Real and Nominal Effects of Monetary Shocks under Uncertainty [*]

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Abstract

This paper investigates possible heterogeneity and asymmetry of monetary policy transmission under different uncertainty regimes using threshold VAR. I use the dispersion of nominal GDP from the Survey of Professional Forecasters as a measure of economic uncertainty. I focus on how increasing uncertainty may affect the effectiveness of monetary policy on output and inflation. In high uncertainty periods, monetary policy has stronger real effects, yet weaker price effects. Thence, conventional uncertainty predictions does not seem to match the empirical results in this paper. I argue that a rational inattention framework could be more suited to analysing this particular question than a full-information rational expectations benchmark.

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1 Introduction

A key challenge for policymakers is the recent elevated uncertainty such as the Great Recession, Euro-area debt crisis and the UK's EU Referendum vote. A large literature, following Bloom (2009), examines how uncertainty shocks – the sudden chance in the variance of shocks – *directly* affect goal variables of policymakers – for example, inflation and output. However, policymakers' response would in part be dictated by the *indirect* effects of uncertainty – that is, how does heightened uncertainty affect the strength of economic policy in controlling target variables. In this paper, I focus on how heightened uncertainty may affect effectiveness of monetary policy on output and inflation, and how the conventional uncertainty predictions does not seem to match the empirical results in this paper.

A closely related strand of the literature tries to understand how the effects of monetary policy differ under different states – in particular, expansions and recessions. An oft-emphasised mechanism in explaining the heterogeneity in monetary transmission is the role of uncertainty, as recessions are typically associated with higher uncertainty. However, uncertainty and recessions do not overlap completely. Uncertainty proxies indicate many more episodes of high uncertainty than NBER-dated recessions since 1970.[1] In addition, there are also large variations in uncertainty within and across different periods of expansions and recessions. This helps the identification of the effect of uncertainty. Furthermore, a dual mandate central bank like the Federal Reserve (partially) aims to prevent recessions. Yet, uncertainty often rises before a recession begins. Studying the effect of monetary policy only during recessions precludes much of the period that a central bank is interested in. Knowing how monetary policy should react in different uncertainty states – not just in recessions vs expansions – would be useful to policymakers.

The usual intuition from the uncertainty literature is that monetary policy is less powerful under higher uncertainty, because agents are more cautious and respond more slowly (Bachmann et al., 2013; Aastveit et al., 2017; Castelnuovo and Pellegrino, 2017). For example, firms with irreversible investments – such as long-term physical capital investments – may find it difficult to change their investment plans even when their cost of borrowing changes in response to monetary policy shocks. This effect is amplified further when uncertainty is high. The intuition is that firms align their estimate of the underlying state of the economy

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[1]There are only 7 NBER-dated recessions since 1970, averaging around 4 quarters each.

to its true value and future demand, more slowly when uncertainty is high. This is because the signal in observing current demand is less valuable to a firm in filtering the state of the economy when uncertainty is higher.[2]

However, as I will show later in the paper, the results suggest that monetary policy is actually *more* powerful in affecting output, in times of high uncertainty, but *less* influential on prices. I argue instead that a rational inattention framework could be more suited to analysing this particular question. The key story in rational inattention is endogenous information acquisition – agents have a finite information processing capacity, and thus actively choose what information to gather that is most relevant for their respective utilities.[3] Thus, relative to a full-information rational expectations benchmark, rationally inattentive firms and households would move their decision variables more slowly in response to a monetary shock as they are unable to process all the information.

How does time-varying uncertainty fit into the rational inattention framework? Uncertainty affects the costs and benefits of gaining information. Increased uncertainty quite obviously means that the cost of information (or reducing entropy) is higher given their finite information processing constraints, and thus agents may 'buy' less information in equilibrium. For example, in response to the Brexit vote, firms may decide to hire (costly) experts to advise on the potential impacts and outcomes for the company. Furthermore, the firm may decide to re-allocate resources from other parts of the company to maximise their readiness in times of high uncertainty. On the other hand, it is more beneficial for firms to gain more accurate information in times of high uncertainty, as decisions fed by poor information may lead to increasingly costly mistakes. Ultimately, the amount of information gained by agents will determine how responsive their actions are to shocks. Thus, the predictions of rational inattention to heightened uncertainty is ambiguous in equilibrium. The empirical evidence here suggests that the costs seem to rise by more than the benefits. In high uncertainty times, firms decide to process less information and they react less to aggregate shocks. Given that firms set prices, this implies that prices become more 'sticky' (moves by less) and thus output responds by more to a contractionary monetary shock.

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[2]A more technical intuition is to imagine a firm that is Kalman filtering the state of the economy to forecast the future demand that it needs to satisfy. The Kalman gain of the filter will be lower if the variance of the noise on the observations (current demand) is higher, and thus the estimate of the state – and investment – will move more sluggishly.

[3]Formally, Sims (2003) modelled rational inattention as agents using their finite capacity to reduce *entropy* (a measure of how much uncertainty is in a probability distribution) of the system to the best of their ability.

My empirical approach is to use a threshold VAR of Koop et al. (1996) to empirically investigate possible heterogeneity and asymmetry of monetary policy transmission under different uncertainty regimes. The general idea of the methodology is to pick a 'threshold variable' that contains information about the different regimes – in this case, high and low uncertainty. The threshold variable is endogenous, and thus allows for endogenous regime switching. It implies that the response of economic variables can depend on the sign and magnitude of the structural shock, unlike linear VARs. This flexible methodology allows us to examine the potentially different properties of the transmission of contractionary/expansionary monetary policy shocks. As will be discussed in greater detail, the particular threshold variable that is chosen is the dispersion of nominal GDP forecasts from the Survey of Professional Forecasters.

There appears to be little consensus in the literature of the heterogeneity of monetary policy effects in different economic regimes. There is more work on differentiating the effects of recessions and expansions, rather than high and low uncertainty, on the strength of monetary transmission. Tenreyro and Thwaites (2016) and Caggiano et al. (2014) find that monetary shocks have less impact on output and prices in *recessions*, while others such as Peersman and Smets (2001) and Lo and Piger (2005) find the opposite. Similarly, when emphasising on uncertainty, Aastveit et al. (2017) and Castelnuovo and Pellegrino (2017) find monetary policy to be less effective in affecting both, output and prices, in *high uncertainty*. It is interesting to note these papers find in adverse conditions (high uncertainty or recessions), that either: (1) monetary policy has *weaker* effects on output *and* prices, or (2) monetary policy has *stronger* effects on output *and* prices.

Meanwhile, this paper's results lie in the middle of the literature. I find that in high uncertainty periods, monetary policy has stronger real effects but weaker price effects. An explanation concerning rationally-inattentive firms could reconcile this result. If the marginal costs of gaining information during times of higher uncertainty is higher, then firms may decide to process less information, and thus react less to aggregate shocks. Given that they set prices, this implies that prices become more 'sticky' and thus output responds by more to a monetary shock. Furthermore, I observe some asymmetry to positive and negative shocks, especially with prices. In particular, prices respond more to expansionary monetary shocks under both high and low uncertainty.

This paper is structured as follows. Section 2 briefly summarises the related literatures. Section 3 describes the data used, and goes into detail why the particular threshold variable was chosen and Section 4 explains the threshold VAR and the

computation of generalised impulse responses. Section 5 highlights the main empirical results from the model. Section 6 concludes.

2   Brief Literature Review

This paper is connected to the uncertainty shocks literature – the 'direct' impact of uncertainty. Bloom (2009), and Jurado et al. (2015) investigates how increases in uncertainty can depress hiring and investment if agents are subject to fixed costs or partial irreversibility (a 'real options' effect) and so they find it optimal to postpone an investment. Furthermore, with regard to consumption and the concept of precautionary savings, Caballero (1990) illustrates how increased uncertainty can lead to a drop in consumption. Increased uncertainty in the economy can lead to higher uncertainty about labour income, which may lead to risk-averse behaviour, such as reducing consumption today and increasing savings to ensure consumption tomorrow. Therefore, if jumps in uncertainty can lead to a pause in consumption and investment, it is then important that firms and households pay attention to uncertainty, and monetary policymakers to understand how it could affect its policy transmission.

This paper contributes to the recent empirical literature on the relations between uncertainty and monetary policy. Bloom (2009), Mumtaz and Theodoridis (2015), Baker et al. (2016), and Leduc and Liu (2016) are among those who employ structural VAR models to study the impact of uncertainty on the economy. Various structural VARs have been employed to study the effectiveness of monetary policy under different uncertainty regimes. The threshold VAR, popularised by Koop et al. (1996) and Tsay (1998), is one of the methodologies that allow researchers to capture the nonlinear or asymmetric effects of monetary policy given different uncertainty regimes.

For example, similar to this paper, Castelnuovo and Pellegrino (2017) also work with two-regime threshold VAR model to investigate the uncertainty-conditional impact of monetary policy shocks. However, the threshold variable in their paper is treated as an exogenous variable instead of an endogenous variable like in this paper. This means that uncertainty is not modelled in their threshold VAR, and thus cannot react to monetary policy shocks. The main difference between this paper and theirs is the calculations of impulse responses. Since they treat uncertainty as an exogenous variable, they can compute the responses to a monetary policy shock in a conditionally-linear fashion, which retains all the properties

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associated with impulse responses in linear VARs. By contrast, I compute the impulse responses using generalised impulse response function which accounts for the endogenous threshold variable that creates nonlinearities in my threshold model. Aastveit et al. (2017) and Pellegrino (2017) also treats uncertainty as an exogenous interaction variable, but uses interacted VAR instead of threshold VAR. The interacted VAR augments an otherwise standard VAR with an interaction term including two variables – the variable used to identify the monetary policy shock (the Federal Funds Rate) and a conditioning variable that identifies uncertainty states. This methodology enables them to model the interaction between monetary policy and uncertainty in a parsimonious manner.

More recently, the rational inattention literature makes contribution in studying the impact of monetary policy shocks under high and low economic uncertainty. Menkulasi (2009) considers a dynamic general equilibrium model in which firms are limited in their ability to process information and allocate their limited attention across aggregate and idiosyncratic states. According to the model, an increase in the volatility of aggregate shocks causes the firms optimally to allocate more attention to the aggregate environment. Similarly, Zhang (2017) studies a model where firms choose to process more information when uncertainty rises, especially about aggregate conditions, and their pricing behaviour changes accordingly.

The analysis of this paper is closest to Zhang (2017) who investigates the endogenous information processing capacity – rational inattention – as a channel through which uncertainty affects price dynamics, and empirically tests it with a Markov-switching FAVAR. The regimes in the model are 'high' and 'low' volatility. However, the problem with the Markov-switching framework for studying this paper's research question is, for the most part, that it tends to capture steady state step-changes in the dynamics of the US economy. It is clear that in the earlier part of the sample that regime 1 (the 'high volatility' regime) dominates, and regime 0 (the 'low volatility' regime) dominates in the later half. In other words, primary regime change within the particular sample is between the volatile 70's and Great Moderation. The central premise is that uncertainty and rational inattention is very closely linked — the more uncertain the economy is, the more effort people would exert into monitoring the economic state. Zhang finds firms' optimal attention exhibits inertia and asymmetry in response to volatility changes. Predictions from rational inattention approaches can explain better the sluggish responses of output and prices found in the empirical evidence from VAR studies than rational expectations.

3   Data

I obtained quarterly data of real GDP, GDP deflator, commodity price index, and effective Federal Funds Rates from Federal Reserves Economic Data (FRED) for the sample period from 1970Q1 to 2015Q3. Real GDP and GDP deflator are measures of economic activity and prices, sourced from the Bureau of Economic Analysis, and are seasonally adjusted. Later on in the analysis, I also take real consumption expenditures and real private fixed investment: non-residential from the same source. I include commodity price index is to control for oil price shocks and captures supply side factors that may influence output and prices. This data is from the Bureau of Labour Statistics, and is originally not seasonally adjusted.[4] The choice of these variables is standard in the empirical literature studying monetary policy transmission as noted by Christiano et al. (1994), Sims (1992), and Bernanke and Gertler (1995). I transform real GDP, GDP deflator and commodity price index with log first-differences.

I replaced the effective Federal Funds Rates (FFR) between 2009Q1 and 2015Q3 with the Wu and Xia (2016) shadow rate to account for the zero lower bound (ZLB) and quantitative easing.[5] During these periods, the effective Federal funds rate was in the 0 to 0.25 percent range, so the Wu-Xia shadow rate captures the overall monetary policy stance better than FFR on its own.

3.1   Measuring Economic Uncertainty

In this paper, I treat the disagreement among professional forecasters as a proxy for economic uncertainty.[6] There are various measurements for uncertainty, such as the forecaster disagreements, Chicago Board Options Exchange (CBOE) Volatility Index (VIX), Economic Policy Uncertainty Index (newspaper based index) from Baker et al. (2016), or factor-based estimates from Jurado et al. (2015). Aastveit

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[4]I have seasonally adjusted commodity price index using the Census Bureaus X-13 ARIMA-SEATS, with near identical results.

[5]After the 2007-09 financial crisis, the Fed took drastic measures that took the FFR in to the zero lower bound from December 2008 to 2015. Additionally, the Fed took unconventional measures such as quantitative easing, to further ease credit conditions and lower long-term interest rates. Thus, after December 2008, the FFR is less likely to describe the monetary policy stance well. To overcome this issue, Wu and Xia (2016) propose a non-linear term structure model to construct a 'shadow interest rate' that captures the effect of QE on the overall stance of monetary policy. Aastveit et al. (2017) also utilise Wu-Xia shadow rate. They analyse how a shock to the shadow rate affects investment under high and low uncertainty.

[6]This approach builds on a long literature, such as Baker et al. (2016), Rich and Tracy (2006), and D'Amico et al. (2008).

et al. (2017) finds the results from various uncertainty measures is qualitatively similar.

I draw the disagreement among forecasters – dispersion data – from the Federal Reserve Bank of Philadelphia's Survey of Professional Forecasters (SPF). This quarterly survey covers a wide range of macroeconomic variables. Each quarter, every forecaster receives a form in which to fill out values corresponding to forecasts for a variety of variables in each of the next five quarters, as well as annualised values for the following 2 years. The SPF provides the resources for evaluating the predictions and performance of professional forecasters. The SPF dispersion measures how close the individual forecasters' projections in the SPF with each other. It is provided in the form of the interquartile range which ensures that any outliers do not unfairly influence the measure of disagreement. I focus on nominal GDP because it is directly influenced by monetary policy actions. And, nominal GDP is subject to less data revisions than real GDP.

The idea is that if all the forecasters are forecasting similar numbers, there is a sense in which uncertainty may be lower, and vice versa.[7] One of the benefits of SPF dispersion as a proxy for uncertainty is that it can be computed in a consistent way for the entire history of the future. Forecasters update their projections when new macroeconomic data becomes available, which sometimes may change dramatically. Often, for simplicity, economists assume that market participants update their information set costlessly. In reality, information is not only costly and costly to process but also often subject to data revision. For example, the release of quarterly real GDP data is revised even up to the next five years of its initial release. Hence, forecasters recognise the data they have today is only an imperfect signal of the true state of the economy.

4 Methodology

4.1 Threshold Vector Autoregression Model

The baseline methodology of this paper is a threshold VAR that allows us to capture potentially different effect of monetary policy shocks to differ high and low uncertainty regimes. The VAR model parameters are allowed to differ across (uncertainty) regimes, and the transition between the regimes being governed by the evolution of a single *endogenous* variable of the VAR crossing a threshold (the

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[7]Sill (2012) gives a detailed explanation of how forecasters' dispersion is measured.

'threshold variable'). Therefore, this makes it possible that regime switches may occur after the shock to each variable. Because of this, the magnitude (and even the sign) of the impulse response may be affected by: (1) the state of the system at the time of the shock, (2) the sign of the shock, and (3) the magnitude of the shock.

The difference between a threshold VAR (TVAR) and the more common Markov-switching approach, is that Markov-switching models examine the whole empirical model for regime breaks (which may be affected by various shocks and structural changes unrelated to uncertainty). As a result, Markov-switching approaches tend to pick up the large regime change from the Great Inflation to the Great Moderation period, and very small number of regime changes within the Great Moderation era. Instead, by specifying a 'threshold variable' to the TVAR – which would then determine the threshold that govern which regime a particular point in time is in – I show that there suggests a significant variation in uncertainty even *within* the Great Moderation period.

The threshold VAR model is described below. The first term in on the right hand side of the equation is analogous to a linear VAR. The non-linearity of the model comes from introducing different regimes on the second term of RHS.

$$Y_t = \left[c_1 + \sum_{j=1}^{p} \gamma^1(L)Y_{t-j} \right] + \left[c_2 + \sum_{j=1}^{p} \gamma^2(L)Y_{t-j} \right] I(y_{t-d}^* > \theta) + U_t$$

where Y_t is a vector of endogenous (stationary) variables as mentioned in the previous section. I is an indicator function that takes the value of 1 when the threshold variable is higher than the *estimated* threshold parameter θ, and 0 otherwise, with time lag d set to 1. U_t are reduced-form disturbances.

$\gamma^1(L)$ and $\gamma^2(L)$ are lag polynomial matrices with order p. The lag order selection by Akaike information criteria marginally chose 2 lags in the threshold VAR and 4 lags in the linear VAR. This is as expected, as the threshold VAR has more parameters to estimate. As the middle ground, I chose 3 lags for threshold VAR which is more consistent with the findings in the literature that monetary policy's effect is long and variable. In terms of information, the AIC criterion for lag 2 and lag 3 is almost identical.

The specific identification – real GDP, GDP deflator, the commodity price index, the Federal Funds Rates and the SPF dispersion – reflects some assumptions about the links in the economy. The ordering of the first four variables associated with the Cholesky decomposition of the covariance matrix of U_t is widely used,

such as in Bernanke and Gertler (1995). Ordering SPF dispersion last implies that it reacts contemporaneously to all other variables. The results are robust to other orderings.

As this is a non-linear model, I use the generalised impulse response (GIRF) approach of Koop et al. (1996). The full algorithm, including the computation of bootstrap confidence intervals, is described in Appendix C of Caggiano et al. (2015).
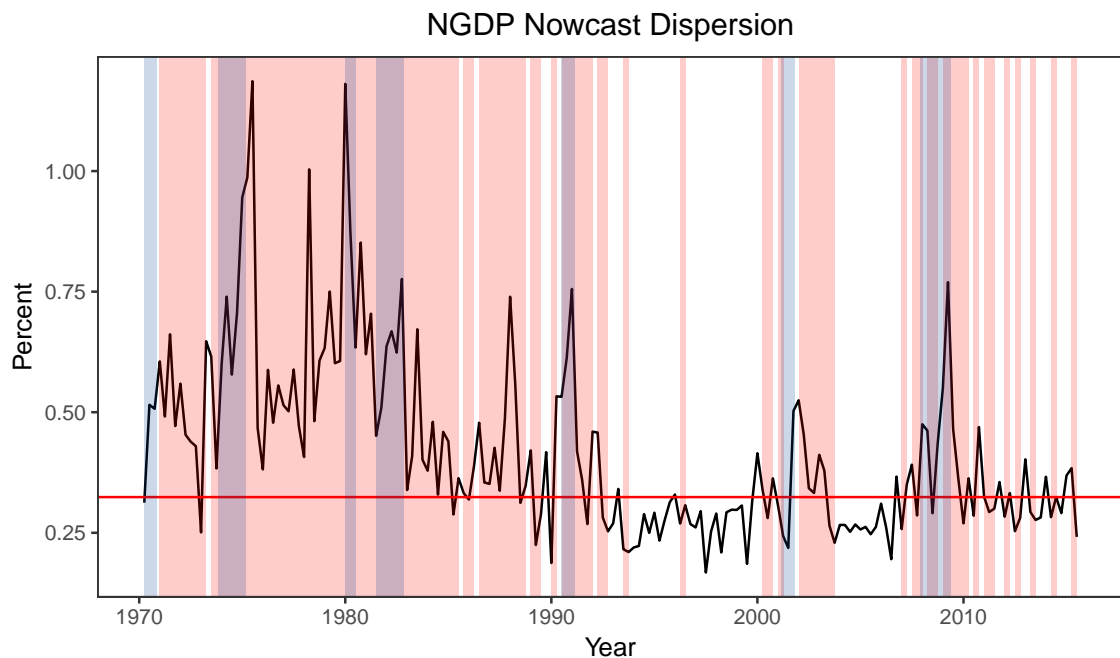
5   Empirical Analysis

Figure 1: Blue shade – NBER Recessions. Red shade – High Uncertainty

The estimated value of the threshold parameter is the solid red line in Figure 1. High uncertainty periods are defined as the periods where the uncertainty proxy is above the threshold (as estimated by the model) – depicted in the red shaded area. The delay parameter is set to 1, hence the regimes change with a lag of one period, after crossing the threshold. Much of the high uncertainty regimes is seen to be on the in the volatile 1970s, but more recently in the Great Moderation, we can still observe high uncertainty regimes. While high uncertainty is correlated with recessions, high uncertainty episodes are more prolonged than recessions, and regime changes typically occur at a higher frequency than business cycles.
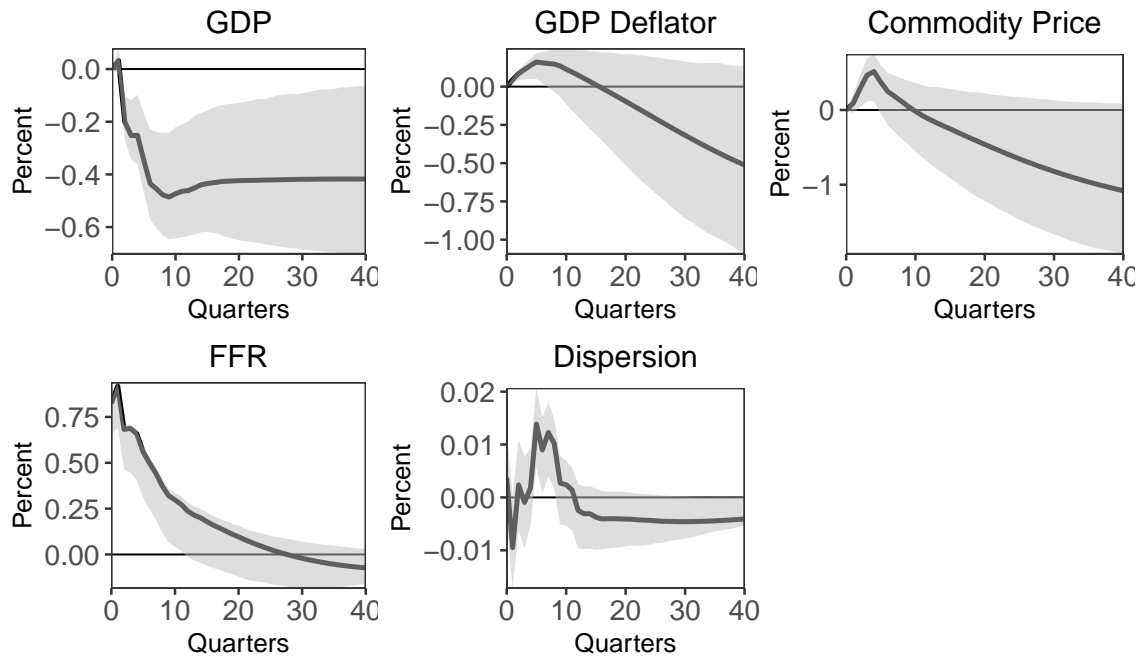
Figure 2: 1 SD shock to FFR, 68% bootstrapped CI, Linear VAR

Figure 2 and Figure 3 show the impulse responses to a 1 standard deviation positive shock to FFR, while the shaded area corresponds to a 68% bootstrapped confidence interval. Figure 2 show the IRFs of linear vector autoregressive without differentiating the level of uncertainty in economy. Figure 3 show the GIRFs of the baseline threshold VAR, allowing for a shock that occurs initially in a low uncertainty regime (blue line) and high (red-dash line) uncertainty regime.

In the linear VAR, the peak effect on GDP is 0.5% after around 8 quarters or 2 years, which is a typical horizon in the literature. The GDP deflator depicts a weak 'price-puzzle' – prices increase after an increase in FFR. The commodity price index drops more quickly than GDP deflator as expected by Bernanke and Gertler (1995). The sluggish responses in GDP and price level, as well as the persistent decline in GDP deflator is fairly consistent with the literatures e.g. Galí (2015) and Christiano et al. (1999). The latter also depicts a 'price-puzzle', which in general is a common finding for monetary shocks identified with a recursively identified VAR.
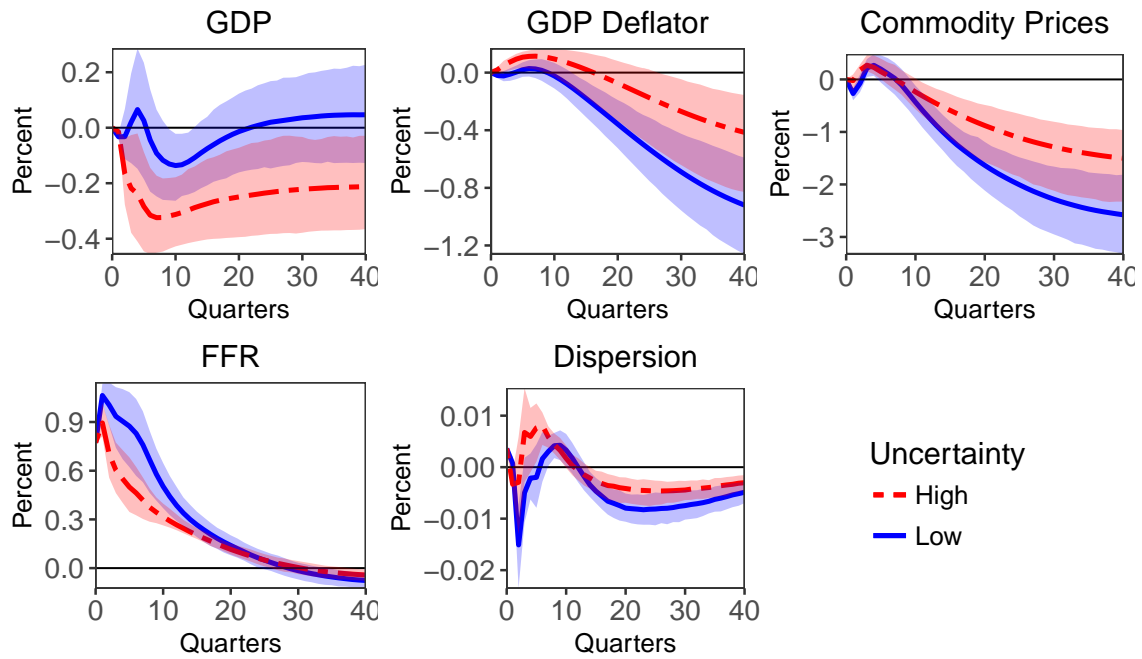
Figure 3: 1 SD shock to FFR, 68% bootstrapped CI, Threshold VAR

The main result in 3 is the heterogeneity in the effect of monetary policy shock across high and low uncertainty regimes.

There is a long debate in the literature on the predictions of policy transmission in different economic regimes. When looking at higher uncertainty, the typical intuition would be that agents becomes more cautious and therefore responds more slowly. Caggiano et al. (2014) and Tenreyro and Thwaites (2016) hypothesise that monetary policy might be less effective in recessions, the period they relate with high uncertainty. Aastveit et al. (2017) supports this in their empirical findings. In this paper I observe, in high uncertainty periods, a positive shock to FFR is less powerful in controlling prices. The GDP deflator under low uncertainty becomes statistically significant from zero at a horizon less than half of the GIRF under high uncertainty. Specifically, under low (high) uncertainty, the GDP deflator is statistically significant from zero at 68% confidence interval by quarter 12 (26).

In contrast, under high uncertainty, a contractionary monetary policy is more powerful in controlling output. GDP barely moves to a statistically significant different level from zero under low uncertainty for a few quarters. Meanwhile with high uncertainty, the GIRF is statistically significant from zero very quickly, and the peak response of GDP is around twice of that in low uncertainty. This is the opposite of what many macro uncertainty models predict, because they suggest that output would respond to shocks slowly when uncertainty is high.

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Rational inattention offers an explanation for the empirical findings. If the costs of gaining information in times of high uncertainty outweighs the benefits of paying more attention, then firms would absorb less information. This would imply that prices remain more subdued, but also output responds more strongly under high uncertainty. This is similar to prices being more sticky – a standard NK model with stickier prices, would predict that output would respond more to a monetary shock.

Another interesting observation is, in low uncertainty, FFR is high for a longer period of time. It is possible to think of it as the central bank needing to signal to economic agents that increasing the interest rate is necessary. In high uncertainty, agents pay more attention, so they do not another signal from the central bank that the economy is heating up. Recall the prediction that low uncertainty means low attention, thus the agents might have needed either an extra push or a longer signal for them to understand the policy intended by the central bank.
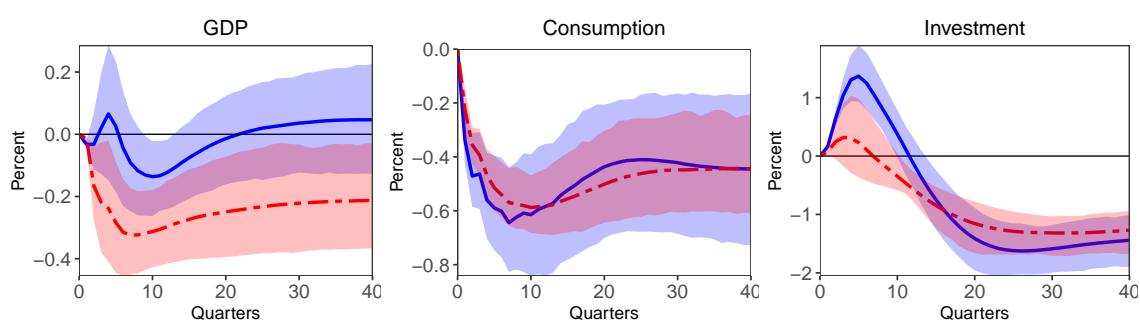
5.1 Consumption and Investment

Figure 4: 1 SD shock to FFR, 68% bootstrapped CI. In the threshold VAR, I replace GDP with consumption and investment in turn.

The purpose of this exercise is to have a better understanding on the real effects of monetary policy components of GDP. First, I replace GDP with consumption, while keeping everything else the same. What I find is, consumption is well behaved, meaning they are what is expected when the central bank raises interest rate. However, unlike the effect on output, there is not much heterogeneity between low and high uncertainty in the impact of monetary policy on consumption.

Second, I replace GDP with investment. There is a strong and different response by investment. Given the data is private non-residential fixed investment, it is

more likely that the source of the overall heterogeneity in GDP that we observe, is from firms' behaviour. The rational inattention literature has focused more on firms, but in the standard NK framework of a labour-only production function – in other words, no physical capital investment is present. Therefore, this paper's empirical results suggests that an important addition to the rational inattention literature is to model firms' investment behaviour, not just their price-setting actions.

The take away message from this can be that, while consumption is a large proportion of the GDP, investment is the variable that is strongly drives it. A further investigation of firms' investment could be into other types of investment such as inventories.

5.2 Asymmetric Responses to Positive and Negative Shocks in the Studied Model
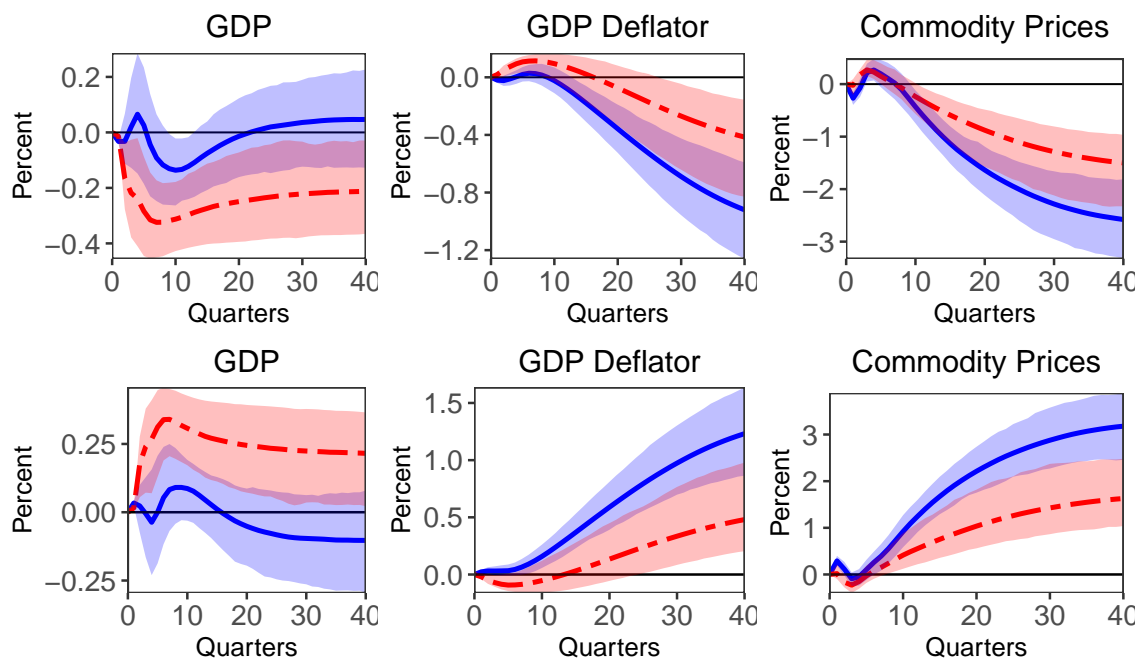

Figure 5: **Standard shock (±1) SD shock to FFR** Top (bottom) figure is the responses to positive (negative) shock. Red (blue) lines indicates high (low) uncertainty, with 68% bootstrapped confidence intervals. It is important to note that the scales for positive and negative shocks are slightly different.

One of the reasons for studying non-linear effects is to see whether asymmetric response to positive and negative shock exists.

We observe asymmetry in the response to GDP, inflation and commodity prices to a certain extent – it appears only in the *magnitudes* of the responses, rather than the shape. It is most apparent on the size of the response by GDP deflator. In a low uncertainty regime, positive shock creates price-puzzle for about 10 quarters, while a negative shock only for 6 quarters. The difference is about one year. If the downward wage rigidity argument pass on to prices, via the virtue that labour is an input to production, then this is fairly consistent with that hypothesis. The case for high uncertainty is similar. With respect to the size, it also differs. For positive shock, prices drops only to -1%. for negative shock, it is up to 1.2%. The corresponding response in output is that it is less responsive to a expansionary monetary shock, relative to an expansionary shock, consistent with a stronger response of prices.
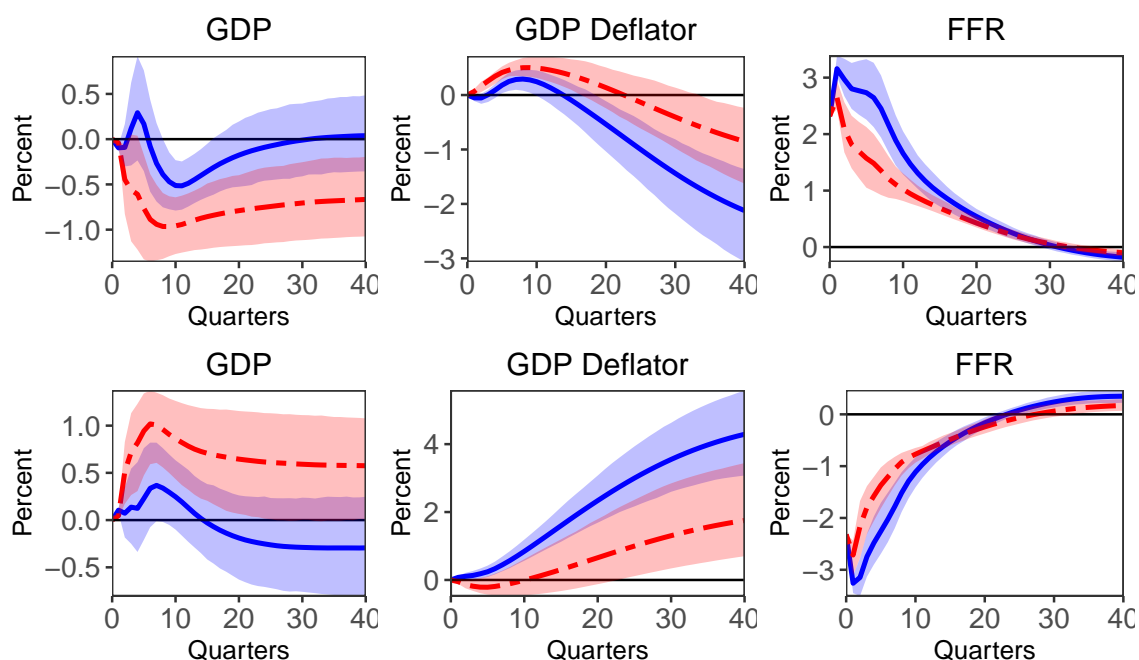

Figure 6: **Large Shocks ($\pm$3) SD shock to FFR** Top (bottom) figure is the responses to positive (negative) shock. Red (blue) lines indicates high (low) uncertainty, with 68% bootstrapped confidence intervals. It is important to note that the scales for positive and negative large shocks are different, especially for prices.

As an exercise, I tried to shock with 3 standard deviation shocks to see whether we get more asymmetry the larger the shock, to get make the regime switches happen more frequently during the GIRF computation. This is indeed the case. GDP deflator response to positive shock is to drop up to 2%, but to negative shock, is up to 4%. To contractionary shock, GDP is significantly below zero for a couple of quarters when the economy is in a low uncertainty period. But to an

expansionary shock, it is not significant at any point.

Nevertheless, either contractionary/expansionary monetary policy shocks or standard/large shocks, the key results do not change. In a high uncertainty state, monetary policy has stronger real effects, while in low uncertainty, monetary policy has stronger price effects. Still, the GIRFs show more noticeable asymmetry in larger shocks, in terms of the magnitude of the responses.

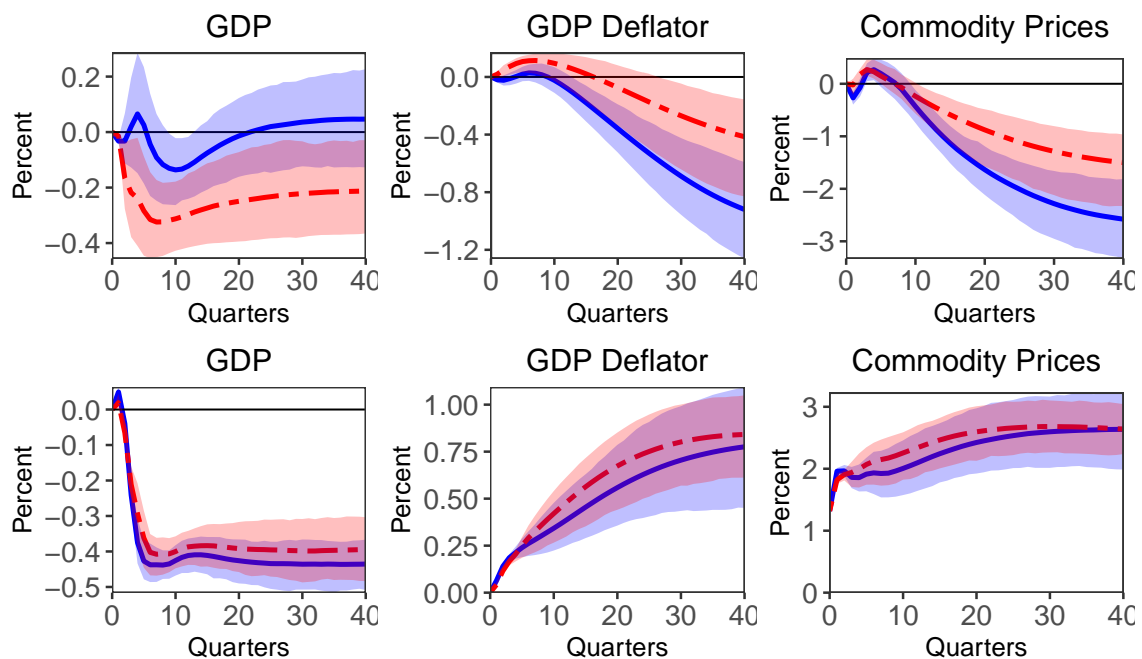## 5.3 Shock to Commodity Prices

Figure 7: Top: shock to FFR, Bottom: shock to Commodity Prices

One of the predictions of rational inattention demonstrates the various response of firms to different type of shocks. As noted by Mackowiak et al. (2016), firms respond very quickly to a firm specific productivity, fairly quickly to aggregate technology shock, and only slowly to monetary policy shock. Here, I investigate whether these hold under for uncertainty-dependent economies with two different regimes. Figure 7 shows that the response to commodity prices is quick, and do not show much heterogeneity. This is in contrast to the impulse responses of a shock to FFR. Under the rational inattention framework, this could be explained because a commodity price shock involves a shock that is directly contained in an easily-observable price. Therefore, higher uncertainty does not increase the cost or difficulty about gaining information on the commodity price shock. On

the other hand, a monetary shock is more difficult to process for a rationally inattentive agent, and uncertainty is more likely to induce heterogeneity across uncertainty regimes.

6 Conclusion

The recent increased in uncertainty brings challenges to monetary policymakers. This paper asks how does heightened uncertainty affect the strength of economic policy in controlling target variables. I focus on how it may affect the effectiveness of monetary policy on output and inflation, and how the conventional uncertainty predictions do not seem to match the empirical results in this paper. I argue that a rational inattention framework could be more suited to analysing this particular question than a full-information rational expectations benchmark. My empirical approach is to use the threshold VAR of Koop et al. (1996) to empirically investigate possible heterogeneity and asymmetry of monetary policy transmission under different uncertainty regimes.

I find two main results. First, in high uncertainty periods, monetary policy has stronger real effects and weaker price effects. This shows heterogeneity of monetary transmission when considering different uncertainty regimes. This stronger reaction of output to a monetary shocks is in contrast to the result in the uncertainty literature. I provide an explanation where firms and households are rationally inattentive such that they would move more slowly in response to a monetary shock as they are unable to process all the information. Second, I observe some asymmetry to positive and negative shocks, especially with prices.

A future work is to build an empirically driven theoretical model to help explain monetary policy transmission under different uncertainty regimes, given that agents in the economy are rationally inattentive. Additionally, it would be interesting to extend the empirical framework using, for example, a threshold FAVAR approach. This methodology is appealing because it allows the model to incorporate a large dataset that can be captured by principal components.

References

Aastveit, K. A., Natvik, G. J., and Sola, S. (2017). Economic uncertainty and the influence of monetary policy. *Journal of International Money and Finance*, 76:50–67.

Bachmann, R., Born, B., Elstner, S., and Grimme, C. (2013). Time-varying business volatility, price setting, and the real effects of monetary policy. Technical report, National Bureau of Economic Research.

Baker, S. R., Bloom, N., and Davis, S. J. (2016). Measuring economic policy uncertainty. *The Quarterly Journal of Economics*, 131(4):1593–1636.

Bernanke, B. S. and Gertler, M. (1995). Inside the black box: The credit channel of monetary policy transmission. *Journal of Economic Perspectives*, 9(4):27–48.

Bloom, N. (2009). The impact of uncertainty shocks. *Econometrica*, 77(3):623–685.

Caballero, R. J. (1990). Consumption puzzles and precautionary savings. *Journal of monetary economics*, 25(1):113–136.

Caggiano, G., Castelnuovo, E., Colombo, V., and Nodari, G. (2015). Estimating fiscal multipliers: News from a non-linear world. *The Economic Journal*, 125(584):746–776.

Caggiano, G., Castelnuovo, E., and Groshenny, N. (2014). Uncertainty shocks and unemployment dynamics in us recessions. *Journal of Monetary Economics*, 67:78–92.

Castelnuovo, E. and Pellegrino, G. (2017). Uncertainty-dependent effects of monetary policy shocks: A new keynesian interpretation.

Christiano, L. J., Eichenbaum, M., and Evans, C. (1994). The effects of monetary policy shocks: some evidence from the flow of funds. Technical report, National Bureau of Economic Research.

Christiano, L. J., Eichenbaum, M., and Evans, C. L. (1999). Monetary policy shocks: What have we learned and to what end? *Handbook of macroeconomics*, 1:65–148.

D'Amico, S., Orphanides, A., et al. (2008). *Uncertainty and disagreement in economic forecasting*. Divisions of Research, Statistics and Monetary Affairs, Federal Reserve Board.

Galí, J. (2015). *Monetary policy, inflation, and the business cycle: an introduction to the new Keynesian framework and its applications*. Princeton University Press.

Jurado, K., Ludvigson, S. C., and Ng, S. (2015). Measuring uncertainty. *The American Economic Review*, 105(3):1177–1216.

Koop, G., Pesaran, M. H., and Potter, S. M. (1996). Impulse response analysis in nonlinear multivariate models. *Journal of econometrics*, 74(1):119–147.

Leduc, S. and Liu, Z. (2016). Uncertainty shocks are aggregate demand shocks. *Journal of Monetary Economics*, 82:20–35.

Lo, M. C. and Piger, J. M. (2005). Is the response of output to monetary policy asymmetric? evidence from a regime-switching coefficients model. *Journal of Money, Credit, and Banking*, 37(5):865–886.

Mackowiak, B., Matejka, F., and Wiederholt, M. (2016). The rational inattention filter. Technical report, CEPR Discussion Papers.

Menkulasi, J. (2009). Rational inattention and changes in macroeconomic volatility, university of maryland. Technical report, Working Paper.

Mumtaz, H. and Theodoridis, K. (2015). The international transmission of volatility shocks: An empirical analysis. *Journal of the European Economic Association*, 13(3):512–533.

Peersman, G. and Smets, F. (2001). The monetary transmission mechanism in the euro area: more evidence from var analysis (mtn conference paper).

Pellegrino, G. (2017). Uncertainty and monetary policy in the us: A journey into non-linear territory.

Rich, R. and Tracy, J. (2006). The relationship between expected inflation, disagreement, and uncertainty: Evidence from matched point and density forecasts. Technical report, FRBNY Working Paper.

Sill, K. (2012). Measuring economic uncertainty using the survey of professional forecasters. *Federal Reserve Bank of Philadelphia Business Review*, 92:16–27.

Sims, C. A. (1992). Interpreting the macroeconomic time series facts: The effects of monetary policy. *European Economic Review*, 36(5):975–1000.

Sims, C. A. (2003). Implications of rational inattention. *Journal of monetary Economics*, 50(3):665–690.

Tenreyro, S. and Thwaites, G. (2016). Pushing on a string: Us monetary policy is less powerful in recessions. *American Economic Journal: Macroeconomics*, 8(4):43–74.

Tsay, R. S. (1998). Testing and modeling multivariate threshold models. *journal of the american statistical association*, 93(443):1188–1202.

Wu, J. C. and Xia, F. D. (2016). Measuring the macroeconomic impact of monetary policy at the zero lower bound. *Journal of Money, Credit and Banking*, 48(2-3):253–291.

Zhang, F. (2017). Rational inattention in uncertain business cycles. *Journal of Money, Credit and Banking*, 49(1):215–253.