Uncertainty and Exchange Rates: Global Dynamics (Well, I Don't Quite Know Anymore)

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Abstract

This paper offers two points on the impact of uncertainty and exchange rate shocks on output. (1) A conceptual model where behavioural frictions — rational inattentiveness and bounded expectations — interact with uncertainty, generating aggregate fluctuations. Central banks can target these behaviourial frictions to stabilise output and prices. (2) Empirical findings from a panel of advanced and emerging economies. Output and inflation slow in response to uncertainty shocks. Government bond yields moderate and exchange rates depreciate, suggesting within-country and between-country flight-to-safety respectively. Exchange rate appreciation shocks generate similar responses. The Malaysia-specific analysis finds divergent responses in employment and output, likely reflecting compositional effects in more productive tradable and less productive non-tradable sectors. In a panel fixed effects and quantile regression setting, I find indicative interaction between output, exchange rate and uncertainty, and a distributional dimension.

Keywords: Uncertainty, Rational Inattention, Bounded Rationality, VAR
JEL Classification: E0, E7

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1 Introduction

Two stylised observations since the Global Financial Crisis (GFC) — (i) a secular slowdown in output growth across emerging and advanced economies, though more noticeably for the former, and (ii) a steep, sustained, increase in economic policy uncertainty, due to Davis (2016) [16]. The latter, not only trends upwards, but registers spikes corresponding to major risk events — the Eurozone Sovereign Debt Crisis, Brexit, the US-China trade war, the COVID-19 pandemic, and surges in geopolitical tensions. Certainly, these risk events have direct effects on output and prices. Of importance for policymakers is if the accompanying spike in uncertainty, in and of itself, affects output and prices.

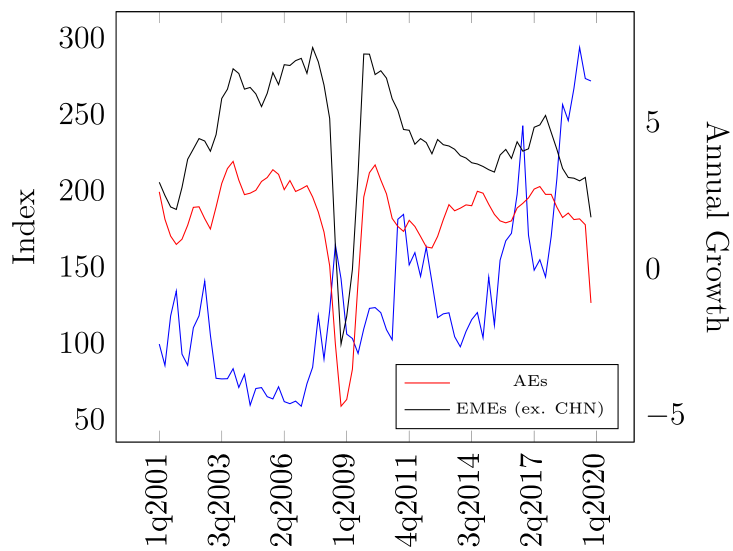

Figure 1: Global EPU Index (LHS) and Real GDP Growth (RHS)

The literature has broadly two findings. (i) The response of real economic activity in response to uncertainty shocks is well established, though largely on the US and some advanced economies, and rarely considered in a panel data setting. (ii) Macro-financial responses to uncertainty shocks, such as exchange rates and bond yields, is more ambiguous and given less attention to. In light of these gaps, this paper expands both issues to a wider set of advanced and emerging economies. On the second issue, I analyse also the responses of currency and bond markets. Specifically, this paper considers the impact of exchange rates, a determinant of the well-being of small open economies, which is better documented in the exchange rate and capital flows literature.

This leads us to two questions. (i) What are the dynamics between uncertainty, the exchange rate and output? (ii) What may be the frictions and channels underlying these effects? The empirical section addresses the first and the theoretical section addresses the second.

Empirical findings from the uncertainty literature suggest that in response to uncertainty shocks, real economic activity slows in the near-term. Bloom (2009)[11] used a calibrated general equilibrium model for the US to examine the impact of adverse shocks to the Chicago Board of Exchange Volatility Index (CBOE VIX), a measure of realised volatility over a rolling 20-day period in US equity markets, on investment made by firms. Subsequently, Baker, Bloom and Davis (2016)[8] proposed a news-based index of economic policy uncertainty. This included a Purchasing Power Parity (PPP)-weighted global index.

The degree of persistence and the presence of a post-shock correction, or overshoot, in output varies according to the how uncertainty is measured. Macroeconomic uncertainty, as estimated in Jurado, Ludvigson and Ng (2015) [25], generates persistent output slowdowns without rebounds, compared to output responses to realised volatility in financial markets or subjective uncertainty. Alessandri and Mumtaz (2019) [5] used a threshold VAR to assess differences in the impact of macroeconomic uncertainty shocks between financial crises and normal times. They find similar responses in Jurado, Ludvigson and Ng (2015) [25]. Output responses during periods of financial stress are sharper, and takes a similar duration to return to its steady state.

The literature offers two strands of theoretical underpinnings. The first points to a build-up of precautionary savings amongst households and firms. Risk averse agents defer expenditure, deterred by the possibility of downside surprises to real income. This subsequently leads to near-term losses in output. However, there are multiple points of controversies within the literature. This includes a lack of consensus over the intensity and duration of such motives, as well as the appropriateness of selected uncertainty measures, as documented by Lugilde, Bande and Riveiro (2017) [30]. The second points to real options effects, where adjustments to employment and investment are costly. Firms enter a decision paralysis when faced with uncertainty. This results in a "wait-and-see" behaviour, where investment, production and employment decisions are deferred. Bloom (2000) details the long and short-run impact of the real options channel.

In extension, Leduc and Liu (2016) [28] posit that uncertainty shocks are aggregate demand shocks. This contributed to theoretical and quantitative research that linked sustained shortfalls in demand and output responses to transitory uncertainty shocks. Fajgelbaum, Schaal and Taschereau-Dumouchel (2017) [20] viewed uncertainty as a shortfall of information flow essential to investment decisions. Using a calibrated quantitative model, they showed that a temporary uncertainty shock leads to a prolonged slowdown in output. Persistence arises from the endogeneity between uncertainty, the flow of economic information, and aggregate demand.

Kamber, Karagedikli, Ryan and Vehbi (2016) [26] offers a contrarian view. Using a structural

Factor-Augmented Vector Autoregression (FAVAR) model on US data, they find that whilst macroeconomic uncertainty shocks lead to a shortfall in output as expected, the exchange rate appreciates and corporate bond yields increase, a direction that juxtaposes an aggregate demand shock. However, the study also examines spillovers to other advanced and emerging economies. Notably, for emerging economies, exchange rates depreciate in response to uncertainty shocks originating from the US. The opposite is observed for advanced economies typically classified as safe havens, such as the Japanese Yen and the Swiss Franc, suggesting flight-to-safety.

The real effects of exchange rates, and capital flows, are well documented, though only a selection consider uncertainty and exchange rates concurrently. Veerhoogen (2008) [37] used the 1994 Mexican Peso Crisis as a 'natural' experiment, which found that the depreciation shock induced quality-upgrading in the manufacturing sector, especially exporters, consequently widening within-industry wage inequality. Cravino and Levchenko (2017) [15] documented the distributional effects of the Peso's depreciation in 1994 on prices, and found larger inflationary pressures for households in lower income deciles. Saffie, Varela and Yi (2020) [19] and Benigno, Fornaro and Wolf (2020) [9] studied the effect of capital flows on sector-level productivity and output in Hungary and the US respectively.

I offer a theoretical framework to examine the effects of uncertainty shocks on the real economy, specifically output and inflation, through macro-behavioural frictions. The model has two behavioural frictions. Firstly, firms and households are rationally inattentive. I simplify Sims (2003)'s [34] conjecture that agents incur costs when processing information, leading to incomplete usage of the full set of information made available to them. Specifically, my model posits that households and firms are only able to process information up to k-periods prior. This limited information span informs expectations of future output and prices, as well as influences the degree of risk aversion. This time-varying parameter then influences both the quantum and allocation of savings. Secondly, expectations formation are rational but bounded, drawing from Ding (2018)'s [18] κ-augmented Phillips Curve. In Ding (2018), price expectations are forward-looking, but limited, and anchored by the central bank's forecast. I posit that macroeconomic uncertainty dis-anchors agents' expectations from a credible 'best guess', represented by the central bank's forecast. Agents thens resort to their own heuristics to form expectations, which are subject to innate biases.

These behavioural frictions have three implications. Firstly, output falls when risk aversion rises. Secondly, subsequent expectations formed for real output are biased downwards, due to a high weight assigned to the immediate past, thereby deviating from optimal price-setting and expenditure-savings behaviour. This element contributes to the persistent shortfall in output relative to the steady state that recent literature on macroeconomic uncertainty found, such as in Jurado, Ludvigson and Ng (2015) [25], and Kamber, Karagedikli, Ryan and Vehbi (2016) [26]. Thirdly, monetary policy eases aggressively, and the certainty over the efficacy of monetary policy transmission diminishes due to behavioural changes. This opens up the possibility for central banks to influence price and output expectations when uncertainty rises.

My empirical strategy is five-fold, each corroborating my attempt to answer the question — "what is the impact of uncertainty shocks on the aggregate economy for open economies in tandem with exchange rate shocks?".

The first is closely related to Jackson, Klieson and Owyang (2019) [23], who employed a non-linear vector autoregression (VAR) with a max-uncertainty variable, drawn from Hamilton (1996)'s [22] max-oil variable. I depart from the extant literature that focuses on firm-level investment and aggregate-level private sector investment, and focus on aggregate real economic activity. The second extends the analysis to a panel of advanced and emerging economies with a panel VAR, with General Method of Moments (GMM)-style instruments as per Abrigo and Love (2016) [1], and a Bayesian pooled panel VAR as documented in Dieppe, Legrand and van Roye (2016) [17]. The third estimates a Bayesian Hierarchical Panel VAR to account for cross-sectional heterogeneity in the panel, as per Jarocinski (2010) [24] and documented by Dieppe, Legrand and van Roye (2016) [17]. The fourth analyses the nonlinear relationship between economic uncertainty, the exchange rate and other macroeconomic variables in a fixed effects setting, departing from structural analysis. The final analyses the dsitributional dimension of the uncertainty-exchange rate-output nexus using a panel quantile regression model, building on Adrian, Boyarchenko and Giannone (2019) [2], and as per Machado and Silva (2018) [31].

The remainder of the paper will be structured as follows. Section 2 proposes the theoretical framework. Section 3 describes the data. Section 4 discusses the empirical strategies, followed by the findings in section 5. Finally, section 6 concludes.

2 Theoretical Framework

The conceptual model contains three building blocks - households, firms and policymakers. With a continuum of economies, the model may be generalised to a global model with multilateral flows, both real goods and services, and financial, in which exchange rate dynamics can be modelled explicitly.

2.1 Household

Households maximise expected-utility, subject to a budget constraint. Here, households are rationally inattentive. Expectations formation is rational but bounded. Both of these are key elements underpinning my explanation of the empirical findings later. Decision-making is forward-looking. Written sequentially, consumption and labour supply decisions are determined to maximise the household's expected lifetime utility, where β is the subjective discount factor. Conventionally, this is the inverse of the long term real interest rate $\frac{1}{1+\bar{r}}$.

$$\max_{c,h} \sum_{t=0}^{\infty} \beta^t \mathbf{E}_0(U(c_t, h_t)),\ \beta < 1 \tag{1}$$

subject to

$$c_t + d_t(1 + r_t) + \sum_{a=1}^{A}(z_t^{(a)} b_t^{(a)}) \leq w_t h_t + \sum_{a=1}^{A}(z_t^{(a)} b_{t-1}^{(a)}(1 + r_t^{(a)})) \tag{2}$$

The budget constraint has three components. At equality, households' consumption expenditure, debt repayments and savings over a class of A assets, are balanced by their contemporaneous wage income, as well as the cash value of all assets held at the start of the period. In summary, this is the household's balance sheet.

The utility function is increasing and concave in consumption, whilst decreasing and concave in labour supply. The former captures non-satiation and diminishing marginal utility. The latter allows for disutility from working, in lieu of leisure. As work hours increase, the pace at which disutility rises similarly increases.

$$U'(c) > 0, U''(c) < 0 \tag{3}$$

$$U'(h) < 0, U''(c) < 0 \tag{4}$$

The A classes of assets that households can invest in differ across two aspects. The first is risk profile, particularly the variability in prices $z_t^{(a)}$. The interest rate $r_t^{(a)}$ offered increases with the underlying degree of risk, reflecting the higher premium placed by investors to offset the disutility generated from the uncertainty in price outturns. The second is time-to-maturity. Returns risks and maturity terms are independent. This yields two concerns

- households' tolerance of price uncertainty and liquidity shocks. Households invest savings between safe and risky assets, while considering their liquidity buffers. To generalise, this decision is defined by the euler equation for these savings instruments, where the marginal costs and benefits of investing in any asset type a are held at equality.

$$U'(b_t^{(a)}) = \beta(1 + r_t^{(a)})\mathbf{E}_t U'(b_{t+1}^{(a)}) \tag{5}$$

The empirical study focuses on the sustained shortfall of output in response to a transitory shock to uncertainty, without a noticeable temporary overshoot. As such, the theoretical segment should include an element that maintains expenditure decisions below the baseline. To this end, I formally consider that risk preferences may be time-varying and expectations on returns are informed by the immediate past, rather than the full set of information available at period t. The latter yields rational inattentiveness, particularly in savings decisions. Parameters in the savings euler equation can be made time-varying, influencing the expected marginal costs and benefits of each class of assets.

$$U'(b_t^{(a)}; \gamma_t, \lambda_a) = \beta(\gamma_t)(1 + r_t^{(a)})\mathbf{E}_t U'(b_{t+1}^{(a)}; \mathbf{E}_t\gamma_{t+1}, \lambda_a) \tag{6}$$

γ_t is the risk preference of the household in period t, which determines the allocation of savings across all A classes of assets. This preference differs across time, and is influenced by two factors, the degree of economic uncertainty and the household's expected future income at the start of period t.

$$\gamma_t = f(\mathcal{U}_t, \gamma_{t-k}; \rho(t)) \; where \; \rho(t) < 1 \; and \; \rho'(t) < 0 \tag{7}$$

A key channel in which uncertainty shocks affect output is through the temporary build-up of precautionary savings, as reflected by the risk preference parameter entering the subjective discounting factor. Crucially, the change in risk preference affects not only the allocation of savings, but the quantum of savings relative to total household budget inflows. I rewrite the household's optimisation problem, allowing for this generalisation.

$$\max_{c,h} \sum_{t=0}^{\infty} \prod_{t=0}^{\infty} (\beta(\mathbf{E}_0\gamma_t))\mathbf{E}_0(U(c_t, h_t)) \; , \; \beta(\gamma_t) < 1 \tag{8}$$

subject to

$$c_t + d_t(1 + r_t) + \sum_{a=1}^{A}(z_t^{(a)} b_t^{(a)}) \leq w_t h_t + \sum_{a=1}^{A}(z_t^{(a)} b_{t-1}^{(a)}(1 + r_t^{(a)})) \tag{9}$$

λ_a characterises the risk profile of the A classes of assets considered. An asset class a is considered a 'safe/hedge' asset if returns are inversely related with aggregate output growth and inflation, and, conversely, a 'risk' asset if this relationship is positive. This classification guides the asset allocation decision of households when the risk appetite parameter γ_t changes. For simplicity, during risk-on periods, households substitute away from 'safe/hedge' assets and towards 'risk' assets. The converse occurs during risk-off periods. Allocation between the two classes of assets is broadly balanced during risk-neutral periods.

$$\lambda_a = b \; if \; \kappa^a > 0 \; and \; \lambda_a = -b \; if \; \kappa^a < 0, \; where \; b > 0 \tag{10}$$

$$\kappa^{(a)} = g(cov(g_t^{(a)}, z_t^{(a)}), cov(\pi_t^{(a)}, z_t^{(a)})), \; where \; g'(\cdot) > 0 \; and \; g''(\cdot) \leq 0 \tag{11}$$

Risk preferences form only one part of household response to uncertainty. Both the quantum and allocation of savings also depend on expected asset value. Rational inattention can imply a prolonged shortfall in output, similar to the conjectures in Leduc and Liu (2016) [28], Fajgelbaum, Schaal and Taschereau-Dumouchel (2017) [20], and Ludvigson, Ma and Ng (2018) [29]. In this strand of the uncertainty literature, the build-up of precautionary savings and real options effects first lead to a shortfall in economic activity, leading to lower information flow. Agents then perceive the state of low information as a persistent state of uncertainty, further delaying investment and consumption. Ultimately, the shortfall in output is prolonged and uncertainty remain elevated.

$$\mathbf{E}_t(z_{t+1}^{(a)} b_{t+1}^{(a)}) = h(\mathbf{E}_t(g_{t+1}), \; \mathbf{E}_t(\pi_{t+1})) \tag{12}$$

Household expectation of asset value depends on expected economic growth and inflation. Sims (2003) [34] posits that costs arising from processing the full span of information flow leads to a deviation from the full-information rational expectations behaviour. Sim's (2003) [34] seminal paper focuses on a constraint on the rate of entropy of information flow. whereas I posit a simple representation. Households form expectations using only limited information from the immediate past k months, rather than the full span of information I_t. By assigning larger weights, $\rho(t)$, to the immediate past, post-shock, households treat the projected economic growth and inflation trajectories to be materially different from the true long-term average. We can treat $\rho(t)$ as an inverse of the cost of processing or acquiring information from that past. Adding a contemporaneous dimension on signal-processing costs may provide greater depth to further work. We can treat this decreasing weight on information sets as the revealed preference of the household having considered the signal-processing cost minimisation problem. Where macroeconomic conditions undershoot expectations due to unanticipated shocks, agents behave as if the impulse of shocks do not dissipate, leading to prolonged undershooting of macroeconomic outturns. Expectations on macroeconomic conditions are procyclical here, which then provide justification to use policy interventions aimed at augmenting expectations when adverse uncertainty shocks materialise. Nevertheless, this is conceptually generalisable to any adverse macroeconomic shock.

$$\mathbf{E}_t(g_{t+1}) = L_g(I(t, ..., t-k); \rho(t)),\ where\ 0 < \rho(t) < 1\ and\ \rho'(t) < 0 \tag{13}$$

$$\mathbf{E}_t(\pi_{t+1}) = L_\pi(I(t, ..., t-k); \rho(t)),\ where\ 0 < \rho(t) < 1\ and\ \rho'(t) < 0 \tag{14}$$

I propose further details on the formation of inflation expectations, drawing from the bounded expectations literature, particularly that of Ding (2018) [18]. Ding (2018) proposed a Neo-Keynesian Philips Curve with rationally bounded agents (κ-augmented NKPC), where inflation expectations are anchored by the central bank's projection. I weave this principle with findings from surveys conducted by various central banks, such that inflation expectations are typically biased upwards. I model households' expectations of inflation as biased upwards from the long-term mean, but anchored by the central bank's forecast. The weight on the latter's projection decreases on two counts. The first comes from Ding (2018) [18], where the central bank's credibility gravitates expectations formation closer to the rational expectations case. The second comes from the degree of prevailing economic uncertainty in period t. Uncertainty erodes the precision of macroeconomic indicators, reducing the reliability of central bank forecast. As the span of information set considered is rife with imprecision, agents resort to judgment heuristics. Though not essential, we may generalise this conjecture to the formation of economic growth expectations.

$$\mathbf{E}_t(\pi_{t+k}) = (\bar{\pi} + \chi_t)\triangle_t + (1 - \triangle_t)\hat{\pi}^{t,CB}_{t+k},\ where\ \triangle_t \leq 1 \tag{15}$$

Formally, the household's inflation expectation is a weighted average of its own projection, formed through judgment heuristics with an upward bias χ_t in period t, and the central bank's forecast produced in the same period. $\triangle_t$ is a increasing and convex function of macroeconomic uncertainty. Uncertainty erodes agents' reliance on the central bank's forecast. This yields an inflation response that overshoots the baseline projection. Absent of

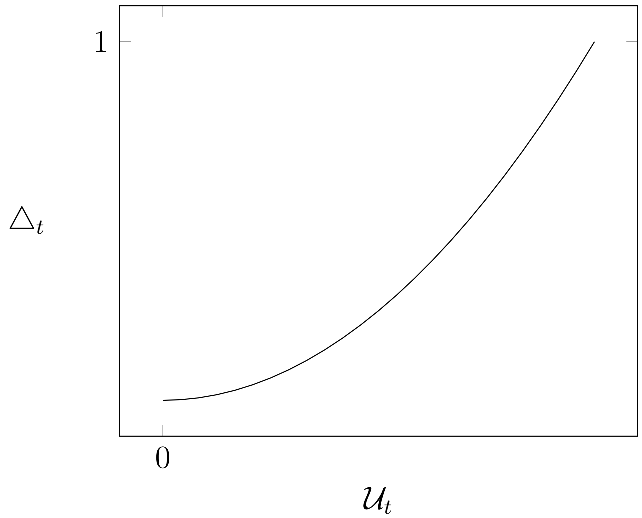

Figure 2: Aggreggate Uncertainty and Agents' Reliance on Own Projection

shocks, expectations are anchored by the central bank. Once uncertainty shocks materialise, the upward bias pushes price-setting behaviour into an acceleration, despite output moderating.

$$\frac{\mathrm{d}\triangle_t}{\mathrm{d}\mathcal{U}_t} > 0 \tag{16}$$

$$\frac{\mathrm{d}^2\triangle_t}{\mathrm{d}\mathcal{U}_t^2} > 0 \tag{17}$$

2.2 Firms

A continuum of $\{i\}_0^\infty$ firms employ labour L_{git} and capital K_{git} to produce an amount Y_{git} of goods of type g , priced at p_{git}, in period t. The production function satisfies constant returns to scale. A workhorse model would be the Cobb-Douglas production function, with labour input shares α_{git} and firm-goods-level total factor productivity (TFP) A_{git}.

$$Y_{git} = A_{git}F(K_{git}, L_{git}; \alpha_{git}) \tag{18}$$

$$y_{git}^{(K)} = A_{git}f(l_{git}) \tag{19}$$

$$y_{git}^{(L)} = A_{git} f(k_{git}) \tag{20}$$

Firms maximise expected profits. Hence, employment and investment, and similarly separation and dis-investment, decisions depend on profit expectations. Similar to the household's problem, this depends on the firms' expectations for inflation and economic growth. While rational inattentiveness and bounded expectations similarly apply, parameters may differ. The degree of behavioural frictions amongst firms may be less binding than amongst households. Firms may have longer records-keeping and inertia in institutional behaviour. Hence, the information considered for the average firm may span a longer period than for the average household.

$$\{L_{git}^{(D)}, K_{git}^{(D)}, \} = \max_{L,K} \{\mathbf{E}_t(\Phi)_i\} \tag{21}$$

$$\Phi_i = \sum_{t=0}^{\infty} \frac{\mathbf{E}_0(\phi_{it})}{(1+r_t)^t} \tag{22}$$

From the expected profit equation, written sequentially, employment and investment decisions are directly dependent on expected prices and output, and, by extension, expected wages and rent. By requiring the rate at which the information weights for period t decreases to be smaller amongst firms, we can capture the asymmetry in attentiveness between firms and households.

$$\mathbf{E}_0(\phi_{it}) = \sum_{g=1}^{G} \mathbf{E}_0\{(p_{git} Y_{git} - w_{git} L_{git} - r_{git}^{(K)} K_{git})\} \tag{23}$$

$$\mathbf{E}_t(g_{t+1}) = L_g(I(t, ..., t-k); \rho(t)),\ where\ 0 < \rho(t)^{(i)} < 1\ and\ \rho'(t)^{(i)} < 0 \tag{24}$$

$$\mathbf{E}_t(\pi_{t+1}) = L_\pi(I(t, ..., t-k); \rho(t)),\ where\ 0 < \rho(t)^{(i)} < 1\ and\ \rho'(t)^{(i)} < 0 \tag{25}$$

$$\rho'(t)^{(firm)} > \rho'(t)^{(household)} \tag{26}$$

A key deviation in expectations formation amongst firms, notably that of inflation, from the household is the lack of a systematic upward bias. The empirical literature on firm-level expectations finds that biases are broadly firm-specific, informed by their experience. Presence of upward biases, similar to those that of household inflation expectations, is not uniform. For instance, Richards and Verstraete (2016) [32] finds that whilst upward biases are found in the Bank of Canada's Business Outlook Survey (BOS), this is generally absent amongst firms surveyed in the Business Confidence Survey (BCS). Unsurprisingly, professional forecasters, with expertise in processing macroeconomic data and likely to utilise such data at a more intensive rate than the average firm or household, do not exhibit such biases. Together with the well-established evidence on upward inflation expectation biases amongst households, this gives rise to an upshoot of inflation away from its steady state in response to an uncertainty shock.

Uncertainty clouds the reliability of expectations, leading to the build-up of precautionary savings and the exercise of real options by delaying investment and employment decisions. Drawing from the literature that discusses uncertainty traps, notably Fajgelbaum, Schaal and Taschereau-Dumouchel (2017) [20], economic growth first undershoots the steady state as uncertainty shocks materialise, and firms subsequently take that as the ex post anchor due to inattentiveness to the full information span. Ultimately, a supposedly transitory downturn posited, such as Bloom (2009) [11] become prolonged and amplified, akin to that of Leduc and Liu (2016) [28] and Fajgelbaum, Schaal and Taschereau-Dumouchel (2017) [20].

2.3 Policy

The economy has two policymakers - the treasury (fiscal policy authority) and the central bank (monetary policy authority). The former decides on public expenditure and taxes, whilst the latter determines the nominal interest rate through the policy rate. As with standard theoretical and quantitative macroeconomic , one may assume exogeneity in the way government expenditure and taxes are determined. However, this framework should be generalisable to the case of endogenous fiscal policy.

The central bank minimises a quadratic Barro-Gordon loss function, due to Kydland and Prescott (1977). The central bank suffers value losses $\mathcal{L}_t$ that are increasing in the deviation of inflation π_t and the output gap x_t from their respective targets, $\pi^* and x^*$, in period t. The relative importance of the inflation target relative to the output gap target, λ, is predetermined. In practice, this may be informed by the central bank's institutional memory, mandates and preferences of its monetary policy committee.

$$\mathcal{L}_t = \lambda(\pi_t - \pi^*)^2 + (1-\lambda)(x_t - x^*)^2, \; where \; 0 < \lambda < 1 \tag{27}$$

Due to lags in the collection and publication of macroeconomic data by statistical agencies, central banks are unlikely to have access to the necessary span of contemporaneous data. GDP, industrial production, and likewise major labour market data such as wages, employment and unemployment, typically follow a substantial lag of up to a quarter. While inflation data are published with a shorter lag, incomplete information motivates the use of an expected loss function rather than a realised loss function. Uncertainty that concerns macroeconomic conditions now affects policy decisions, where the contemporaneous estimates of the output gap and inflation enter the loss function as second moments.

$$\mathbf{E}_t(\mathcal{L}_t) = \lambda \mathbf{E}_t(\pi_t - \pi^*)^2 + (1-\lambda)\mathbf{E}_t(x_t - x^*)^2, \; where \; 0 < \lambda < 1 \tag{28}$$

Rather than solving for the optimal policy rule, which may be subject to a nonstandard Philips Curve and IS function due to the presence of macro-behavioural frictions outlined in the previous subsections, I consider a forward-looking Taylor Rule policy response function, due to Taylor (1993) [35] and Romer and Romer (2004) [33], expressed in terms of inflation and the output gap. Taking first differences then yields the evolution rule for the nominal interest rates in response to movements in inflation rate and in the output gap. Adhering to the Taylor's Principle requires $\beta_{\pi,t} > 1$.

$$i_t = \beta_{0,t} + \beta_{\pi,t}\mathbf{E}_t(\pi_{t+1} - \pi^*) + \beta_{x,t}\mathbf{E}_t(x_{t+1} - x^*) + \epsilon_t \tag{29}$$

$$\triangle i_t = \beta_{\pi,t}\mathbf{E}_t(\triangle \pi_{t+1}) + \beta_{x,t}\mathbf{E}_t(\triangle x_{t+1}) + \triangle \epsilon_t \tag{30}$$

To relate uncertainty with policymaking, I posit that central banks face cognitive limitations on forming contemporaneous expectations, which builds on two observations. Firstly, macroeconomic data crucial to central banks, such as GDP and industrial production, are released with noticeable lags. Secondly, Central Banks are generally non-participants, or, at best, limited participants, in the real economy and financial markets. The ability to access information is likely less comprehensive that agents deeply integrated within market operations. In this model, central banks do not know what π_t and x_t are. Rather, they form expectations of inflation and the output gap, both of which are subject to estimation errors, contemporaneously. This is not to say that firms and households have an idea of what aggregate output and prices are contemporaneously. Rather, firms and households know their respective output and prices. The central bank's estimates are, amongst all economic agents, the 'best guesses' of aggregate economic variables contemporaneously. The central bank's $\mathbf{E}_t\pi_t$ and $\mathbf{E}_t x_t$ may differ from actual outturns. To simplify, the central bank's projection is a function of uncertainty, which multiplicatively interacts with the projection error.

$$\mathbf{E}_t(\pi_t) = \pi_t + \kappa(\mathcal{U}_t)\epsilon_{\pi,t} \tag{31}$$

$$\mathbf{E}_t(x_t) = x_t + \kappa(\mathcal{U}_t)\epsilon_{x,t} \tag{32}$$

$$\kappa = p(\mathcal{U}_t),\ where\ p(0) = 1,\ p'(\cdot) < 0,\ p''(\cdot) < 0 \tag{33}$$

Uncertainty adversely affects the precision in evaluating macroeconomic conditions crucial for policy decisions and the efficacy of monetary policy transmission channels. The latter draws from behavioural changes established in earlier subsections, where agents' price, output and expenditure decisions deviate from a baseline where uncertainty is absent. With higher uncertainty having a multiplicative effect on the precision of inflation and output gap estimates, we expect the second moment of the deviation of inflation and output gap from respective targets to rise. Expected loss, therefore, increases with uncertainty, prompting central banks to react more aggressively to a shortfall in the output gap. Even if the central bank possesses full information rational expectations, without any behavioural frictions, central banks can respond to a shortfall in economic growth and hence the output gap, but to a different degree of aggressiveness. This differs from an increase in uncertainty in policy parameters, drawing from the literature on monetary policy uncertainty, notably Brainard (1967) [12], where policy reaction become more modest, contrary to the type of uncertainty here that concerns the first moment estimates in the loss function. Discussion of interactions with policy parameter uncertainty, as well as implications to monetary policy with quantitative applications may be steps for further research.

In sum, policy has a role in stabilising inflation and the output gap. Importantly, $\mathbf{E}_t(\pi_t)$ and $\mathbf{E}_t(x_t)$, as well as k periods-ahead forecasts, $\pi_{t+k}^{\hat{C}B}$ and $x_{t+k}^{\hat{C}B}$ may be made known to the public to anchor expectations. Policy efficacy depends on the central bank's ability to influence the reliance of agents on official projections, $\triangle_t$, when uncertainty rises. Central banks can provide a credible anchor to lower $\frac{\mathrm{d}\triangle_t}{\mathrm{d}\mathcal{U}_t}$. Social welfare may be relative higher if the upward bias of households and firms χ_t is shut off when uncertainty rises, which could coincide with a shortfall in the output gap, as well as a multiplicative increase in the second moment terms $\mathbf{E}_t(\cdot)^2$ in the loss function.

3 Data

This paper uses a panel of macroeconomic data from 16 advanced and emerging economies — the United States of America (USA), Eurozone (EUR), Japan (JPN), United Kingdom (GBR), Canada (CAN), PR China (CHN), South Korea (KOR), Chinese Taipei (TWN), Singapore (SGP), Malaysia (MYS), Thailand (THA), Philippines (PHL), India (IND), Mexico (MEX), Brazil (BRA) and South Africa (ZAF).

This sample is sufficiently representative of the global economy, as they account for 71.1% of global real GDP in purchasing power parity (PPP) terms in 2018, based on the IMF's October 2019 World Economic Outlook (WEO) Database. Moreover, it covers the major advanced and emerging economies, with additional granularity in East Asia. All variables used — industrial production (IPI), consumer price index (CPI), 10-year government bond yields, nominal effective exchange rate (NEER) and the news-based economic policy uncertainty (EPU) index — are commonly available from June 2013 to February 2020 at a monthly frequency.

The variables here are chosen as proxies for specific macroeconomic factors, considering also their availability at a monthly frequency. IPI proxies for aggregate output, CPI for prices, NEER for the exchange rate and bond yields for the degree of risk aversion. EPU proxies for uncertainty. The Malaysia-specific study is conducted on quarterly data spanning 1Q 2001 to 3Q 2019. I used GDP growth as a proxy of output, instead of IPI growth, and also included employment growth as a measure of labour market conditions.

3.1 Uncertainty

The measure of uncertainty, EPU, was prepared by Baker, Bloom and Davis (2016) [8]. Country-specific indices were additionally prepared by Baker, Bloom, Davis and Wang (2013) [7], Arbatli, Davis, Ito and Miake (2019) [6] and Davis (2016) [16]. For economies without a country-specific index, the global PPP-weighted index was used, prepared by Davis (2016) [16]. These economies are small open economies, whose economic conditions likely depend on global developments. All major economies in the sample had respective indices.

3.2 Macroeconomic Data

The main measures used are IPI, CPI, 10-year government bond yields and NEER. Except the NEER, which is published by the Bank for International Settlements (BIS), all variables are published by the statistical agencies of respective countries, and compiled through Haver Analytics and CEIC.

Bond yields underwent year-on-year difference transformation, while the rest of are transformed into year-on-year growth rates. While this addresses non-stationarity issues in the respective time series, the transformation accounts for seasonality by directly comparing against the same period from the preceding year. One source of seasonality may be holidays that fall on the same period every year, such as Lunar New Year in several of the East Asian economies covered. Additionally, this transformation is commonly used by policymakers, market participants, and professional forecasters.

In the Malaysia-specific study, a different set of transformation was applied on the data set, which spanned a longer period and is available at a quarterly frequency. World GDP growth in this segment is a weighted average of real GDP growth in local constant prices of the following economies — United States, Eurozone, United Kingdom, Japan, Canada, Australia, New Zealand, Switzerland, Sweden, Denmark, Norway, Singapore, Chinese Taipei, Hong Kong SAR, South Korea, PR China, India, Indonesia, Philippines, Thailand, Brazil, Russia, Mexico, Colombia, Chile, Czech Republic, Poland, Romania, South Africa and Turkey. Malaysia is excluded from this measure. These countries accounted for 83.1% of global real GDP in PPP terms in 2018, based on the IMF's October 2019 WEO. The respective shares of global GDP in PPP terms from the IMF's WEO are taken as country weights.

4 Empirical Strategy

Five stages of empirical analysis is conducted, each to address a variant of the question outlined in section 1 — 'what are the dynamics between uncertainty, the exchange rate and aggregate output?' Five strategies will be followed:

1. The country-level max-uncertainty VAR (MUVAR), following Jackson, Kliesen and Owyang (2020) [23] sheds light on the dynamics between output, uncertainty and the exchange rate specifically for Malaysia, accounting for nonlinear uncertainty effects during upward jumps in uncertainty. The later analyses trade this detail off for country coverage, and against the wider global economy, in a panel data setting.

2. I estimate a panel VAR, with GMM-style instruments, following Abrigo and Love (2016) [1]. The paper focuses on the impulse response functions (IRFs) from EPU and NEER shocks, estimated with Cholesky Decomposition. Specifically, these are the estimated average within-country dynamic responses. I have also estimated a Bayesian pooled VAR.

3. The Bayesian Hierarchical Panel VAR allows for cross-sectional heterogeneity, such that estimated country-specific dynamics differ from the sample 'within' estimates, as

per Canova and Ciccarelli (2006) [13], due to Jarocinski (2010) [24] and documented in Dieppe, Legrand and van Roye (2016) [17]. Compared to the second approach, this allows for heterogeneous VAR estimates and IRFs across countries. The Gibbs Sampling further overcomes the limited degrees of freedom posed by the data set.

4. Departs from structural analysis, I analyse the nonlinear relationship between economic uncertainty, the exchange rate and other macroeconomic variables in a fixed effects setting. Additionally, I apply a judgment-free approach to determine any nonlinearities implied by the data by estimating a panel regression augmented with the Least Absolute Shrinkage Selection Operator (LASSO), following Tibshirani (1996) [36] and Ahrens, Hansen and Schaffer (2019) [4]. The sensitivity parameter is estimated through a 10-fold cross validation.

5. I estimate a panel quantile regression, as per Machado and Silva (2018) [31]. This borrows from Adrian, Boyarchenko and Giannone (2019) [2]. I examine if there are material differences in the relationship between uncertainty, the exchange rate and output across various points of the output distribution.

4.1 Country-Level VAR

The Max-Uncertainty VAR is adapted from Jackson, Kliesen and Owyang (2019)[23]. Y_t contains real GDP growth in period t. X_t is a vector of CPI inflation, NEER growth, 10-year government bond yield in period t, and global PPP-weighted real GDP growth. Z_t is the measure of uncertainty — the global PPP-weighted EPU. Finally, $\hat{Z}_{t-1}$ is the max-uncertainty measure, which is the percentage change of uncertainty relative to its highest level in the past 12 months. $\hat{Z}_{t-1}$ takes the value of zero if this change is nonpositive. Additionally, sign restrictions are imposed on the Malaysian variables in the global equations to reflect Malaysia's position as a small open economy. Shocks from the domestic economy should not affect the global economy. In the global GDP and EPU equations, the coefficients of Malaysian variables are restricted to zero.

$$\begin{bmatrix} Y_t \\ X_t \\ Z_t \end{bmatrix} = \begin{bmatrix} \beta_{11} & \beta_{11} & \beta_{11} \\ \beta_{21} & \beta_{22} & \beta_{23} \\ \beta_{31} & \beta_{32} & \beta_{33} \end{bmatrix} \begin{bmatrix} Y_{t-1} \\ X_{t-1} \\ Z_{t-1} \end{bmatrix} + \begin{bmatrix} \gamma_{yz} \\ \gamma_{xz} \\ 0 \end{bmatrix} \hat{Z}_{t-1} + \begin{bmatrix} \epsilon_{Y,t} \\ \epsilon_{X,t} \\ \epsilon_{Z,t} \end{bmatrix} \tag{34}$$

$$\hat{Z}_{t-1} = \max\{0, \frac{100 * (Z_{t-1} - \max\{Z_{t-2}, ..., Z_{t-13}\})}{\max\{Z_{t-2}, ..., Z_{t-13}\}}\} \tag{35}$$

The merits of this approach is of two-fold. Firstly, we distinguish between an elevation in uncertainty and spikes in uncertainty that are 'abnormal' relative to the immediate past. A 12-month period could reflect possible rational inattention of agents who may have limited retrospective vision. However, this choice of backward visibility may be arbitrary and could vary. This representation is a simplification of Sims (2003)'s [34] principles, where agents face signal-processing costs in consuming the span of informational set available to them, leading to inefficient consumption of information and, hence, producing decisions that deviate from the rational expectations case. Kamdar (2019) [27] proposes a suite of structural models, augmenting workhorse models with these behavioural properties. We may interpret the limit on the backward-looking abilities of agents, as well as the decreasing weight of longer lags, as the revealed preference of the information-processing problem faced by the respective agents. Secondly, the convenient structure of the max-uncertainty VAR allows for a linear estimation, as well as standard computation of the IRFs, allowing for a simple, non-parametric and data-driven procedure.

Nevertheless, I note two key shortcomings, in reference to the theoretical underpinnings of this paper's analysis. Firstly, while allowing for substantial jumps in uncertainty to have an added effect, parameters of the model remain linear. Secondly, similar to a regular VAR, responses to a downward shock in uncertainty are treated as symmetric.

4.2 Panel VAR

Taking the estimation exercise to a panel of 16 economies outlined in section 3, the following model estimates the average within-country dynamics of IPI growth, CPI inflation, the annual difference of bond yields, NEER growth and uncertainty growth. The reduced form within-effect estimates $\boldsymbol{\beta}$ are estimated with GMM-style instruments, as per Abrigo and Love (2016) [1].

Impulse responses are structurally estimated with Cholesky Decomposition, shown in section 5.2. In the main results, EPU is ordered after IPI, CPI inflation and the NEER under the assumption that an unanticipated movements in uncertainty do not immediately feed into macroeconomic variables. This intends to reflect nominal frictions in trade, e.g. contract lock-ins, and price-setting, e.g. informational and price adjustment cost. An alternative set of estimates, where EPU is ordered first — that the pass-through of uncertainty shocks to macroeconomic variables (output, prices and the exchange rate) is immediate — is reported in the appendix for both the GMM-style (section A.1) and Bayesian Pooled (section A.2) Panel VARs.

$$\textbf{Ordering:}\ \text{Output} \rightarrow \text{NEER} \rightarrow \text{Inflation} \rightarrow \text{Uncertainty} \rightarrow \text{Bond Yields} \tag{36}$$

In this model, Y_{it} is the IPI growth of country i in month t, X_{it} the vector of CPI inflation, and the annual difference in bond yields, and Z_{it} the vector of EPU and NEER growth, the shock variables of interest. α_i^Y, α_i^X and α_i^Z are endogenous variable-specific fixed effects for country i. All variables here are treated as endogeneous. The fixed effects control for variable-country-specific heterogeneity that are time-invariant but unaccounted for by the variables in the reduced form VAR.

$$\begin{bmatrix} Y_{it} \\ X_{it} \\ Z_{it} \end{bmatrix} = \begin{bmatrix} \alpha_i^Y \\ \alpha_i^X \\ \alpha_i^Z \end{bmatrix} + \begin{bmatrix} \beta_{11} & \beta_{11} & \beta_{11} \\ \beta_{21} & \beta_{22} & \beta_{23} \\ \beta_{31} & \beta_{32} & \beta_{33} \end{bmatrix} \begin{bmatrix} Y_{i,t-1} \\ X_{i,t-1} \\ Z_{i,t-1} \end{bmatrix} + \begin{bmatrix} \epsilon_{it}^Y \\ \epsilon_{it}^X \\ \epsilon_{it}^Z \end{bmatrix} \tag{37}$$

4.3 Bayesian Panel VARs

In this segment, I estimate two versions — (i) a pooled panel VAR, as documented in Dieppe, Legrand and van Roye (2016) [17], with IRFs estimated with Cholesky Decomposition as per section 4.2, and (ii) a hierarchical model, due to Jarocinski (2010) [24], with IRFs estimated with sign restrictions.

While not covered here, further work may consider the structural factor models in Canova and Ciccarelli (2013) [14], which allows also for static and dynamic interdependencies. The reduced form errors are correlated across units, capturing static interdependencies. Shocks from the lagged endogenous variables of all countries $i \neq j$ affect variables in country i equation, capturing dynamic interdependencies. A model with less macroeconomic variables, but withh wider country coverage may be useful in characterising possibly intricate global linkages.

The Bayesian hierarchical panel VAR extends the GMM-style model in section 4.2 by allowing for cross-sectional heterogeneity. Instead of $\boldsymbol{\beta}$, we estimate $\boldsymbol{\beta_i}$ for each country i, as per Jarocinski (2010) [24]. Section 5.3 reports the IRFs of interest. Compared to the static GMM-style panel VAR, we can extract country-specific responses to their own shocks. This provides a richer characterisation of heterogeneous output responses to uncertainty and exchange rate shocks.

$$\begin{bmatrix} Y_{it} \\ X_{it} \\ Z_{it} \end{bmatrix} = \begin{bmatrix} \alpha_i^Y \\ \alpha_i^X \\ \alpha_i^Z \end{bmatrix} + \begin{bmatrix} \beta_{i,11} & \beta_{i,11} & \beta_{i,11} \\ \beta_{i,21} & \beta_{i,22} & \beta_{i,23} \\ \beta_{i,31} & \beta_{i,32} & \beta_{i,33} \end{bmatrix} \begin{bmatrix} Y_{i,t-1} \\ X_{i,t-1} \\ Z_{i,t-1} \end{bmatrix} + \begin{bmatrix} \epsilon_{it}^Y \\ \epsilon_{it}^X \\ \epsilon_{it}^Z \end{bmatrix} \tag{38}$$

4.4 Fixed Effects Regression

This section deviates from macroeconomic structural analysis. Specifically, we are interested in the possible heterogeneous relationship between output, prices, risk aversion, the exchange rate and uncertainty. This approach entails two steps — (i) model selection with LASSO and (ii) estimation of the selected fixed effects 'within' model.

Firstly, I implemented the LASSO on a fixed effects model, as per Tibshirani (1996) [36] and Ahrens, Hansen and Schaffer (2019) [4], with a triple interaction of risk aversion, uncertainty and the exchange rate. This shrinks the coefficient estimates β towards zero. Variables that are estimated to be close to zero in the fixed effect model are dropped (zero-rised), effectively dropping noise interaction terms.

$$\min \frac{1}{n}\sum_{i=1}^{n}(y_i - x_i'\beta)^2 + \lambda \sum_{j=1}^{p} |\beta_j| \tag{39}$$

Secondly, I estimate the fixed effects model with interaction terms selected in step one. Y_{it} is the IPI growth for country i in month t, X_{it} the vector of selected variables amongst bond yields and inflation, and Z_{it} that of NEER and EPU growth. $X_i t \cdot Z_{it}$ is the vector of selected interaction terms. ϵ_{it} is the unexplained variation in IPI growth.

$$Y_{it} = \alpha_i + X_{it}\beta_1 + Z_{it}\beta_2 + X_{it} \cdot Z_{it}\beta_3 + \epsilon_{it} \tag{40}$$

4.5 Panel Quantile Regression

Finally, to add a distributional dimension to the analysis, I estimate a panel quantile regression model with the same interaction terms chosen by the LASSO in section 4.4. We are interested in β_k^q, the average within-country effect of variable k on IPI growth for country at quantile q of IPI growth, as per Machado and Silva (2018) [31].

$$Y_{it} = \alpha_i^q + X_{it}\beta_1^q + Z_{it}\beta_2^q + X_{it} \cdot Z_{it}\beta_3^q + \epsilon_{it} \tag{41}$$

5 Empirical Findings

5.1 Country-Level Max-Uncertainty VAR

Zooming into Malaysia, the estimated IRFs are broadly in line with the wider literature. Output growth moderates in response to an unanticipated increase in uncertainty for up to 2-years, with a correction absent. Inflation moderates slightly but persistently. At this juncture, this finding deviates from the theoretical model's conjecture, and will be analysed together in section 5.2 with the panel VAR findings. The exchange rate tends towards depreciation persistently. In line with the negative output response, employment growth moderates. Risk premia, as measured by the 10-year yield spread, relative to 10-year US treasury yields, closes, suggesting within-country flight-to-safety. Kamber, Karagedikli, Ryan and Vehbi (2016) [26] finds that bond yields in advanced economies rise in response to uncertainty shocks. For Malaysia, an EME, the opposite response may be expected.

Responses to a 1 S.D. Shock in the Change in the Global EPU Index

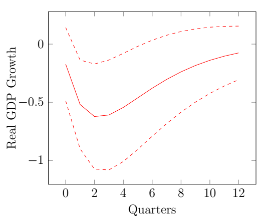

Figure 3:
Real GDP Growth

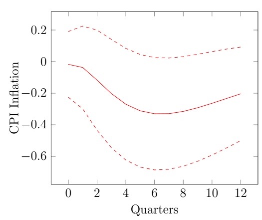

Figure 4:
CPI Inflation

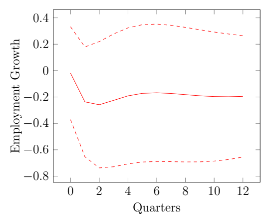

Figure 5:
Employment Growth

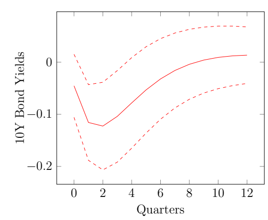

Figure 6:
10-Year Bond Yields

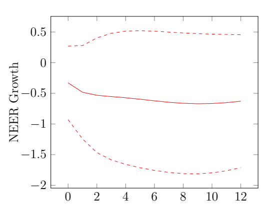

Figure 7:
NEER Growth

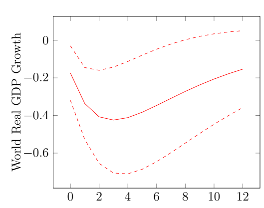

Figure 8:
World GDP Growth

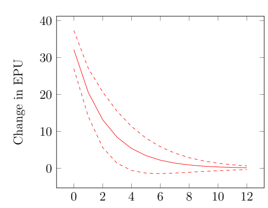

Figure 9:
Change in GEPU

Note: Solid lines show the median impulse response of respective variables to a +1.0 standard deviation shock in the annual change in the global economic policy uncertainty index. Dotted lines represent the 95% confidence bands.

In response to an upward (appreciation) shock in the exchange rate, output moderates, as expected for a trade-dependent small open economy. Inflation moderates, likely due to cheaper imports. Bond yields fall, as prices of portfolio assets increase. Viewed against other economies, a higher valued exchange rate may attract portfolio investors seeking to retain value, hence the higher demand and subsequently lower yields in Malaysian bonds.

While the upward response in employment growth may not be expected, this may arise from compositional effects, as more labour-intensive, less trade-dependent, sectors may experience real income windfalls from the stronger exchange rate, leading to stronger labour demand. The net employment gains can be reconciled with a net output loss if sectors that benefited from a stronger exchange rate, namely the labour-intensive non-tradable sectors, are less productive than capital-intensive tradable sectors, such as manufacturing. This suggests that employment gains in non-tradable sectors dominate the employment losses in tradable sectors. However, the productivity gap is sufficiently large such that output losses in the tradable sectors dominate the output gains in the non-tradable sectors. To corroborate, Benigno, Fornaro and Wolf (2020) [9] argues that capital flows into the US, which strengthened the USD, had prompted an faster expansion in the less-productive services sector relative to manufacturing, hence dampening global productivity growth. Using detailed firm-level data spanning 1992-2008 in a 'natural' experiment — Hungary's full capital account liberalisation in 2001 ahead of its ascension to the European Union (EU) — Saffie, Varela and Yi (2020) [19] found faster expansion in the services sector, whose estimated real productivity is lower as Hungary gained access to international capital markets. In these sectors, relative to the manufacturing sector whose real productivity is estimated to be higher, the number of firms also expanded faster, aligned with the estimated net employment gains in this paper.

Responses to a 1 S.D. Shock in NEER Growth

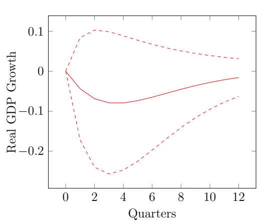

Figure 10:
Real GDP Growth

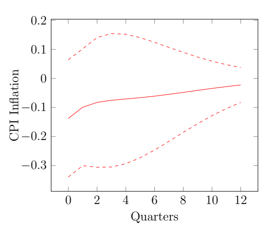

Figure 11:
CPI Inflation

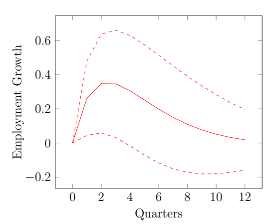

Figure 12:
Employment Growth

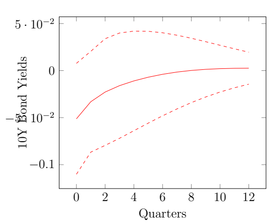

Figure 13:
10-Year Bond Yields

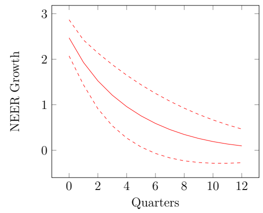

Figure 14:
NEER Growth

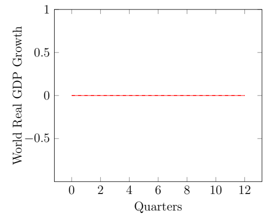

Figure 15:
World GDP Growth

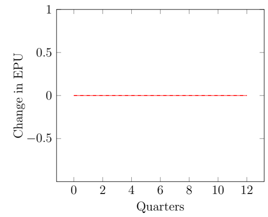

Figure 16:
Change in GEPU

Note: Solid lines show the median impulse response of respective variables to a +1.0 standard deviation shock in the annual growth of the nominal effective exchange rate (NEER; appreciation). Dotted lines represent the 95% confidence bands.

5.2 Panel VAR

Output contracts in the short-run in response to a positive shock in uncertainty growth, before normalising after approximately 1 year. However, there is no positive correction in the aftermath, in contrast to earlier country-specifc studies, such as Bloom (2009) [11]. This may be due to (i) the different transformation conducted to handle nonstationarity in the levels of some country-specific EPU series, and (ii) the differential dynamics of output and uncertainty in the later periods of the 2010s, where the extant literature focuses on the pre-GFC period and the early half of the 2010s.

Inflation moderates, nearly converging to its steady state after approximately 1 year. This contrasts the theoretical mechanism proposed, where the upward bias of household expectations dominate during times of uncertainty. The sign here suggests that the aggregate demand effect, outlined in Leduc and Liu (2016) [28], may dominate. Output and prices move in the same direction.

Bond yields accelerate, suggesting stronger risk aversion behaviour on average across the panel of countries. The overall findings reflects that of Kamber, Karagedikli, Ryan and Vehbi (2016) [26], where bond yields were estimated to rise in response to an uncertainty shock. Finally, the effective exchange rate depreciates, suggesting flight-to-safety in the currency market to trade partners in the basket of countries in Malaysia's NEER.

Responses to a 1 S.D. Shock in Economic Policy Uncertainty Growth

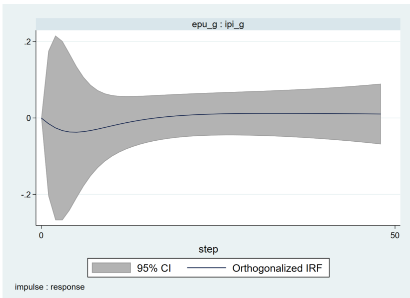

Figure 17: IPI Growth

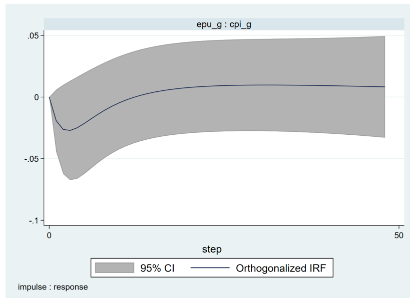

Figure 18: CPI Inflation

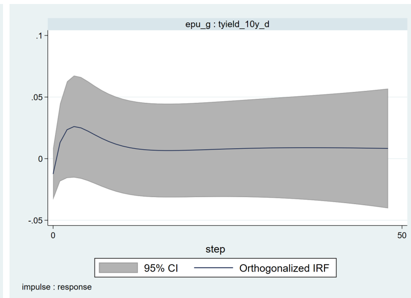

Figure 19: 10Y Bond Yields

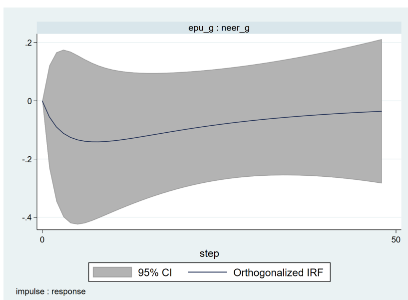

Figure 20: NEER Growth

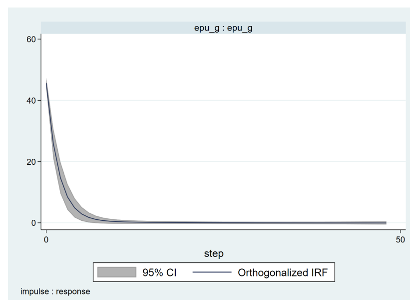

Figure 21: EPU Growth

Note: Solid lines show the median impulse response of respective variables to a +1.0 standard deviation shock in the annual growth of EPU. Shaded area represents the 95% confidence bands, estimated with 200 Monte Carlo draws using Gaussian approximation.

Output moderates persistently in response to an upward exchange rate shock (unanticipated appreciation). The response of NEER growth to its own shock suggest a slow convergence in prices relative to that of trade partners over a period of 4 years. As a stronger exchange rate raises purchasing power relative to other countries, and reduces import prices, inflation moderates persistently. In line with this conjecture, money supply slows gradually but persistently. Likewise, bond yields slow persistently, correcting only after approximately 4 years. As prices of portfolio bond assets would now be more expensive in terms of trade partners' currencies, bond yields moderate. EPU moderates temporarily, likely as the news of higher purchasing power for domestic agents are treated as positive economic news, hence reducing the prevailing level of uncertainty modestly.

Responses to a 1 S.D. Shock in NEER Growth

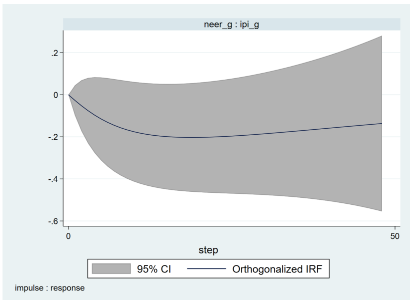

Figure 22: IPI Growth

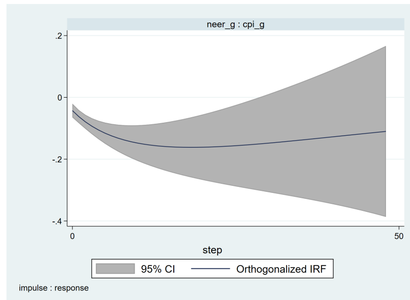

Figure 23: CPI Inflation

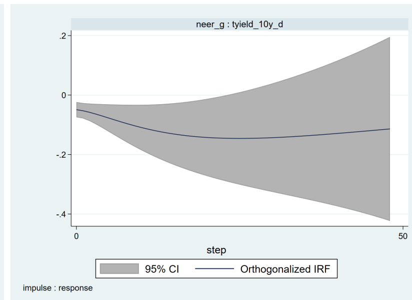

Figure 24: 10Y Bond Yields

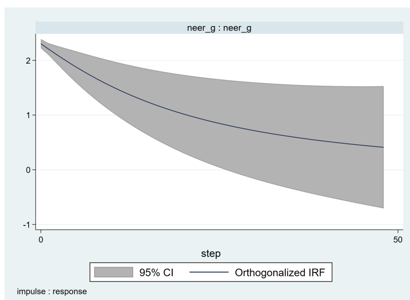

Figure 25: NEER Growth

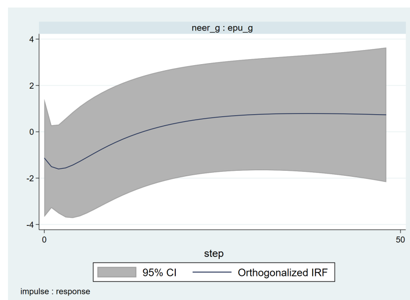

Figure 26: EPU Growth

Note: Solid lines show the median impulse response of respective variables to a +1.0 standard deviation shock in the annual growth of the NEER (appreciation). Shaded area represents the 95% confidence bands, estimated with 200 Monte Carlo draws using Gaussian approximation.

5.3 Bayesian Panel VAR

5.3.1 Pooled Model

The Bayesian pooled estimates are similar to that of the GMM-style panel VAR, except the responses of bond yields and inflation to uncertainty shocks. Responses to exchange rate shocks are similar to that of section 5.2.

Where the earlier estimates showed a temporary acceleration in yields, bonds yields here moderate before converging back to its steady state after approximately 2 years. This suits the prediction of the theoretical model, where risk aversion and flight-to-safety behaviour raise the demand and subsequently prices of safe assets, such as long-term sovereign bonds, leading to lower yields in the near-term.

Inflation is estimated to accelerate marginally in response to an uncertainty shock. This fits the prediction of the theoretical model, where uncertainty dislodges inflation expectations from the 'best guess' anchor, e.g. the central bank's forecast, to households' and firms' own forecast. In this line of thinking, innate biases then drive pricing behaviour away from the steady state in either direction. An upward bias in household or firms expectations, such as documented in Richards and Verstraete (2016) [32], may affect aggregate price-setting behaviour, pushing push inflation upwards from the its steady state. Abstracting from the theoretical model, the exchange rate depreciates in response to an uncertainty shock, hence import prices may rise. To the extent that the exchange rate pass-through affects consumer prices, inflation may accelerate. However, the estimated magnitude of the inflation IRF is small and imprecise.

Responses to a 1 S.D. Shock in EPU Growth

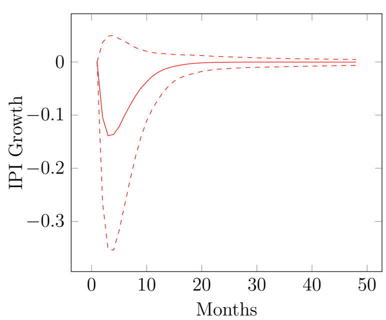

Figure 27: IPI Growth

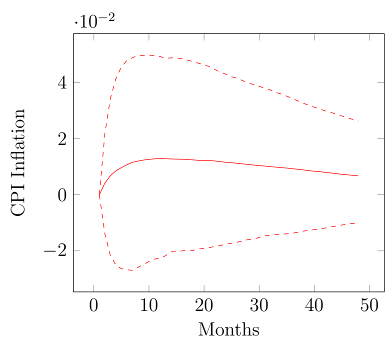

Figure 28: CPI Inflation

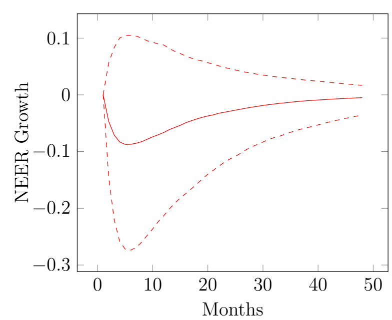

Figure 29: NEER Growth

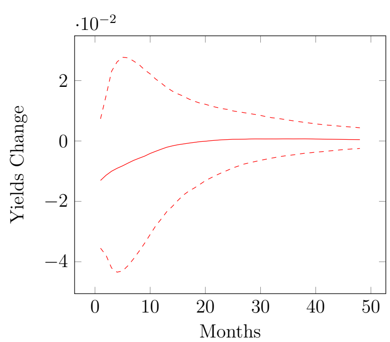

Figure 30: 10Y Yields Change

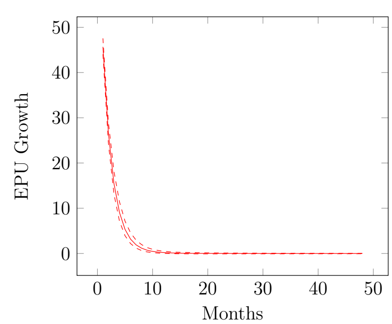

Figure 31: EPU Growth

Note: Solid lines show the median impulse response of respective variables to a +1.0 standard deviation shock in the annual growth of EPU. Dotted lines represent the 95% confidence bands.

Responses to a 1 S.D. Shock in NEER Growth

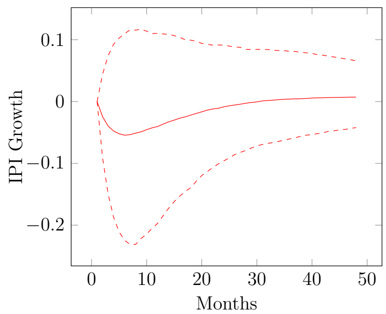

Figure 32: IPI Growth

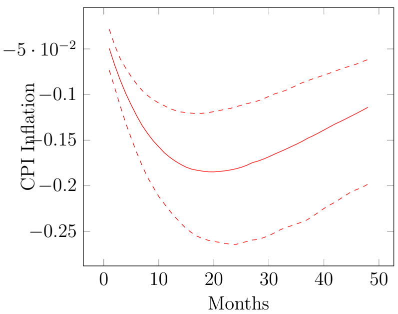

Figure 33: CPI Inflation

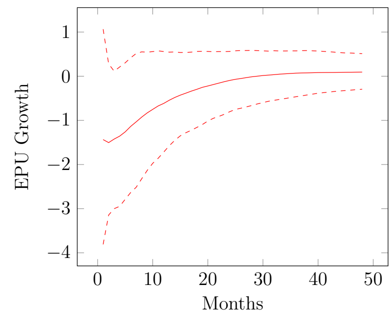

Figure 34: EPU Growth

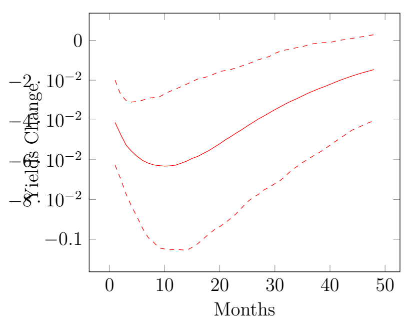

Figure 35: 10Y Yields Change

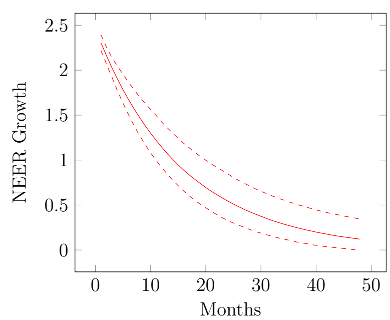

Figure 36: NEER Growth

Note: Solid lines show the median impulse response of respective variables to a +1.0 standard deviation shock in the annual growth of the NEER (appreciation). Dotted lines represent the 95% confidence bands.

5.3.2 Hierarchical Model

As the hierarchical model allows for cross-sectional heterogeneity in responses, this section will analyse output responses to uncertainty and exchange rate shocks for all 16 economies.

While the magnitude differs across countries, uncertainty shocks generate a dip in output growth, before converging to respective steady states after approximately 1 to 2 years, similar to the pooled model. Post-shock overshoots are absent. Exchange rate shocks generate heterogeneous output responses. This may be due to varying trade intensity or exchange rate policy responses. Output growth in economies such as the USA, Japan, Korea and Malaysia slow in response to an appreciation shock. On the other hand, the Eurozone, Brazil and South Africa benefit from a stronger exchange rate. Stronger purchasing power may translate into higher goods and services demand. Finally, J-curve-like responses were estimated for the India, Brazil and South Africa. Stronger purchasing power first dominates, before being offset by export demand adjustments.

Responses to a 1 S.D. Shock in EPU Growth

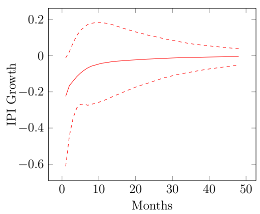

Figure 37: USA

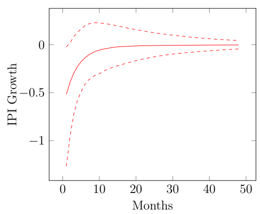

Figure 38: EUR

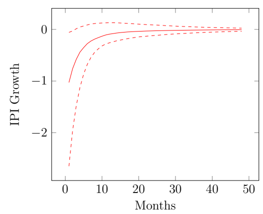

Figure 39: JPN

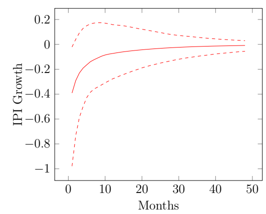

Figure 40: GBR

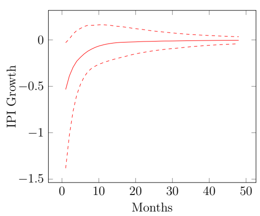

Figure 41: CAN

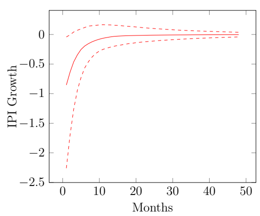

Figure 42: CHN

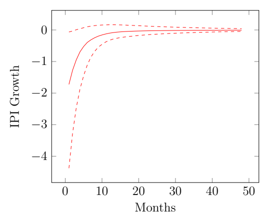

Figure 43: KOR

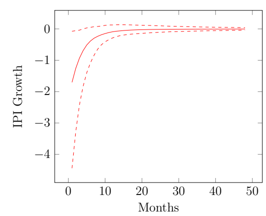

Figure 44: TWN

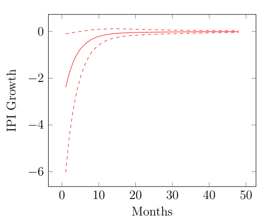

Figure 45: SGP

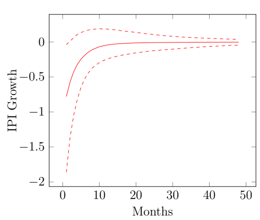

Figure 46: MYS

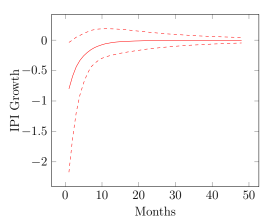

Figure 47: THA

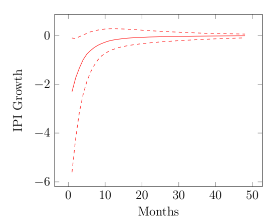

Figure 48: PHL

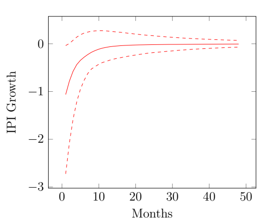

Figure 49: IND

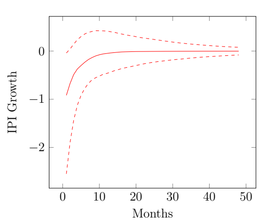

Figure 50: MEX

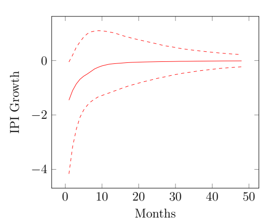

Figure 51: BRA

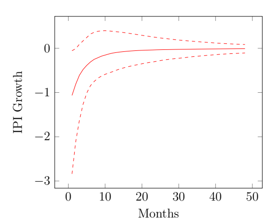

Figure 52: ZAF

Note: Solid lines show the median impulse response of respective variables to a +1.0 standard deviation shock in the annual growth of EPU. Dotted lines represent the 95% confidence bands.

Responses to a 1 S.D. Shock in NEER Growth

95% confidence bands omitted to illustrate clearer the IRFs

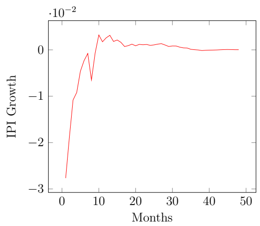

Figure 53: USA

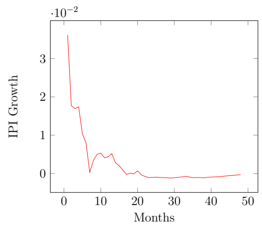

Figure 54: EUR

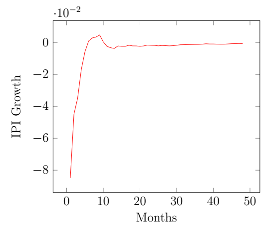

Figure 55: JPN

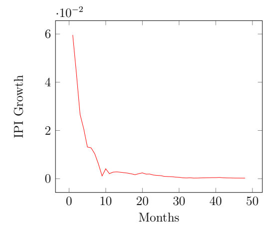

Figure 56: GBR

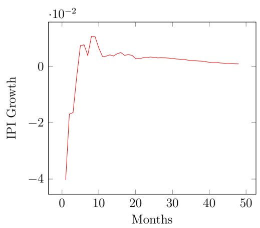

Figure 57: CAN

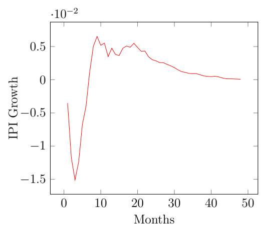

Figure 58: CHN

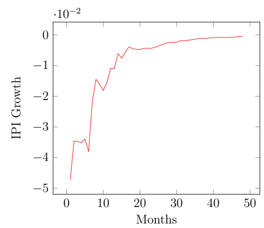

Figure 59: KOR

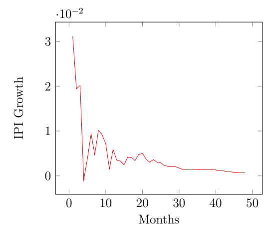

Figure 60: TWN

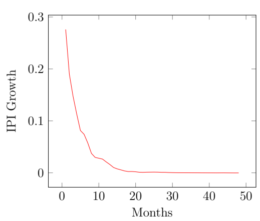

Figure 61: SGP

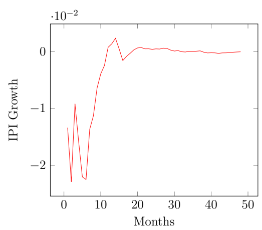

Figure 62: MYS

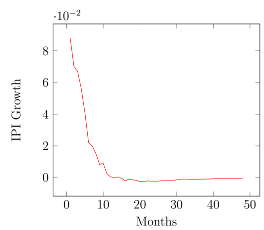

Figure 63: THA

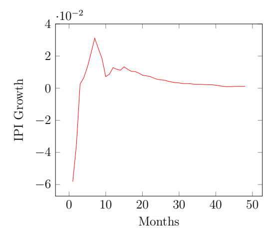

Figure 64: PHL

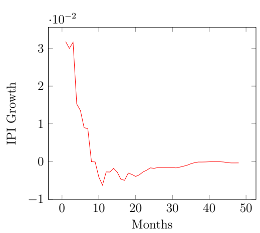

Figure 65: IND

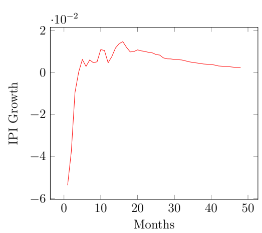

Figure 66: MEX

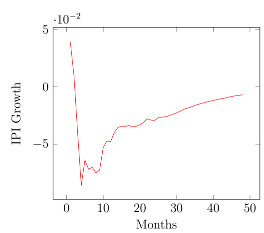

Figure 67: BRA

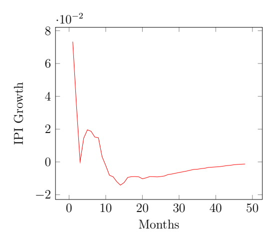

Figure 68: ZAF

Note: Solid lines show the median impulse response of respective variables to a +1.0 standard deviation shock in the annual growth of the NEER (appreciation).

5.4 Fixed Effects Regression

Table 1 column 1 shows the LASSO estimates of the selected variables. Not shown here are the dropped interactions between NEER growth, EPU growth and the 10-year bond yields, each proxies for the exchange rate, uncertainty and risk aversion, drawing from the theoretical framework in section 2.

VARIABLES	(LASSO) IPI	(FE) IPI
Inflation		-0.135
		(0.290)
10-Year Bond Yields	0.307	0.544
		(0.503)
NEER		-0.0144
		(0.0507)
EPU	-0.00203	-0.00498
		(0.00377)
10-Year Bond Yields * NEER	0.0251	0.0418**
		(0.0150)
10-Year Bond Yields * EPU		
NEER * EPU		
10-Year Bond Yields * EPU * NEER		
Observations	1,296	1,296
Number of countries	16	16
FE	Yes	Yes
R-squared		0.022

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 1: LASSO and Fixed Effects Regression Estimates

In line with the previous sections, uncertainty has a negative relationship with output growth. Corroborating findings in sections 5.1 to 5.3, NEER is negatively associated with output growth. Additionally, the interaction effect between the NEER and bond yields is estimated to be a small and statistically significant positive. This suggests that the negative relationship between the exchange rate and output is drawn smaller and towards positive territory as bond yields accelerate, likely during periods of rising risk aversion. Nevertheless, the setup does not permit interpreting these results as causal.

These findings should be interpreted only as statistical co-movements implied by the data. Nevertheless, this may motivate further structural or quantitative analysis that account for nonlinearities along the dimensions of risk aversion and the exchange rate in an environment with economic uncertainty.

5.5 Panel Quantile Regression

Next, building on the model selected in section 5.4, table 2 reports the quantile regression estimates. Figures 69 and 70 show the estimated coefficients on EPU growth and NEER growth (for which the annual change of bond yields is zero) respectively along quantiles of IPI and their 95% confidence intervals. Coefficient estimates on inflation and bond yields are reported in figures 71 and 72.

Of interest here are the coefficients on EPU and NEER. Other variables are included as controls but are nevertheless reported. While uncertainty is negatively associated with output along the distribution of output, the estimates are larger at lower quantiles. The NEER is increasingly negatively associated with output growth along the distribution of output growth, except at the 5$^{\text{th}}$ percentile, where it registers a small positive. In table 2 row 5, the estimates of the interaction term between NEER and bond yields are statistically different from zero, except at the 5$^{\text{th}}$ percentile and upper quantiles, and are positive. As with section 5.4, future quantitative or structural work may consider distributional dimensions of the output-exchange rate-uncertainty nexus.

Panel quantile regression coefficient estimates (reported in table 2)

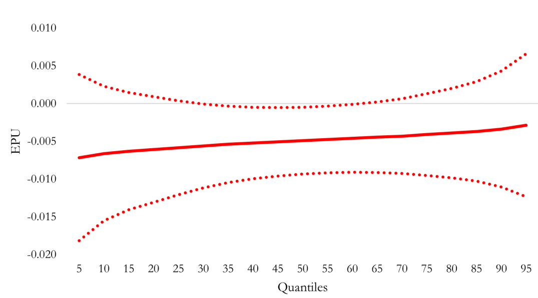

Figure 69: EPU Growth

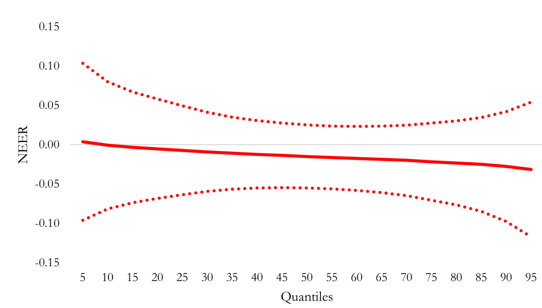

Figure 70: NEER Growth
(Bond Yields Change = 0)

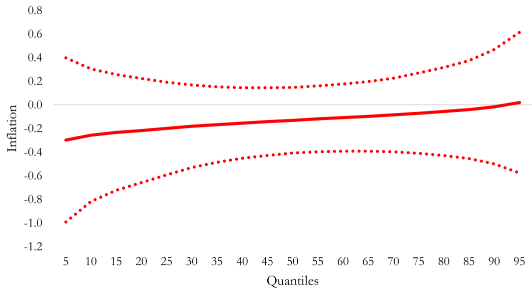

Figure 71: CPI Inflation

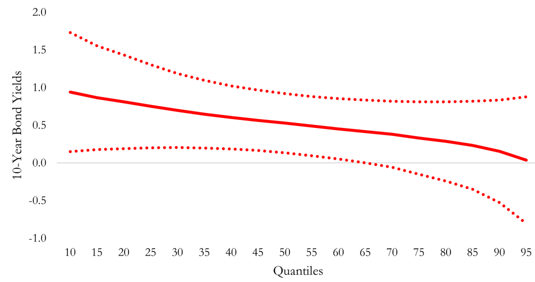

Figure 72: 10-Year Bond Yields Change

Note: Solid lines show the coefficient estimates of respective variables at 5 percentile intervals from a panel quantile regression of IPI growth on EPU growth, NEER growth, CPI inflation, change in 10-year government bond yields, and an interaction term of NEER growth and the change in 10-year government bond yields. Dotted lines represent the 95% confidence intervals at each quantile.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
VARIABLES/ PERCENTILES	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
CPI Inflation	-0.296	-0.256	-0.233	-0.217	-0.199	-0.181	-0.166	-0.153	-0.141	-0.130	-0.118	-0.107	-0.0962	-0.0848	-0.0695	-0.0557	-0.0394	-0.0152	0.0203
	(0.354)	(0.286)	(0.250)	(0.225)	(0.200)	(0.178)	(0.163)	(0.152)	(0.146)	(0.142)	(0.142)	(0.145)	(0.150)	(0.159)	(0.174)	(0.190)	(0.212)	(0.247)	(0.304)
10-Year Bond Yields	1.072**	0.940**	0.865**	0.811**	0.753***	0.696***	0.646***	0.604***	0.566***	0.528***	0.489**	0.453**	0.418**	0.381*	0.331	0.286	0.233	0.154	0.0381
	(0.499)	(0.403)	(0.351)	(0.317)	(0.282)	(0.251)	(0.229)	(0.214)	(0.205)	(0.200)	(0.200)	(0.204)	(0.212)	(0.224)	(0.245)	(0.268)	(0.298)	(0.348)	(0.429)
NEER	0.00373	-0.000792	-0.00338	-0.00522	-0.00721	-0.00919	-0.0109	-0.0123	-0.0136	-0.0150	-0.0163	-0.0175	-0.0187	-0.0200	-0.0217	-0.0232	-0.0251	-0.0278	-0.0317
	(0.0509)	(0.0412)	(0.0359)	(0.0323)	(0.0288)	(0.0256)	(0.0234)	(0.0218)	(0.0209)	(0.0204)	(0.0204)	(0.0208)	(0.0216)	(0.0228)	(0.0250)	(0.0273)	(0.0304)	(0.0356)	(0.0437)
EPU	-0.00716	-0.00662	-0.00631	-0.00608*	-0.00584*	-0.00561**	-0.00540**	-0.00523**	-0.00507**	-0.00491**	-0.00475**	-0.00460**	-0.00446*	-0.00431*	-0.00410	-0.00391	-0.00369	-0.00337	-0.00289
	(0.00562)	(0.00454)	(0.00396)	(0.00357)	(0.00317)	(0.00283)	(0.00258)	(0.00241)	(0.00231)	(0.00225)	(0.00225)	(0.00230)	(0.00239)	(0.00252)	(0.00276)	(0.00302)	(0.00336)	(0.00393)	(0.00483)
10-Year Bond Yields * NEER	0.0798	0.0703*	0.0649*	0.0610**	0.0568**	0.0527**	0.0491**	0.0461**	0.0433**	0.0406**	0.0378*	0.0352*	0.0327	0.0300	0.0264	0.0232	0.0194	0.0137	0.00533
	(0.0490)	(0.0396)	(0.0345)	(0.0311)	(0.0277)	(0.0247)	(0.0225)	(0.0210)	(0.0201)	(0.0197)	(0.0196)	(0.0201)	(0.0208)	(0.0220)	(0.0240)	(0.0263)	(0.0293)	(0.0342)	(0.0421)
Observations	1,296	1,296	1,296	1,296	1,296	1,296	1,296	1,296	1,296	1,296	1,296	1,296	1,296	1,296	1,296	1,296	1,296	1,296	1,296

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 2: Panel Quantile Regression Estimates

6 Conclusion

Building on the growing literature on uncertainty and the macroeconomy, this paper offers two contributions.

Firstly, this paper proposed a conceptual framework to analytically view uncertainty shocks. Macro-behavioural frictions, specifically agents with rational inattention and bounded expectations, produce a prolonged slowdown in output, as unanticipated uncertainty shocks materialise. Moreover, the model indicates that central banks could employ communication-based unconventional monetary policy to anchor expectations when aggregate uncertainty rises, thereby providing countercyclical balances against output shortfalls. This framework appends the literature on uncertainty through a macro-behavioural lens, whereas the extant literature mainly views uncertainty in a neokeynesian framework, such as Leduc and Liu (2016) [28] and Jurado, Ludvigson and Ng (2015) [25] that characterises uncertainty shocks akin to demand shocks. From this paper's perspective, uncertainty shocks generate output responses through behavioural frictions, and also allows for policy responses that exploit these frictions to generate countercyclical responses.

Secondly, this paper provides an empirical analysis on the impact of uncertainty and exchange rate shocks in open economies.

The country-level exercise, focusing on Malaysia, in a max-uncertainty VAR framework due to Jackson, Kliesen and Owyang (2019) [23], finds that output, price and bond yield responses are broadly in line with the extant literature. Specifically, output and inflation moderate while yields fall, suggesting flight-to-safety in response to an uncertainty shock. In response to an exchange rate appreciation shock, output moderates, an expected response as exports become more expensive. Inflation moderates, reflecting likely cheaper imports from a stronger exchange rate. Bond yields fall, likely an implication of higher priced portfolio assets relative to that of other economies. Net employment gains and net output losses, taken together, indicate heterogeneity at the sectoral-level. Low productivity labour-intensive non-tradable sectors experience a boom from positive real income effects, prompting a larger expansion in labour hiring. However, output gains in the non-tradable sectors are offset by output losses in the higher productivity capital-intensive tradable sectors.

Taking the analysis to a panel of advanced and emerging economies, I find similar responses in a Bayesian panel VAR setting, except the response of bond yields, which suggests stronger risk aversion on average across the panel of countries. Output responses do not exhibit post-shock overshoots, in contrast to earlier studies. This may be due to two reasons. Firstly, key variables had undergone different transformation to overcome country-specific non-stationarity, which is likely absent in other country-level empirical studies. Secondly, the data covered heavily the later half of the 2010s, whereas the bulk of the uncertainty literature focused on the pre-GFC period and the early half of the 2010s. Dynamics may differ over the two periods.

Departing from structural analysis, I used a fixed effects setting to examine possible nonlinearities in the relationship between the exchange rate, uncertainty and output, as implied by the data. Interaction terms were selected by a shrinkage algorithm, the L1 norm — the LASSO, as per Tibshirani (1996) [36] and Ahrens, Hansen and Schaffen (2019) [4]. The model motivates the possibility of nonlinearities between risk aversion, the exchange rate and output. Finally, I examined the distributional dimension in a panel quantile regression setting, due to Machado and Silva (2018) [31]. While the interpretation of the findings were limited to statistical co-movements and not causal, they motivate further research on the distributional dimension in the output, uncertainty and exchange rate nexus.

A Appendix

A.1 GMM-Style Panel VAR with Alternate Ordering

The estimated responses of output and inflation to uncertainty shock are sensitive to the ordering of variables in the initial months. However, the path and direction of IRFs in the both the GMM-style and Bayesian pooled panel VAR, described in section 4.2 and 4.3 respectively, are relatively stable. A plausible explanation is that the ordering of variables used here do not reflect frictions underlying the transmission of uncertainty to output and price-setting behaviour. Hence, the model produces counterintuitive IRFs, at least in the initial months.

$$\textbf{Ordering: } \text{Uncertainty} \rightarrow \text{Output} \rightarrow \text{NEER} \rightarrow \text{Inflation} \rightarrow \text{Bond Yields} \tag{42}$$

Responses to a 1 S.D. Shock in Economic Policy Uncertainty Growth

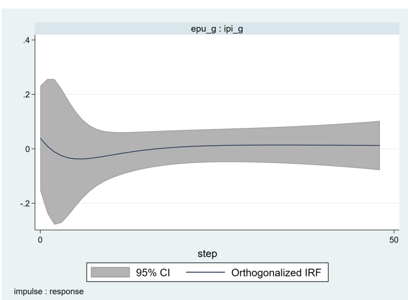

Figure 73: IPI Growth

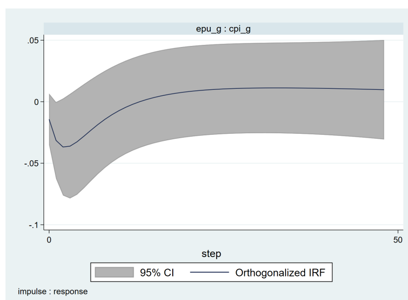

Figure 74: CPI Inflation

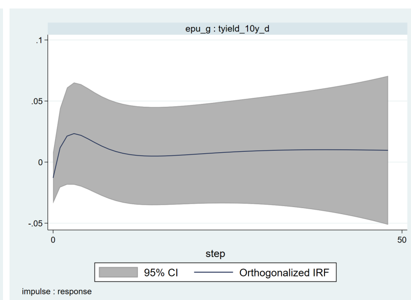

Figure 75: 10Y Bond Yields

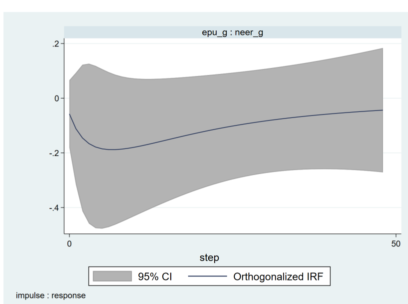

Figure 76: NEER Growth

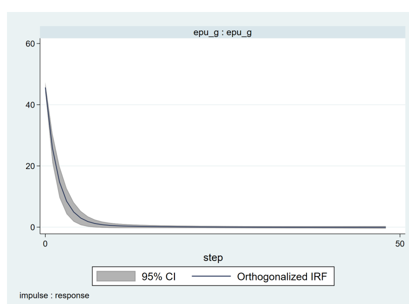

Figure 77: EPU Growth

Note: Solid lines show the median impulse response of respective variables to a +1.0 standard deviation shock in the annual growth of EPU. Shaded area represents the 95% confidence bands, estimated with 200 Monte Carlo draws using Gaussian approximation.

Responses to a 1 S.D. Shock in NEER Growth

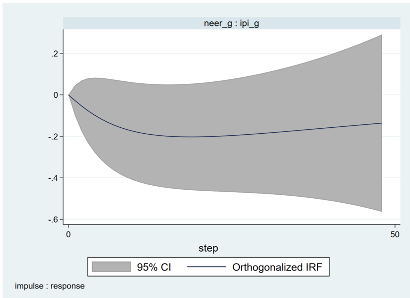

Figure 78: IPI Growth

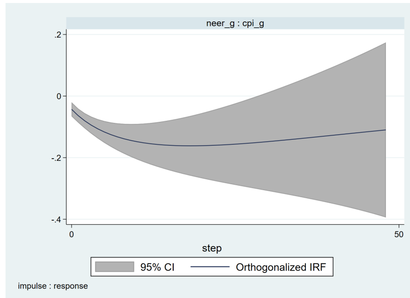

Figure 79: CPI Inflation

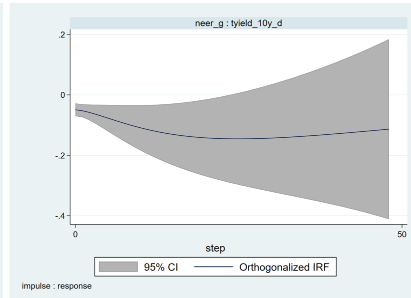

Figure 80: 10Y Bond Yields

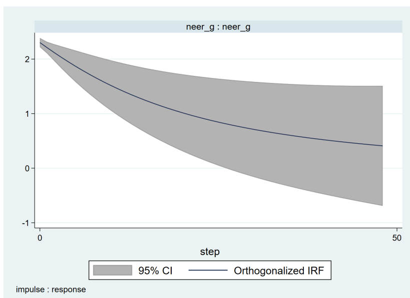

Figure 81: NEER Growth

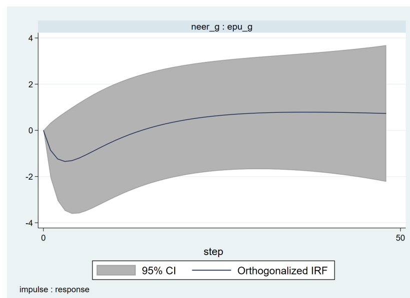

Figure 82: EPU Growth

Note: Solid lines show the median impulse response of respective variables to a +1.0 standard deviation shock in the annual growth of the NEER (appreciation). Shaded area represents the 95% confidence bands, estimated with 200 Monte Carlo draws using Gaussian approximation.

A.2 Bayesian Pooled Panel VAR with Alternate Ordering

Responses to a 1 S.D. Shock in EPU Growth

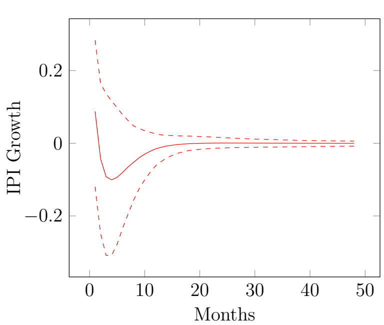

Figure 83: IPI Growth

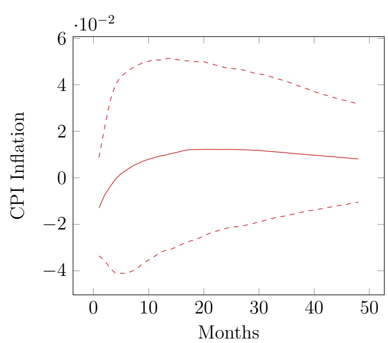

Figure 84: CPI Inflation

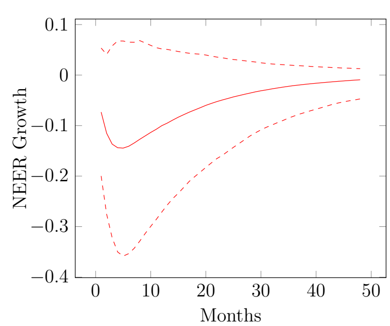

Figure 85: NEER Growth

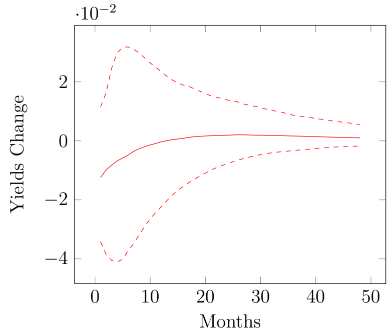

Figure 86: 10Y Yields Change

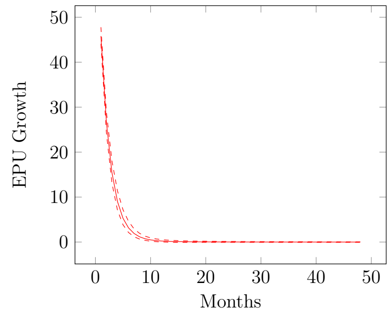

Figure 87: EPU Growth

Note: Solid lines show the median impulse response of respective variables to a +1.0 standard deviation shock in the annual growth of EPU. Dotted lines represent the 95% confidence bands.

Responses to a 1 S.D. Shock in NEER Growth

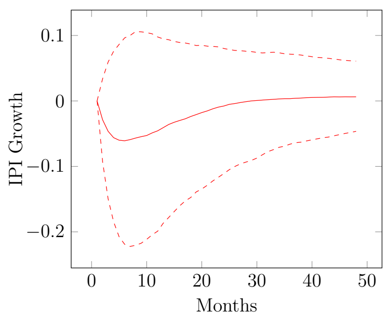

Figure 88: IPI Growth

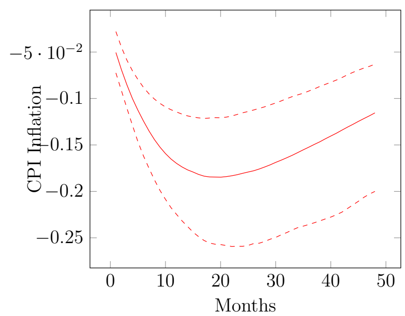

Figure 89: CPI Inflation

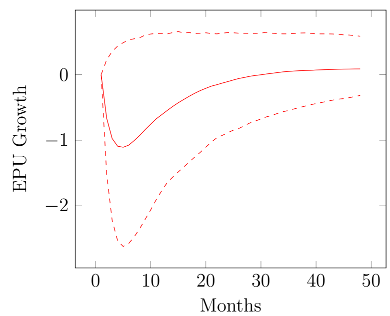

Figure 90: EPU Growth

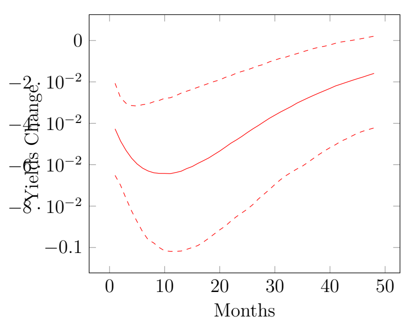

Figure 91: 10Y Yields Change

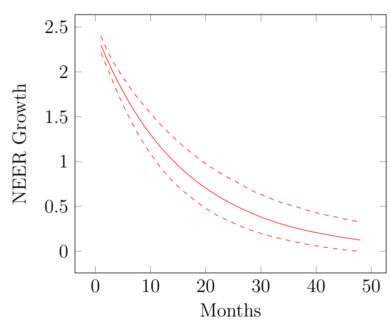

Figure 92: NEER Growth

Note: Solid lines show the median impulse response of respective variables to a +1.0 standard deviation shock in the annual growth of the NEER (appreciation). Dotted lines represent the 95% confidence bands.

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