, some of the model's parameters were chosen to make the model match output volatility, investment and job separation relative volatility. The model is simulated with technological shocks (equations (1) and (2)).

Table 3: Business cycle statistics: Model versus data

	Volatility		Cyclicality	
	(1) Data	(2) Model	(3) Data	(4) Model
Y (i)	2.07	2.07	1 (iii)	1
C (ii)	1.44	0.59	0.86	0.75
I	2.42	2.20	0.83	0.90
JSR	8.74	8.78	-0.73	-0.68
JFR	4.13	3.77	0.48	0.76
U	8.44	9.70	-0.81	-0.77
V	8.54 (iv)	8.73	0.9 (iv)	0.35
corr(U,V)			-0.80 (iv)	-56.4

(i). Output std. in %, in columns (1) and (2).

(ii). For all variables except output, std. relative to output, in columns (1) and (2)

(iii). Correlation with output in columns (3) and (4)

(iv). For want of Korean data, US value

With respect to labor market variables, the model is able to produce volatile job finding and separations rates. In particular, separation are more volatile than job findings, which is a specific feature of the Korean economy. The model's predicted volatility of unemployment and vacancies is consistent with the data. For vacancies, there is no available data on Korean vacancies, we then report the business cycle statistics on US data.

Consumption is more volatile than output in Korean data. It is a well-known feature in emerging economies (Aguiar & Gopinath (2007) among others). The model fails to capture this feature. Capturing the high consumption volatility is beyond the scope of the paper. Furthermore, the high consumption volatility is not a robust stylized fact in Korean data. From 1980Q1 to 1995Q4, the relative volatility of consumption was 0.67. The relative consumption volatility prevailing during this period is closer to the model's predicted consumption volatility.

Finally, the model predicts a negative correlation between unemployment and vacancies. This is an interesting feature as a positive correlation between unemployment and vacancies is a well-known feature of Mortensen & Pissarides (1994)'s model with endogenous destruction.

Indeed, with the separation margin, firms can quickly adjust the employment level, which is preferred by the firm as hiring is costly and takes time. Following a positive TFP shock, firm can increase employment by keeping more workers, even less productive ones, rather than waiting for new workers to arrive from the matching market. Vacancies can go down, so does unemployment, thereby generating a positive correlation between unemployment and vacancies. With firm entry, unemployment and vacancies can display a negative correlation in spite of endogenous separation. Indeed, as firm entry falls, with the decline in the number of firms actually result in a fall in aggregate vacancies.