Monetary Policy Reaction to Uncertainty in Japan: Evidence from a Quantile-on-Quantile Interest Rate Rule[1]

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Abstract:

Japan's episodes of lower bound of interest rates together with macroeconomic uncertainty for over the past two decades stands as a tremendous hurdle for the estimation of Taylor-type rule models. We demarcate our study from previous literature by conducting the estimations not only at various points on the conditional distribution of the interest rate but also at various quantiles of an additional regressor on top of inflation and output, viz., an economic uncertainty measure, by adopting a quantile nonseparable triangular system estimation. The results show that the reaction to uncertainty seems to have substituted the Bank's reaction to inflation and output, lending support to the Brainard attenuation principle. In essence, faced with higher economic uncertainty, the monetary authority reacts by cutting (attenuating) its policy rate across all quantiles of uncertainty at all conditional quantiles of interest rate, with an increased response of the Bank of Japan to uncertainty at its lower quantiles when interest rate is at its lower conditional quantiles. A possible explanation is the greater concern of getting out from the lower bounds of interest rate amidst deflationary outcomes.

Keywords: Conditional quantile on quantile regressions, interest rate rule, zero lower bound, shadow rate of interest, uncertainty, Japan.

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1. Introduction

Conditional quantile regression estimates of Taylor (1993)-type monetary policy reaction functions are becoming increasingly popular in the literature for both developed and developing economies, due to its contribution to the nonlinear reaction of monetary authorities to inflation, output gap and other variables at each of the points (quantiles) of the interest rate distribution and not only at the central mean (see for example, Wolters (2012), Miles and Schreyer (2012, 2014), Christou et al., (2018), and Liu (2018)). Hence, it can be seen as worthwhile rivals to both linear and nonlinear empirical models (predominantly smooth transition autoregressive models, STAR) or semi-parametric and nonparametric estimations as done in Milas and Naraidoo (2012) for instance. This paper marks a significant point of departure from the literature whereby the estimations are conducted not only at various points on the conditional distribution of the dependent variable, i.e., the interest rates but also at various quantiles of an uncertainty measure which acts as an additional regressor on top of inflation and output gap, the foremost variables that go in a Taylor rule model.

The main idea is to investigate the relationship between economic uncertainty, which has now plagued Japan for over almost two decades and its accompanying unusually low interest rate episodes. The Japanese economy represents a natural testing ground, since the Bank of Japan has been dealing with challenges of deflation and the effective lower bound on short-term interest rates that the country has faced from October 1995 to February 2017, the period during which the call rate was at or close to zero, which is pretty much of the sample period in this paper. However, the zero interest rate policy (ZIRP, henceforth) that the country has adopted over more than two decades stands as a tremendous hurdle for the estimation of Taylor-type rule models and explains why previous works have chosen sample periods during which the effective lower bound was not effective.[2]

Furthermore, monetary policy in Japan has followed broad unconventional measures including Abenomics, when Shinzo Abe became Prime Minister in December 2012 and put in place the three pillars of monetary policy, fiscal policy and structural reform. For the purpose of this paper, it is worth touching on the first pillar which relates to the inflation target of 2 percent in place on January 2013, the so called quantitative and qualitative easing (QQE) which include the purchases of a number of private assets, exchange-traded funded and Japanese government bonds, negative interest rates have also been implemented together with targeting of long term yields on ten-year Japanese government bonds. While the ZIRP has been in place, these policies undertaken seem to have some positive effects with Japan recently growing on an average of 1.1 percent and inflation around 1 percent.

To this end, we make use of the shadow interest rates, which is the nominal interest rate that would prevail in the absence of its effective lower bound, with it derived by modelling the term structure of the yield curve. Thus, we are also able to study the monetary policy behaviour across conventional and unconventional monetary regimes without worrying about explicitly modelling the ZIRP, as the shadow short rates (SSR) offer an excellent description of the historic interest rate behaviour (Wu and Xia, 2016). Understandably, by using the SSR and the quantiles based approach, with lower conditional quantiles of the estimated monetary policy function econometrically

[2] Bernanke (2017) for instance uses monthly data for the sample period over 1985-1995 to estimate a Taylor rule. He then projects how the call rate would have evolved out of sample from 1995-2017 if the Bank of Japan had been able to respond to economic conditions without the constraint of the effective lower bound.

capturing the reaction of central banks corresponding to the abnormal lower bounds period[3], we do not need to pursue any kind of censoring as in Chen and Kashiwagi (2017). Furthermore, given that the term structure of the yield curve contains valuable information on fundamentals such as growth and inflation rate and expectations of the future, we would expect that the resulting SSR to some extent captures key aspects of economic conditions together with policy implementations.

The most popular form of monetary policy reaction functions typically assume that interest rates relate linearly to the gap between actual and desired values of inflation and output (see e.g. Taylor, 1993, Clarida et al., 2000, and Swamy et al., 2005). Nonlinear policy rules emerge from either asymmetric central bank preferences (e.g. Nobay and Peel, 2003, and Cukierman and Muscatelli, 2008) or a nonlinear (convex) aggregate supply or Phillips curve (e.g. Dolado et al., 2005), or still when central banks follow the opportunistic approach to disinflation (Aksoy et al., 2006).

Empirical work on the analysis of monetary policy is dominated by studies that use both the linear Taylor rule and its nonlinear version to capture potential asymmetric monetary policy reaction. Cukierman and Gerlach (2003), Ruge-Murcia (2003), Dolado et al. (2004, 2005), and Surico (2007) have shown evidence supporting asymmetries by adopting a monetary policy reaction function that feature asymmetries in either inflation or the output gap for the US, UK, EU, Japan and OECD countries.

[3] Since lower conditional quantiles of interest rates are more likely linked to lower inflation rate, i.e., deflationary periods which usually coincide with the lower bound of interest rates.

Kohn (1996) and in the context of the Japanese economy, Jung, Teranishi, and Watanabe (2005), Kato and Nishiyama (2005), Sugo and Terinishi (2005) and Bernanke and Reinhart (2004) among others have pointed to a more aggressive reaction of the central bank when interest rates approach the lower bound in order to guard against the possibility of deflation and negative demand shocks. However, the estimates based on a polynomial reaction function with a Tobit estimator reported in Kato and Nishiyama (2005) study of Japanese data in the 1990s show low and weak response to inflation at the local convexity, i.e., as the lower bound is approached. They concluded that the shift from adjustment of short-term rates toward more unconventional monetary policies might be the explanation aimed at managing future expectations (Eggertsson and Woodford 2003) and quantitative easing (Bernanke and Reinhart 2004).

In the context of quantile regression, the response of interest rate to inflation and output (and exchange rate) has been investigated at various quantiles on the conditional distribution of interest rates. This method has particular appeal for advanced economies in an attempt to gauge the policy makers' reactions at the zero and lower bound amidst recent financial crisis and economic events. Chevapatrukul et al. (2009) in a pioneering paper, use conditional interest rate quantile regression applied to Taylor rules for Japan and the USA. They found for both Japan and the US that inflation has a larger effect on higher quantiles of interest rates than at lower quantiles of interest rates contrary to the greater aggression to inflation that they expected to find as interest rates reach low levels as the lower bound is approached. Chen and Kashiwagi (2017), using a sample that includes recent periods of zero interest rates for Japan highlight the potential downward biased of using uncensored quantile regressions versus censored ones.

Moreover, the Bank of Japan's monetary reaction function has been plagued by financial crisis and macroeconomic uncertainty since the late 1980's (Jinushi et al. (2000)). There has been considerable uncertainty viz., delayed policy actions and the dire financial woes and deflationary outcomes. The concept of uncertainty in monetary policy practice was coined by Brainard (1967) and hence the Brainard's attenuation principle. The former Federal Reserve Chairman, Greenspan (2003), contends that "Uncertainty is not just an important feature of the monetary policy landscape, it is the defining characteristic of that landscape". Mishkin (2010) laments the unfortunate reality that most existing studies on optimal monetary policy have abstracted from considerations of macroeconomic risk in the context of financial disruptions. Thus empirical and theoretical formulations of monetary policy must take into account the quantitative relevance of uncertainty because it is a constant feature of monetary policy practice.

This literature includes Svensson (1999), Peersman and Smets (1999), Estrella and Mishkin (2000), Orphanides et al. (2000), Rudebusch (2001), Ehrmann and Smets (2003), Martin and Milas (2009) and Naraidoo and Raputsoane (2015) who present evidence in support of the seminal Brainard (1967) attenuation principle. This principle hypothesizes that uncertainty dampens the monetary authorities' response to the target variables of monetary policy compared to when monetary policy decisions are made under complete certainty or certainty equivalence. On the contrary, Giannoni (2002) and Sonderstrom (2002), among others, have presented evidence that supports an aggressive reaction of monetary policy under uncertainty.

We contribute to this debate by assessing how the Bank of Japan has reacted to a (news-based) measure of uncertainty. The news-based measure perform searches of major newspapers for terms related to economic and policy uncertainty (EPU) and to use the results of this search to construct measures of uncertainty. And as discussed in the introduction, unlike the existing literature on quantile-regressions, we rely on a quantile-on-quantile (QQ) approach, whereby we are able to study the (asymmetric) response of both conventional and unconventional monetary policy decisions at their various phases (conditional quantiles), corresponding to the alternative size (quantiles) of the variations in the EPU. In this regard, our study adds to the work of Christou et al., (forthcoming), which used quantiles-based interest rate rules for Japan (besides, the US, UK and Europe) to study the impact of EPU on interest rate setting. The authors found that in the wake of uncertainty, the Bank of Japan reduces interest rate more strongly at the lower-end of its conditional distribution. Using a QQ approach, our paper aims to add another layer to this recent work of Christou et al., (forthcoming), by also simultaneously studying the influence of the state of economic uncertainty (besides the inflation rate and output-gap), on the corresponding conditional-state of the interest rate.

The key result of the paper are firstly, our first stage regression shows that higher level of economic uncertainty are driven by both higher inflation and inflationary pressures of higher output gap whereas when uncertainty is low, increases in inflation and output tends to bring better sentiment in the economy. Secondly, the Taylor rule estimation shows that though no detectable evidence of increasing aggression to inflation is found as the lower bound is approached, yet the reaction of the Bank of Japan towards uncertainty by cutting down its policy rate particularly strongly at lower conditional quantiles of interest rates lends support to the Brainard (1967) attenuation principle and the continued efforts by the Bank to alleviate deflationary recessionary outcomes that the country has faced over its extended economic history. Thirdly, the greater reaction to economic uncertainty at its lower quantiles versus when uncertainty is at its higher quantiles with this being more so at lower conditional quantiles of interest rate, reinforces the first stage regression results, suggesting that once higher economic uncertainty is associated with higher inflationary pressures, the Bank is more cautious in taking expansionary measures.

The remainder of the paper is organized as follows: Section 2 discusses the methodology, while Section 3 presents the data, and results, with Section 4 finally concluding the paper.

2. Methodology: The Interest Rate Rule Estimation using Quantile on Quantile Triangular System Approach

For the purpose of this study, we extend Taylor's original rule in order to capture the reaction of monetary policy to economic policy uncertainty movement:

$$i_t = \alpha_0 + \alpha_\pi \pi_{t+k|t} + \alpha_y y_t + \alpha_{epu} epu_t + \varepsilon_t, \tag{1}$$

where ε_t is a policy shock, y_t is the output gap, $\pi_{t+k|t}$ is a k-period-ahead inflation forecast and epu_t is the economic policy uncertainty index. The standard approach of estimating a forward-looking Taylor rule, is to estimate the model parameters at the mean by GMM due to endogeneity, with a limited number of lagged variables included in the instrument set. However, parameter estimation at the mean of the interest rate distribution conditional on inflation and output gap is an incomplete description of monetary policy reactions.

In this paper, we want to investigate the monetary policy rules defined in Eq. 1 over the whole conditional distribution of interest rates relative to the whole conditional distribution of EPU. In order to accomplish this, we adopt the following quantile nonseparable triangular system:

$$i_t = \alpha_0(\tau_1, \tau_2) + \alpha_\pi(\tau_1, \tau_2)\pi_{t+k|t} + \alpha_y(\tau_1, \tau_2)y_t + \alpha_{epu}(\tau_1, \tau_2)epu_t, \quad (2)$$

$$\mathrm{epu}_t = \beta_0(\tau_1) + \beta_1(\tau_1)\pi_{t+k|t} + \beta_2(\tau_1)y_t. \quad (3)$$

The above triangular system exhibits a high degree of flexibility since it allows for two different kinds of heterogeneity, one through τ_1 and the other through τ_2.

We estimate the triangular system (2)-(3) using the quantile regression methodology suggested by Jun (2009).[4] The methodology adjusts for endogeneity by adopting a control function approach. Specifically, the control variable τ_1 is allowed to enter into the structural equation (Eq. 2), which ensures that the marginal effect of the endogenous variable can be arbitrarily heterogeneous over different values of τ_1. June (2009) proposes the following model:

$$I = D\alpha_D(\tau_1, \tau_2) + X'\alpha_X(\tau_1, \tau_2), \quad (4)$$

$$D = X'\beta_X(\tau_1) + Z'\beta_Z(\tau_1), \quad (5)$$

where I is the dependent variable, D is the endogenous explanatory variable, X is the vector of exogenous explanatory variables, Z is the vector of instruments, and τ_1 and τ_2 are two independent uniform random variables. The parameters of interest

[4] Recently, Sim and Zhou (2015) suggest a different quantile-on-quantile approach to examine the relationship between oil prices and US equities. Their approach constitutes in adopting the conditional quantile regression approach for the dependent variable (US stock returns) relative to the first order Taylor expansion around a specific quantile of the regressor (oil price). Contrary, Jun (2009) employs a quantile nonseparable triangular system which provides a more complete picture about heterogeneous effects by jointly investigating two different quantile points, a quantile point of the conditional distribution of the dependent variable relative to a quintile point of the conditional distribution of a possibly endogenous regressor.

are$\alpha_D(\tau_1, \tau_2)$ and $\alpha_X(\tau_1, \tau_2)$ for some fixed $\tau_1, \tau_2 \in (0,1)$, which are chosen by the researcher. [5]

Let us denote the τth quantile of A conditional on $C = c$ as $Q_{A|C}(\tau)$. According to (4) and (5), we get:

$$P\big(I \leq D\alpha_D(\tau_1, \tau_2) + X'\alpha_X(\tau_1, \tau_2) \,/ D = Q_{D|X,Z}(\tau_1), X, Z\big) = \tau_2 \tag{6}$$

$$Q_{D|X,Z}(\tau_1) = X'\beta_X(\tau_1) + Z'\beta_Z(\tau_1). \tag{7}$$

For the estimation, Jun (2009) adopts a local quantile regression approach by using the kernel smoothing idea. Specifically, estimation is carried out in a two-step procedure. In the first step, the τ_1 conditional quantile of *D* given *X* and Z, is estimated:

$$\hat{Q}_{D|X,Z}(\tau_1) = X_t{}'\hat{\beta}_X(\tau_1) + Z_t{}'\hat{\beta}_Z(\tau_1), \tag{8}$$

$$\big(\hat{\beta}_X(\tau_1)', \hat{\beta}_Z(\tau_1)'\big)' = \underbrace{argmin}_{\beta_X,\beta_Z} \sum_{t=1}^{T} \xi_{\tau_1}\big(D_t - X'\beta_X(\tau_1) - Z'\beta_Z(\tau_1)\big), \tag{9}$$

where $\xi_{\tau_1}(\kappa) = |\kappa| + (2\tau_1 - 1)\kappa$, $\kappa \in (0,1)$, the check function. In the second step, the parameters of interest are estimated by local smoothing quantile regression:

$$(\hat{\alpha}_D(\tau_1, \tau_2), \hat{\alpha}_X(\tau_1, \tau_2)')' = \underbrace{argmin}_{\alpha_D,\alpha_X} \sum_{t \in \hat{S}_T(\tau_1)} \xi_{\tau_2}\big(I_t - D_t\alpha_D(\tau_1, \tau_2) + X_t{}'\alpha_X(\tau_1, \tau_2)\big), \tag{10}$$

where $\hat{S}_T(\tau_1) = \left\{1 \leq t \leq T \colon \left|D_t - X_t{}'\hat{\beta}_X(\tau_1) - Z_t{}'\hat{\beta}_Z(\tau_1)\right| \leq \frac{h_T}{2}\right\}$ and h_T is a bandwidth choice that shrinks to zero. This is kernel smoothing with a uniform kernel

[5] Our work is mainly in-sample investigation using a QQ approach. The construction of a point forecast in the case of quantile-to-quantile regressions is left for future work.

$1\left\{|s| \leq \frac{h_T}{2}\right\}$, where $1\{\cdot\}$ the standard indicator function. Jun (2009) shows that the resulting indicators in Eq. 10 are consistent and asymptotically normal.

In our case, the dependent variable I_t is the interest rate. We set $D_t \equiv epu_t$ and $X \equiv (\pi_{t+12}, y_t)'$, where epu_t is the economic policy uncertainty, π_{t+12} is the forward looking inflation and y_t denotes the output gap.

3. Data and Empirical Analysis

3.1. Data

Our analysis uses monthly data on Japan, with the period of coverage being: 1995:01 to 2017:05. The estimation of the Taylor-rule involves four variables, namely a measure of output, inflation, interest rate and uncertainty. In our case, output is captured by the (seasonally adjusted) industrial production, while month-on-month inflation is computed based on the (seasonally adjusted) Consumer Price Index (CPI). Data on both these variables under consideration is derived from the main economic indicators (MEIs) database of the Organisation for Economic Co-operation and Development (OECD).

Besides using a quantile-on-quantile based estimation approach, a unique feature of our study is that our data sample covers Japan ZIRP period as from 1995 to 2017, with the end-point being purely driven by availability of data at the time the paper was being written. In a way, we would like to uncover the myriad of unconventional monetary policies (such as large scale asset purchases, a maturity extension program and efforts of forward guidance in order to manage expectations of a prolonged period of low policy rates, targeting of yield curve) impact on the shadow short term interest rate in an effort at improving financial conditions for firms and thereby eventually supporting an expedited recovery from the financial crisis and deflationary periods. Given the IRP, and the fact that a range of unconventional monetary policies was pursued, for estimation of policy rules across the unconventional regimes of central banking, we would need a uniform and coherent measure of the monetary policy stance. For our purpose, we use the shadow short rate (SSR). The SSR is the nominal interest rate that would prevail in the absence of its effective lower bound. The SSR used in this paper is developed by Krippner (2013), based on (two-factor) models of term-structure, at a daily frequency for the four economies of our concern, and is available for download from the website of the Reserve Bank of New Zealand.[6] The yield curve-based framework developed by Krippner (2013) essentially removes the effect that the option to invest in physical currency (at an interest rate of zero) has on yield curves, resulting in a hypothetical "shadow yield curve" that would exist if physical currency were not available. The process allows one to answer the question: "what policy rate would generate the observed yield curve if the policy rate could be taken negative?" The "shadow policy rate" generated in this manner, therefore, provides a measure of the monetary policy stance after the actual policy rate reaches zero. The main advantage of the SSR is that, it is not constrained by the ZLB and thus allows us to combine the data from the ZLB period with the data from the non-ZLB era, and use it as the common metric of monetary policy stance across the conventional and unconventional monetary policy episodes. Note that, to match the monthly frequency of our other variables, the end of the month value of the daily SSR is used for our analysis.[7]

[6] The data can be downloaded from the following link: https://www.rbnz.govt.nz/research-and-publications/research-programme/additional-research/measures-of-the-stance-of-united-states-monetary-policy/comparison-of-international-monetary-policy-measures.

[7] For comparability, all of the estimates are obtained using the Krippner (2013) shadow/lower bound framework with two factors, i.e. the K-ANSM(2), a fixed 12.5 basis point lower bound, and yield curve data with maturities from 0.25 to 30 years with the sample beginning in 1995. SSR estimates can be very sensitive to the model specification, data, and estimation method. Krippner's (2013) approach is designed to be as comparable as possible by holding each of the above aspects consistent between the four

Our final variable that goes in the estimation of the monetary policy rules is uncertainty. However, uncertainty is a latent variable, and in order to quantify the impact of uncertainty on the interest rate (SSR) decisions, one requires ways to measure the former. In this regard, we follow Christou et al., (forthcoming), and use the uncertainty measure of Arbatli et al., (2017), derived from a news-based approach of Baker et al., (2016). Specifically, Arbatli et al., (2017) construct an index of overall EPU for Japan by counting articles in four major Japanese newspapers (Yomiuri, Asahi, Mainichi and Nikkei) that contain at least one term in each of three categories: (E) 'economic' or 'economy'; (P) 'tax,' 'government spending', 'regulation,' 'central bank' or certain other policy-related terms; and (U) 'uncertain' or 'uncertainty'. The authors scale the raw EPU counts by the number of articles in the same newspaper and month, standardize each paper's series of scaled counts to the same variability over time, and then average across papers by month to obtain their overall EPU index. To the best of our knowledge, this is the only publicly available measure of EPU for Japan,[8] which is a broad metric of macroeconomic uncertainty, unlike the available implied volatility index of the Nikkei 225, which relates to the financial market.

3.2. Estimates at the Conditional Mean

To fix ideas, Table 1 reports GMM estimates of the Taylor rule equation (1) together with OLS and two-stage least squares estimators. Inflation, output gap and uncertainty measure are instrumented using appropriately chosen lags of these variables. The set of instruments are determined by choosing lags that are sufficiently long to avoid

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economies. In addition, SSR results from different K-ANSM(2) applications are shown by Krippner (2013) to be robust in profile and magnitude, and correspond well with unconventional monetary policy events. These properties do not generally hold for SSR estimates from three-factor models, which includes K-ANSM(3) model of Wu and Xia (2016). Hence our decision to use this database, besides the fact that Wu and Xia (2016) does not report SSR estimates for Japan.

[8] The data can be downloaded from: http://policyuncertainty.com/japan_monthly.html.

correlation with the error term. In the case of GMM estimation, we use the *J*-test (Hansen; 1982) for the validity of overidentifying restrictions for each set of chosen instruments and test for exogeneity of regressors using the difference-in-Sargan C-statistic (Hayashi, 2000), with the results confirming the exogeneity of inflation and output gap.

The specification for equation (2) allows for a forward-looking rate of inflation 12 months ahead, k=12 for inflation, a contemporary output gap (the dependence of these countries monetary policy on current rather than expected output gaps agrees with general consensus as for example in Chevapatrakul et al. (2009)), and a contemporaneous uncertainty measure. We have tried various lags of uncertainty measure and we report the contemporaneous effect since it is of most importance. *, **, *** denote statistical significance at 10%, 5% and 1%, respectively. Our results show that the set of instruments includes a constant, 1-3 lagged values of inflation, output gap and uncertainty measure. The inflation coefficient estimate for Japan is insignificant with the wrong sign while the response to output gap is significantly positive and the response to uncertainty is not significant. The negative response to inflation is not surprising when taken over the whole sample range of the study since post financial crisis, the shadow short rate kept a downward trend given the expansionary unconventional monetary policy even though these were followed by inflationary pressures of enhanced demand since the authorities were fighting economic uncertainty to prevent recession with focus on output and financial conditions.[9]

[9] We re-ran the regression over a sample period (1995:m1 to 2002m12) prior to the financial crisis to confirm the positive and significant relationship between inflation and the interest rate as found in previous studies such as Chevapatrakul et al. (2009). These results are not included in the paper due to space but provided by the authors upon request.

Table 1: Conditional mean results

	α_{π}	α_{y}	α_{epu}	Testing endogeneity			Testing the validity of overidentifying restrictions
				H0: inflation and output gap are exogenous	H0: output gap is exogenous	H0: inflation is exogenous	
OLS	-0.2187	0.0345	-0.0025				
2SLS	-0.1874	0.0409*	-0.0016	0.1655 [0.9206]	0.1651 [0.6877]	0.0001 [0.9929]	1.008 [0.9097]
GMM	-0.1247	0.0436*	-0.0017	0.1914 [0.9088]	0.1895 [0.6634]	0.0035 [0.9525]]	1.0688 [0.8992]

Notes: Forward looking monetary rule: $i_t = \alpha_0 + \alpha_{\pi}\pi_{t+12} + \alpha_y y_t + \alpha_{epu} epu_t$, where i_t is the end of month shadow interest rate, π_t is inflation, y_t is the output gap, and epu_t is the news-based economic policy uncertainty index of Baker et al., (2016). Instruments: 1-3 lags of inflation, output gap and epu. In the case of GMM estimation, difference-in-Sargan C-statistic (Hayashi, 2000) and Hansen's (1982) J-statistic are used for testing the exogeneity of regressors and the validity of overidentifying restrictions, respectively. In the case of 2SLS estimation, exogeneity is tested using the Wu–Hausman (Wu, 1974; Hausman, 1978) statistic, while the validity of overidentifying restrictions is examined by the Sargan's (1958) test Figures in square brackets are p-values

3.3. The Quantile-on-Quantile Taylor Rule Estimation Results

Table 2 reports the estimated coefficients of the first stage regression using Jun's (2009) QQ methodology based on the non-separable triangular system of equations (2)-(3). The estimates are based on equation (3) where we assume that EPU is our endogenous variable, which depends on forward looking inflation and output gap. Equation (3) is a quantile regression whereby EPU is the dependent variable and inflation and output gap are the regressors and τ_1 refers to the conditional quantiles of EPU. We use 3 lags of inflation, output gap and EPU as the set of instruments. These results in general suggest that increases in inflation tends to generate more economic uncertainty at its higher conditional quantiles, i.e., at the 95th conditional EPU quantile and this is also true for increases in output gap which generates more uncertainty at the 60th and 80th to the 95th conditional EPU quantiles. While higher inflation and output gap, generate better economic sentiment at lower quantiles of EPU, though most of the estimates are

Table 2: First-stage regression estimates

	τ_1										
	0.05	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.95
β_1	-0.7044	-0.1603	-0.2579	-0.0896	-0.4277	-0.7209	-1.0754***	-0.9406	-0.0076	0.3982	1.2013**
β_2	-0.2098***	-0.2073***	-0.2235***	-0.2032	0.2385	0.2174	0.2286*	0.2091	0.2370***	0.1897*	0.2399**

Notes: First stage regression: $epu_t = \beta_0(\tau_1) + \beta_1(\tau_1)\pi_{t+12} + \beta_2(\tau_1)y_t + \beta_z' z_t$. where π_{t+12} the forward looking inflation, y_t the output gap, epu_t the economic policy uncertainty index and z_t the vector of instruments. Instruments: 3 lags of inflation, output gap and *epu*.

insignificant with respect to inflation. These results are not surprising since Japan's dire experience with deflation and low growth would mean that positive price changes and output would trigger positive macroeconomic outlook. It should also be noted that in general, crudely averaging parameter estimates shows that higher inflation and output in general will tend to accentuate macroeconomic uncertainty.

Next, we report the estimated coefficients based on equation (2), at each quantile-on-quantile for the conditional distribution of interest rates relative to the conditional distribution of EPU. We use the same set of instruments and the same forward-looking horizon as reported for the estimates at the conditional mean in Section 3.2.[10] Table 3 shows that the Bank of Japan reaction to inflation at quantiles of EPU (τ_1), conditional on interest rate quantiles (τ_2), are practically insignificantly different from zero, with some cases with the right sign only at low quantiles of EPU, i.e, when economic uncertainty is low and remote cases of significance at higher quantiles of EPU (90th and 95th conditional EPU quantiles), with however the wrong negative sign. In few cases of Table 4, we can see significant reaction of the Bank to the output gap especially at the lower conditional quantiles of interest rate and higher quantiles of EPU. The coefficients are significant at the 60th and 80th to the 95th EPU quantile with respect to the 5th and 10th conditional interest rate quantiles. What these results tend to suggest is that the Bank of Japan reacts to building inflationary pressures of output gap when the level of uncertainty is generally high. These reactions range from an estimate of 0.12 to 0.19. Similarly, there are signs of positive significant reaction at roughly mid-range quantiles of EPU (30th, 50th and 60th) with respect to the higher conditional quantiles of

[10] We concentrate our results on conditional quantile-on-quantile regressions and would refer the readers to unconditional quantile regressions of Firpo et al., (2009), which we do not pursue in this paper.

Table 3: Estimated inflation coefficients α_π

						τ_2					
	0.05	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.95
τ_1											
0.05	0.6444	0.6440	0.2746	0.2712	0.2712	0.1131	-0.0538	-0.1645	-0.5095	2.8747	2.8748
0.10	0.6348	0.6349	0.6456	0.4203	0.4203	0.2464	0.2464	0.2456	1.3937	2.2836	2.2851
0.20	-0.3723	-0.3718	0.3238	0.3524	0.2902	0.2040	0.2040	0.1823	0.1657	0.1237	0.1241
0.30	-0.7520	-0.7520	-0.0217	-0.0216	0.1144	0.0309	0.0226	-0.0055	-0.0772	0.3043	0.3046
0.40	0.1542	0.1542	0.0843	-0.0286	-0.0529	-0.1688	-0.1818	-0.4954	-0.6899	-0.7125	-0.7669*
0.50	-0.2882	-0.2881	-0.3119	-0.4161	-0.4457	-0.4940	-0.5754	-0.7007	-0.7389	-0.8718*	-0.8718***
0.60	-1.4159*	-1.4200	-1.1331	-1.2642	-1.2866	-1.0695	-0.2960	-0.3476	-0.4286	-0.2239	-0.2238
0.70	0.7090	0.6624	0.2324	-0.3070	-0.0601	0.1840	-0.0280	0.0699	0.1845	0.1126	-0.0195
0.80	-0.1346	-0.1347	-0.1006	-0.1432	-0.0923	0.0050	0.1336	0.1340	0.1419	-0.0613	-0.2690
0.90	-1.3713**	-1.1265	-1.0390	-0.9729	-0.5812	-0.5589	-0.6728	-0.5665	-0.6931	-0.8940	-1.5840**
0.95	-1.2644*	-0.9242	-0.7212	-1.0775	-1.0136	-1.1794	-1.1542	-1.2083	-1.4289	-1.3024	-1.3024**
F-test											
p-value	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0004	0.0006	0.0018	0.0481	0.0117

Notes: Instruments: 1-3 lags of inflation, output gap and *epu* . Taylor rule: $i_t = \alpha_0(\tau_1, \tau_2) + a_\pi(\tau_1, \tau_2)\pi_{t+12} + \alpha_y(\tau_1, \tau_2)y_t + \alpha_{epu}(\tau_1, \tau_2)epu_t$, where i_t the end of month shadow interest rate, π_{t+12} the forward-looking inflation, y_t the output gap, and epu_t is economic policy uncertainty index. F-test's p value refers to the statistical significance of instruments. First stage regression: $epu_t = \beta_0(\tau_1) + \beta_1(\tau_1)\pi_{t+12} + \beta_2(\tau_1)y_t$.

Table 4: Estimated gap coefficients α_y

	τ_2										
	0.05	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.95
τ_1											
0.05	0.0718	0.0718	-0.2105	-0.1937	-0.1937	-0.3061	-0.4252	-0.5038	-0.7494	-0.7869	-0.7869
0.10	0.0174	0.0175	0.0806	0.0135	0.0135	-0.0716	-0.0716	-0.0720	-0.0722	-0.0727	-0.0727
0.20	0.0792	0.0792	0.0439	0.1866	0.1658	0.1371	0.1370	0.1298	0.3263	0.5325	0.5324
0.30	0.0512	0.0512	0.2115	0.2115	0.2263	0.1404	0.1670	0.2545	0.2249	0.2444**	0.2444***
0.40	0.1589*	0.1589	0.1360	0.0990	0.1066	0.0531	0.0488	-0.0538	-0.1174	-0.1249	0.0437
0.50	0.0789	0.0789	0.1199	0.1011	0.0892	0.0695	0.0771	0.0343	0.0212	0.1077	0.1077**
0.60	0.1888***	0.1753**	0.1293	0.1145	0.1231	0.0538	0.0676	0.0683	0.0917	0.0924	0.0924**
0.70	-0.0021	0.0106	0.0561	0.0464	0.0551	0.0528	0.0657	0.0745	0.0766	0.0721	0.0630
0.80	0.1223***	0.1223**	0.1329*	0.1065	0.1117	0.0969	0.0773	0.0774	0.0925	0.0840	0.0705
0.90	0.1161**	0.0746	0.0732	0.0740	0.0539	0.0639	0.0623	0.0754	0.0796	0.0831	0.0635
0.95	0.1643**	0.0996	0.1001	0.1087	0.1020	0.0775	0.0654	0.0308	0.0428	0.0255	0.0256
F-test											
p-value	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0004	0.0006	0.0018	0.0481	0.0117

Notes: See Notes to Table 3.

the EPU (90^{th} and 95^{th}), a result which show inflationary concerns of output gap when conditional interest rate is far from its conditional lower bounds.

Table 5 depicts the impact of economic uncertainty on policy. The results indicate that the Bank of Japan has been concerned about volatility throughout much of the sample period and across each quantile-on-quantile, with a however higher negative response at the conditional lower interest rate bounds and at lower level of uncertainty. These parameters range from -0.2 to -1.1. These results are largely consistent with the Brainard's (1967) attenuation principle and the proposition of cautious policy under uncertainty by Blinder (1999), suggesting that monetary policy becomes less aggressive to a particular variable when it becomes more uncertain. So what might not have been an evidence of aggressive response to inflation as the conditional lower bounds are approached in Japan might well have been translated instead into the increased reaction to uncertainty as financial markets predicament unfolded.[11] These results suggest that once higher uncertainty is associated with higher inflationary pressures as evidence by the first stage regression, the Bank is more cautious in taking expansionary measures. Furthermore, we also notice that such reaction dampens once the economy is away from the conditional lower interest rate bounds.

The response to inflation might be at odd with general consensus and Taylor principle. However, the ZIRP era, which occupies the whole of the sample period, might be at the root of the results with a shift in policy commitment from short-term interest rate management towards alternative policy tools as advocated by Bernanke (2017) in an attempt to reflate the economy. It seems that these unconventional measures are slowly

[11] We conducted additional robustness analyses to assess the sensitivity of our findings. First, we used a different inflation horizon (i.e., one-month ahead) and second, we utilized the average over the month (instead of the end-of-month) measure of SSR. In general, our results were qualitatively similar to those reported in the paper, especially with regard to response to uncertainty measure, and are available upon request from the authors.

Table 5: Estimated epu coefficients α_{epu}

	τ_2										
	0.05	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.95
τ_1											
0.05	-1.0615***	-1.0615***	-1.0159***	-1.0072***	-1.0072***	-0.9842***	-0.9599***	-0.9438***	-0.8936***	-0.8434***	-0.8434***
0.10	-1.0802***	-1.0802***	-1.0585***	-0.9862***	-0.9862***	-0.9446***	-0.9446***	-0.9444***	-0.8687***	-0.8099***	-0.8098***
0.20	-0.9063***	-0.9063***	-0.9312***	-0.8830***	-0.8639***	-0.8376***	-0.8376***	-0.8310***	-0.7406***	-0.6349***	-0.6349***
0.30	-0.8832***	-0.8832***	-0.8053***	-0.8053***	-0.7982***	-0.7590***	-0.7441***	-0.6946***	-0.6751***	-0.6435***	-0.6434***
0.40	-0.8062***	-0.8062***	-0.7847***	-0.7499***	-0.7359***	-0.7068***	-0.7028***	-0.6063***	-0.5465***	-0.5395***	-0.4441***
0.50	-0.6427***	-0.6427***	-0.6148***	-0.5763***	-0.5683***	-0.5550***	-0.5154***	-0.4776***	-0.4660***	-0.3703***	-0.3703***
0.60	-0.5648***	-0.5537***	-0.5138***	-0.4946***	-0.4866***	-0.4480***	-0.4035***	-0.3841***	-0.3611***	-0.3316***	-0.3316***
0.70	-0.5289***	-0.5176***	-0.4607***	-0.4328***	-0.4206***	-0.4046***	-0.3915***	-0.3826***	-0.3734***	-0.3621***	-0.3457***
0.80	-0.4440***	-0.4440***	-0.4239***	-0.4052***	-0.3994***	-0.3870***	-0.3704***	-0.3693***	-0.3563***	-0.3283***	-0.3021***
0.90	-0.4124***	-0.3791***	-0.3743***	-0.3695***	-0.3444***	-0.3353***	-0.3289***	-0.3236***	-0.3111***	-0.2901***	-0.2347***
0.95	-0.4323***	-0.3859***	-0.3615***	-0.3522***	-0.3472***	-0.3112***	-0.2981***	-0.2552***	-0.2416***	-0.1997***	-0.1997***
F-test											
p-value	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0004	0.0006	0.0018	0.0481	0.0117

Notes: See Notes to Table 3.

taking Japan out of its financial woes. Moreover, the negative response of inflation to interest rate is in line with the estimates at the conditional mean as discussed above.

Our work contrasts with notable previous studies on conditional quantile regression in several important ways. Firstly, Chevapatrukul et al. (2009) avoids the zero interest rate policy period altogether and Chen and Kashiwagi (2017) provides both uncensored and censored quantile regressions where the regressors as well as the dependent variable are censored. Secondly, using the nominal interest rate that would prevail in the absence of its effective lower bound derived from the term structure of the yield curve which contains valuable information on fundamentals such as growth and inflation rate and expectations of the future, in fact takes into account unconventional measures of monetary policy that have been largely in place in Japan for a protracted period of time to this date and hence might help us to uncover their relationship and impact on fundamentals. Thirdly, having an economic uncertainty measure as an additional regressor adds importantly to the Japanese economic landscape, which has been influenced by macroeconomic uncertainty for decades. Lastly, the conditional quantile-on-quantile regression approach in this paper adds to the previous results including Christou et al. (forthcoming) that uses both the shadow short rates and an uncertainty measure in the sense that the Bank of Japan reaction now depends both on the conditional interest rate quantiles and largely on the level of macroeconomic uncertainty the country is experiencing.

Our results are somewhat similar to previous studies such as Chevapatrukul et al. (2009) and Chen and Kashiwagi (2017) who found no evidence of higher aggressiveness to inflation as the conditional lower bound of interest rates is approached. It differs from their studies in that the Bank of Japan response to inflation is seemingly insignificant in our sample of study, irrespective of the level of uncertainty. With regards to the reaction to output gap, we contribute to the literature by providing some evidence of concerns for inflationary pressures of higher output gap, which tends to build up macroeconomic uncertainty. These results are in line with Chevapatrakul et al. (2009) who found stronger reaction to output gap at higher conditional quantiles of interest rate for Japan, hence more likely when inflationary pressures build up, whereas Chen and Kashiwagi (2017) found no such significant reaction to output gap in their study. The main contribution to existing literature is with regards to reaction to economic uncertainty measure, where we found significant reaction across quantile-on-quantile with however a higher concern when interest rate is at its lowest conditional quantiles, providing evidence of stronger reaction and greater attenuation of the policy rate as the conditional lower bound is approached. It adds to Christou et al. (forthcoming) results in that such reaction to economic uncertainty is predominantly important at lower level of uncertainty when reflationary outcomes is more conducive.

4. Conclusion

This paper provides some new results to the conduct of unconventional monetary policy for Japan over much of its ZIRP period. Importantly, the paper bridges the gap between existing empirical studies that found no detectable evidence of increasing aggression as the lower bound is approached and the strong theoretical prediction that central banks should guard against the possibility of deflation if they operate near lower bounds by being willing to act especially forcefully. To tackle this issue, the empirical analysis conducted in this paper makes use of the shadow interest rates, i.e., the nominal interest rate that would prevail in the absence of its effective lower bound, together with a news-based measure of economic uncertainty. What the quantile on quantile estimation offers is the possibility to test predictions of greater or lesser aggression at different bounds of uncertainty levels conditional on quantiles of interest rate. The results show an increased negative reaction of the Bank of Japan towards economic uncertainty particularly at lower quantiles of interest rates, hence lending support to both the Brainard's (1967) attenuation principle and the increased aggressiveness as the conditional lower bound is approached. Furthermore, reflationary outcomes seem to take place amidst lower level of economic uncertainty.

Data Availability Statement:
The data that support the findings of this study are openly available in IHS Global Insight and www.policyuncertainty.com

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