The Macroeconomics Effects of the Carry Trade Unwind*

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Abstract

This paper examines the macroeconomic effects of the unwinding of the carry trade in a nonlinear TVAR model using the example of the JPY/AUD carry trade and the Australian macroeconomy. The model endogenously detects regimes of low and high pressure on the carry trade. In the high pressure regime where it is likely for the carry trade to unwind, the fall in the relative Australian interest rate combined with a reduction in commodity price inflation leads the economy to favorably respond with the fall in commodity prices boosting Australian GDP growth. This result confirms that the unwinding of the carry trade and the subsequent stimulus to exports is beneficial to Australian growth when international financial markets are at their most stressed. The probability of regime change is extremely low. However, large shocks in the high pressure regime correspond to a 30 percent probability of moving to a low pressure regime as the system corrects itself.

Keywords: carry trade, macroeconomy, VIX, risk aversion, Australia, Japan.

JEL Classification: E44, F31, Q02

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1 Introduction

Australia has not suffered a major economic downturn since 1992 as shown by Australia's GDP growth in Figure 1. This is despite several regional and global economic and financial market crises and its susceptibility to foreign shocks. Although the Australian equity market fell during the 2008 global crisis, it did not decline by as much as those of its non-commodity exporting peers. However, the Australian dollar plummeted as risk averse investors sought safe haven currencies and the carry trade was unwound (Ranaldo and Söderlind, 2010). This is also evident in Figure 1 which plots the JPY/AUD exchange rate and the VIX measuring risk aversion.[1] The dramatic currency collapse meant that exports did not decline in real terms, and is given as a reason that the fallout to economic growth was minimal (Makin, 2010). This paper aims to examine macroeconomic adjustment to the unwinding of the carry trade using the example of Australia and Japan which is the basis of the profitable JPY/AUD carry trade relationship.

The carry trade rests on the failure of the hypothesis of uncovered interest parity (UIP) which has long been a puzzle in economics (Fama, 1984; Hodrick, 1987; Froot and Thaler, 1990; Lewis, 1995; Engel, 1996). UIP states that assuming risk neutrality, interest rate differentials across countries should be offset by currency movements, equilibrating returns when converted to a common currency. The carry trade occurs when an investor borrows in a currency (funding currency) with low interest rates and then invests in an economy with high interest rates (investment currency). The failure of UIP allows profits to be made by following this strategy. The main challenge for investors wanting to profit from the carry trade strategy is its vulnerability to volatility and market shocks leading to a sudden unwinding of the carry trade relationship. To assess the macroeconomic impact of the carry trade unwinding, a nonlinear threshold vector autoregression model (TVAR) which allows for endogenous regime switching is estimated. The two regimes are one of low pressure on the carry trade and one of high pressure on the carry trade.

In practice it is difficult to precisely measure the aggregate carry trade (Gubler,

[1] In times of heightened risk aversion the Australian dollar tends to plummet dramatically as investors switch their portfolios to reflect safe haven currencies, usually the Swiss Franc, euro, pound, yen and the US dollar. This is evident in the panel of Figure 1 depicting the JPY/AUD exchange rate. Inspection of this series illustrates the sharp falls in the currency during crises including the 1987 stock market crash, the 1997-98 Asian financial crisis, the 2001 dot com collapse and during the 2008- global financial crisis.

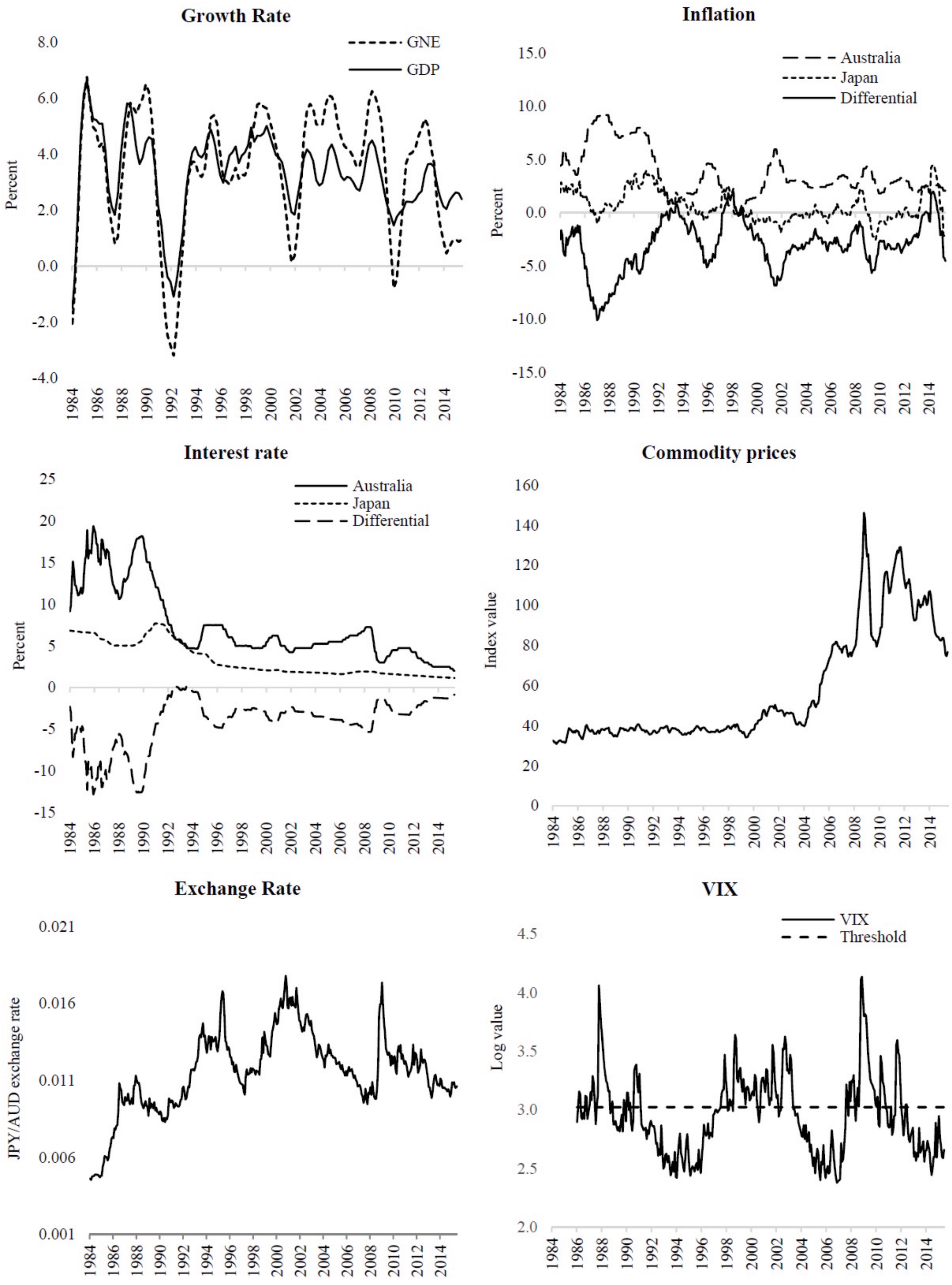

Figure 1: Australian and Japanese macroeconomic and financial market data and the VIX, January 1984 to June 2015.

2011). Some use proxies based on foreign exchange trading activity in futures markets particularly in the commodity sector (Brunnermeier, 2009; **?**). The Bank for International Settlements compiles some data but only for the banking sector. Other authors construct their own portfolios using rules based on sorting by currency forward discount rates and rebalancing (Lustig et al., 2011; Menkhoff et al., 2012; Dobrynskaya, 2014, amongst others). Here we don't try to directly provide a measure of the carry trade, rather we approximate it's unwinding using a range of variables indicative of the breakdown of the carry trade relationship.

Three candidate pressure concepts proxying the likelihood of the carry trade unwinding are examined based on work in the finance literature. The first is international investor risk aversion. Brunnermeier (2009) examine the relationship between the unwinding of the carry trade and sudden crashes in exchange rates and link this to international investor risk aversion as measured by the Chicago Board Options Exchange Market Volatility Index (the VIX) as well as to illiquidity. Engel and West (2010) is consistent with Brunnermeier (2009) and the role for risk aversion when decomposing the real US exchange rates respectively into the real long run interest rate and risk premium components. The correlation between the real interest-rate differential and the real value of the dollar is strongest when the long run real interest rate differential is highly positively correlated with the risk premium.[2] They find that most of the movements arise from the risk premium component under an assumption of 'no-bubbles forward'. Although investment currencies are not examined, their result implies the existence of a threshold where a carry trade would unwind (see also Fong (2010)).

Second, Engel (1996), Chinn (2006) and Anzuini and Fornari (2012) show that periods of low exchange rate volatility are particularly conducive for carry trade activity, while Clarida et al. (2009), Melvin and Taylor (2009), Christiansen et al. (2011) and Menkhoff et al. (2012) find that carry trade returns tend to unwind dramatically as exchange rate volatility increases which again suggests a threshold. Gonzalez-Hermosillo et al. (2011) and Rey (2015) find that an unwinding of the carry trade is unlikely in a low exchange rate volatility regime.

Third, one of the contributions of Brunnermeier (2009) is to recognize the role of higher order moments in the relationship between the carry trade and exchange rate. That is, high interest rate differentials are associated with negative skewness of invest-

[2]Engle and West (2010) is one of the few papers to condition such a model on macroeconomic variables, capturing output gaps and Phillips curves by including relative inflation and unemployment rates as well as commodity price inflation.

ment currency returns. Negative skewness reflects that these particular currencies on average have high returns, but that there is a possibility of large losses.[3,4] The unwinding occurs with negative skewness through funding constraints. More recently, Bekaert and Panayotov (2016) find that if the currencies of Australia, Japan and Norway are excluded from analysis of the carry trade, arguments for the role of skewness and crash risk in understanding carry trade returns are invalidated as these currencies dominate and induce skewness into the statistics. Since Australia and Japan are the focus of this paper the role of skewness and crash risk is still relevant. Drawing on this literature, the three threshold variables considered are: i) the VIX (Brunnermeier, 2009; Engel and West, 2010) which is taken as the benchmark case; ii) the JPY/AUD exchange rate volatility (Clarida et al., 2009); and iii) JPY/AUD exchange rate skewness (Brunnermeier, 2009).

The empirical evidence on the macroeconomic effects of the unwinding of a carry trade is relatively scarce and there is no consensus on the overall macroeconomic effects or even if indeed the effects are positive or negative (Bussiere et al. 2010 provide a comprehensive overview). Anzuini and Fornari (2012) incorporate macroeconomic variables into a model of the carry trade, but with the focus on the effects of the macroeconomy on the carry trade. They find that demand and confidence shocks are important drivers of the carry trade. Bussière et al. (2010) find that currency unwind actually leads to positive output growth. The model most similar to the one here is Gubler (2011) who use a TVAR for the carry trade and the macroeconomy, but the macro variables are limited to those that are measured at a relatively high frequency such as interest rates. Other related work focuses on either the effects of large devaluations (Burstein et al., 2007; Alessandria et al., 2010), the dynamics of currency crises (Eichengreen and Sachs, 1986; Eichengreen et al., 1995; Obstfeld, 1996; Kaminsky et al., 1998; Hartmann et al., 2010), the macroeconomic recovery of crisis countries (Borio, 2014; McKinnon, 2012) or the role of large shocks to the carry trade for international trade (Ready et al., 2013).

The main contribution of this paper is to investigate four questions: (i) what are

[3] Note that the literature generally talks about the sign of skewness for the exchange rates relative to the US dollar. That is, as a funding currency the USD/JPY should have positive skewness. As the investment currency the USD/AUD should have negative skewness. In this paper the exchange rate is expressed in terms of JPY/AUD so the sign of skewness in the carry trade relationship should be negative.

[4] Other financial market models that emphasize higher order moments in explaining asset returns include Harvey and Siddique (2000), Hwang and Satchell (1999), Clarida et al. (2009) and Jondeau and Rockinger (2009).

the macroeconomic effects of shocks in the VIX during a period of low pressure on the carry trade?; (ii) what are the macroeconomic effects of shocks in the VIX during a period of high pressure on the carry trade?; (iii) do shocks of different magnitudes have asymmetric effects on the real economy in the low and high pressure regimes?; and (iv) what is the probability of the macroeconomy transitioning between a low pressure regime to a high pressure regime and vice versa under various shock scenarios? Sensitivity to the alternative threshold concepts of currency market volatility and skewness is also examined and shocks to the interest rate differential are also assessed.

The main findings are as follows. In the low pressure regime, large shocks to the VIX have a contractionary effect on domestic demand growth and smaller effects on GDP growth in comparison to the normal sized shocks. In the high pressure regime where it is likely for the carry trade to unwind, the fall in the Australian interest rate relative to Japan combined with a reduction in commodity price inflation leads the economy to favorably respond with the fall in commodity prices boosting Australian production. This result confirms that the unwinding of the carry trade and the subsequent stimulus to exports is beneficial to Australian growth when international financial markets are at their most stressed.

Second, the probability of switching from a low pressure regime to a high pressure regime is a rare event, with the probability of switching being 3 percent. However, the probability of moving to a low pressure regime from a high pressure regime is much more likely, indicating the ability for the system to correct itself. A two standard deviation shock to the VIX in the high pressure regime corresponds to a 30 percent probability of moving to a low pressure regime, while the one standard deviation sized shock results in a 15 percent probability.

Finally, a shock to the interest rate differential shows evidence of supply side constraints emanating from the global economy, with the cost channel of monetary policy operating as increased borrowing costs raise the cost of producing and investing, leading to a rise in the inflation differential, a reduction in commodity price growth which contributes to the reduction in Australian demand and production growth.

The rest of the paper is organized as follows. Section 2 presents the model specification with a focus on describing the data and background, and outlines the TVAR framework including the calculation of the impulse response functions and the probabilities of regime switching. Section 3 presents the empirical results, focussing on the effects of shocks in the low pressure and high pressure regimes. Section 4 contains the conclusion.

2 Model specification

The adopted TVAR model has three main elements. First, the specification of the TVAR model allows switching between two regimes. The regimes are where the carry trade relationship is sustained (the low pressure period) and where the carry trade relationship is likely to unwind (the high pressure period). Second is that the regimes are separated by a boundary that is equal to a value of a threshold variable indicating the point that the carry trade is estimated to break down. Third is in the construction of a data set that reconciles the financial market aspects of the model (the carry trade unwind) with the real macroeconomy aspects. The rest of this section outlines the dataset and the specification of the TVAR as well the calculation of the nonlinear impulse responses and the probabilities of switching between regimes.

2.1 Background and Data

The choice of variables is motivated by previous theoretical and empirical research on the carry trade and the Australian macroeconomy. The carry trade rests on the failure of UIP which predicts that the return on an investment in foreign currency should be the same as that denominated in domestic currency as the exchange rate will adjust to equilibrate returns. This is often expressed as $E_t\left[z_{t+1}\right]=0$ where z_{t+1} is the return on a foreign currency investment, and $z_{t+1}=(r_t^*-r_t)-\triangle e_t$, or the difference between foreign and domestic interest rates adjusted by the change in the exchange rate ($\triangle e_t$). Drawing on the role of risk aversion in explaining why the UIP relationship does not always hold (Brunnermeier, 2009; Clarida et al., 2009; Engel and West, 2010), the variables reflecting the carry trade relationship in the TVAR model are the interest rate differentials $r_t^J-r_t^A$ between Japan and Australia as well as the threshold variable s_t which reflects investor risk aversion. The threshold variable demarcates the low and high pressure regimes and is either the log of the VIX, the volatility of the JPY/AUD nominal exchange rate, or the skewness of the JPY/AUD nominal exchange rate.

There are several characteristics of the Australian economy that set it apart. Australia, along with Canada and New Zealand are different to most developed countries in that being major suppliers of several key commodities they are heavily dependent on commodity markets. Most commodity exporting countries tend to be emerging markets. Australia supplies about 45 percent of global iron ore, while iron ore exports are 5 percent of Australia's GDP.

At the same time, Australian interest rates have been high relative to other developed markets, a feature argued to be because of the commodity based nature of the economy (Ready et al., 2013). These factors combine to make the Australia dollar the best example of a carry trade recipient country, particularly relative to the Japan with it's virtually zero interest rate policy (Galati et al., 2007; Liu et al., 2012). The Australian dollar as a carry trade target is reflected in the foreign exchange statistics. The Australian dollar is the fifth most traded currency with a daily average foreign exchange turnover of USD632mn in 2013 (Bank for International Settlements, 2014). This equates to around 11.8 percent of total daily foreign exchange turnover, whilst for perspective, Australian GDP is 1.6 percent of world GDP (International Monetary Fund, 2016).

The dataset (Y_t) for the TVAR consists of $n = 6$ variables of commodity price inflation expressed in Australian dollars (pc_t), Australian real domestic demand growth (GNE_t), Australian real GDP growth (GDP_t), the differentials between Japanese and Australian inflation $\left(\pi_t^J - \pi_t^A\right)$ and interest rates $\left(r_t^J - r_t^A\right)$ as well as an indicator of foreign investor risk aversion denoted s_t, such that

$$Y_t = \left\{pc_t, GNE_t, GDP_t, \pi_t^J - \pi_t^A, r_t^J - r_t^A, s_t\right\}.$$

The sample period ranges from January 1984 to June 2015 with the starting point coinciding with the floating of the Australian dollar. Detailed information on the data sources are contained in Appendix A, and Figure 1 contains plots of the data.

The commodity price variable is the monthly Reserve Bank of Australia index of commodity prices which is converted to a commodity inflation series (pc_t) by taking the year on year log difference. Commodity markets are an indicator of Australian inflation, and the interest rate as well as currency movements and are hence an indicator for the carry trade relationship. Commodity variables are routinely included in SVAR models for Australia in some form (Berkelmans, 2005; Lawson and Rees, 2008; Dungey et al., 2013; Jääskelä and Smith, 2013), and the commodity based nature of the Australian economy is also one of the reasons that domestic demand as well as production are usually included in Australian macroeconomic SVAR models as the trade balance (approximately the difference between GNE and GDP) is an important factor in determining Australian macroeconomic outcomes (Dungey and Pagan, 2000).

On the monetary side, the inflation differential $\left(\pi_t^J - \pi_t^A\right)$ is included in the dataset as an indicator of the relative stance of monetary policy in the two countries. In the presence of financial market imperfections, the interbank overnight cash rates r_t^J and r_t^A are used as a proxy to capture the premium for external finance which may be linked to restrictions in the supply of credit in the market (Brunnermeier, 2009; Engel and West, 2010). The interbank overnight cash rate is preferred to other market interest rates as carry trade investments are usually made in liquid, short-terms assets. Moreover, the low default rates on interbank overnight borrowings makes it a close substitute for treasury bills.

A challenge in estimating this model is in reconciling the unwind of the carry trade which is most evident in high frequency data, with the macroeconomy which is usually measured at a lower frequency. For Australia, the key macroeconomic variables of domestic demand, GDP and inflation are available at the quarterly frequency. A compromise on data frequency needs to be made to capture both the financial market elements of the carry trade and the macroeconomy, as the sudden movements in the carry trade are diluted when examined on a quarterly basis. The compromise adopted is to express all data on a monthly basis.

The three alternative investor risk aversion series (s_t) of the VIX, nominal JPY/AUD exchange rate volatility and nominal JPY/AUD exchange rate skewness are originally available on a daily basis. The VIX is converted to a monthly series by taking the average of the data over the month. The JPY/AUD exchange rate data are the mid-points of the buying and selling rates quoted at 4:00 p.m. Sydney time on each trading day. Exchange rate volatility is the standard deviation of the daily nominal exchange rate calculated over a 21 day rolling window and then averaged over a month to obtain the monthly average JPY-AUD exchange rate volatility variable. Similarly, nominal exchange rate skewness is calculated over a 21 day rolling window and then averaged over the month. The VIX version of s_t is displayed in the bottom panel of Figure 1, while exchange rate volatility and skewness are shown in Section 3.4.

The data series available in quarterly frequency of Australian GNE, GDP and inflation are interpolated into monthly series by using the Kalman filter following Mariano and Murasawa (2010) and Kuzin et al. (2011). Figure 2 plots the log of the quarterly and interpolated monthly versions of these series.

The monthly data consists of the commodity price index, the Japanese consumer price index and the Australian and Japanese interbank overnight cash rates. All vari-

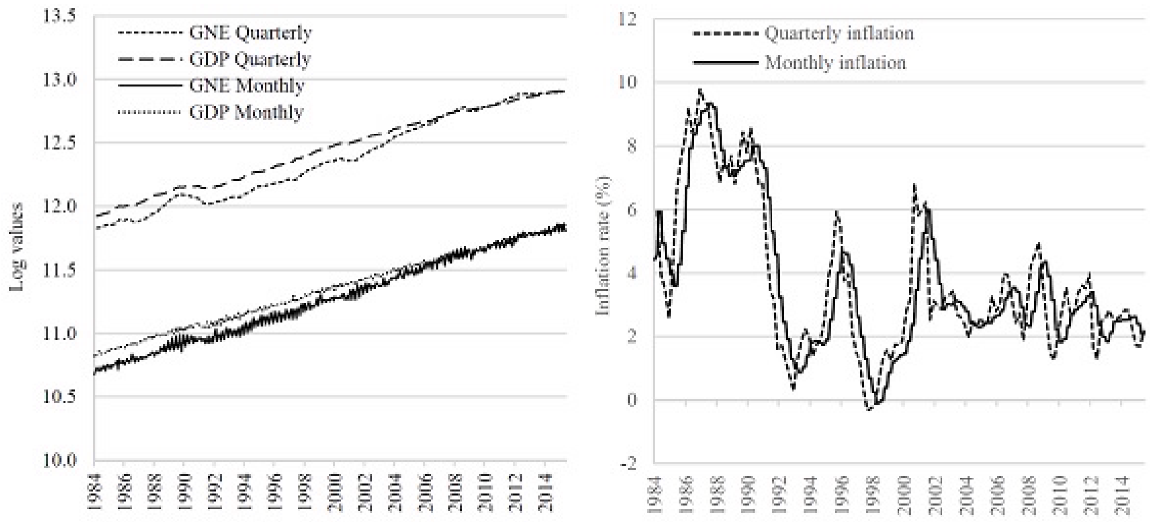

Figure 2: The quarterly Australian domestic demand, domestic production and inflation series plotted against the monthly interpolation.

Table 1

Lag length selection tests (VAR model)

Lag	Log-likelihood	LR	AIC	HQIC	SBIC
0	-766.69		4.132	4.157	4.195
1	4,275.82	10,085.00	-26.682	-26.357	-25.864
2	5,067.55	1,583.50	-26.638	-26.163	-25.442
3	5,095.32	55.543	-26.629	-26.004	-25.055

ables are made stationary prior to the estimation of the TVAR. The commodity price index, GNE, and GDP are in percentage log-deviations from a deterministic trend that is computed using the HP filter. The inflation rate and the interest rate differentials are in percentage form.

The lag length of the TVAR model based on the empirical data set is one lag, as determined by the Akaike information criterion (AIC), Hannan-Quinn information criterion (HQIC) and Schwarz-Bayesian information criterion (SBIC) as shown in Table 1.

2.2 TVAR framework

The TVAR describes the evolution of the dataset Y_t in regime 1 where there is low pressure on the carry trade relationship and regime 2 where there is high pressure on the carry trade whereby

$$Y_t = B_1 + \gamma_1(L)Y_t + (B_2 + \gamma_2(L)Y_t)I(s_{t-d} > \theta) + \varepsilon_t. \quad (1)$$

The regime specific coefficients are denoted by B_1, γ_1 for the low pressure regime and B_2, γ_2 are the increments to the coefficients in the high pressure regime. The indicator function I denotes the regime, with $I = 1$ if the value of the threshold variable (s_t) at lag order d is greater than the threshold value θ indicating a high pressure regime, and 0 otherwise. If s_t crosses the value of the threshold variable, θ at time $t - d$, the dynamics change at time t. The lag polynomials $\gamma_1(L)$ and $\gamma_2(L)$ describe the dynamics of the TVAR system.

By construction, the TVAR model allows for heretoskedasticity as the process within each regime is alternatively depicted in equation (2) as

$$Y_t = B_1 + \gamma_1(L)Y_t + \varepsilon_{1,t} + (B_2 + \gamma_2(L)Y_t + \varepsilon_{2,t})I(s_{t-d} > \theta), \quad (2)$$

with $\varepsilon_{1,t}$ and $\varepsilon_{2,t}$ depicting the error terms specific to the low and high pressure regimes respectively.

2.3 Nonlinear impulse response functions

Impulse responses can be calculated to examine the economic responses to shocks in the model for each regime. However, a second set of impulse response functions incorporating the nonlinear elements of the model can be computed by relaxing the assumption that the economy remains in the same regime prevailing at the time of the shock, allowing the regime switching to be endogenous as in Koop et al. (1996). The nonlinear impulse response functions are the focus of the analysis. The nonlinear impulse response functions are defined for variable y at horizon n as the differences between conditional expectations once a shock (e_t) is known compared to when it is unknown as follows

$$IRF_y(n, e_t, \Omega_{t-1}) = E[y_{t+n}|\Omega_{t-1}, e_t] - E[y_{t+n}|\Omega_{t-1}], \quad (3)$$

where the information set of the size and sign of the shock and the initial conditions of the regime that the economy is starting in, Ω_{t-1}, are required to calculate the impulse responses.

Following Koop et al. (1996), the conditional expectations $E[y_{t+n}|\Omega_{t-1}, e_t]$ and $E[y_{t+n}|\Omega_{t-1}]$ are computed by simulating the model. First, a positive shock to s_t is simulated for periods 0 to 300 using the Cholesky decomposition of the variance-covariance matrix for the TVAR model. For given initial values of the variables, these shocks are fed through the estimated model to produce a set of simulated data series. The result from this step is a forecast of the variables conditional on initial values and a particular sequence of shocks, denoted as the baseline forecast. Second, the same procedure is repeated with the same set of initial values and shocks, with the shock to the variable in period 0 fixed at one standard deviation. The shocks are then fed through the model to obtain a forecast of the variables. The impulse response function for a set of initial values and particular sequence of shocks is then the difference between this forecast and the baseline forecast. This simulation is repeated for 500 draws of the shocks to allow the shocks to average out. Subsequently, these impulse response functions are averaged over the respective regime history to produce an impulse response function conditional only on initial values. To compare the normal sized (one standard deviation) shocks with a large shock, the process is repeated for a two standard deviation sized shock. Appendix B provides information on the algorithm used to compute the nonlinear impulse response functions.[5]

2.4 Probability of regime switching

The likelihood of a regime switching taking place between the low and high pressure regimes given a positive shock to the threshold variable can also be calculated. The probability of the economy being in the low pressure regime given the information set Ω_{t-1}, and a particular realization of an exogenous shock e_t at time t is denoted as

$$P(low) = P[I(s_{t-d} \leq \theta)|\Omega_{t-1}, e_t]. \tag{4}$$

Similarly, the probability of the economy being in the high pressure regime under the same conditions is denoted as

$$P(high) = P[I(s_{t-d} > \theta)|\Omega_{t-1}, e_t]. \tag{5}$$

The impulse response functions of the threshold variable are calculated for each observation in the initial regime. The probability of regime switching is estimated

[5] The regime dependent impulse response functions are not the focus of this paper but are presented in Appendix C for completeness.

by calculating the number of times the switching variable crosses the threshold value in the data. Accordingly, the probabilities of regime switching to take place for the economy starting in the low and high pressure regimes can be computed as

$$P(low) = \frac{1}{n}\sum_{i=1}^{n}[I(s_{t-d} \leq \theta)|\Omega_{t-1}, e_t], \tag{6}$$

and

$$P(high) = \frac{1}{n}\sum_{i=1}^{n}[I(s_{t-d} > \theta)|\Omega_{t-1}, e_t], \tag{7}$$

respectively.

3 The macroeconomy and the carry trade unwind

A condition for the carry trade unwind in the TVAR model is that the VIX has crossed the threshold and is in the high pressure state. A further feature of the model is that apart from depending on the initial state, the impulse response functions also depend on the magnitude and sign of the shocks. Thus, the aspects of the model most interesting for the analysis of the unwinding of the carry trade are the impulse responses for a large positive shock to the VIX in the high pressure state. However, prior to examining these effects in Section 3.2, it is pertinent to first examine the effects of a normal and a large shock to the VIX in a low pressure regime. Section 3.1 presents these results. Section 3.3 then examines the probability of switching between the low and high pressure regimes given an initial shock size, while Section 3.4 considers shocks to the alternative threshold variables (s_t).

3.1 Low pressure regime

A normal shock is defined to be a one standard deviation shock and a large shock is a two standard deviation shock. The impulse responses comparing the one and two standard deviation increase in the VIX when the initial state is a low pressure regime are shown in Figure 3, with the solid line corresponding to the one standard deviation impulses and the dashed line corresponding to the two standard deviation impulses.[6] The impulse responses of the two standard deviation shocks are scaled down by a factor of two in order to allow direct comparison with the responses to the one standard deviation shock.

[6] Negative shocks are not considered in this paper although the non-linear framework allows non-symmetrical impulse response to a negative shock compared to a positive shock.

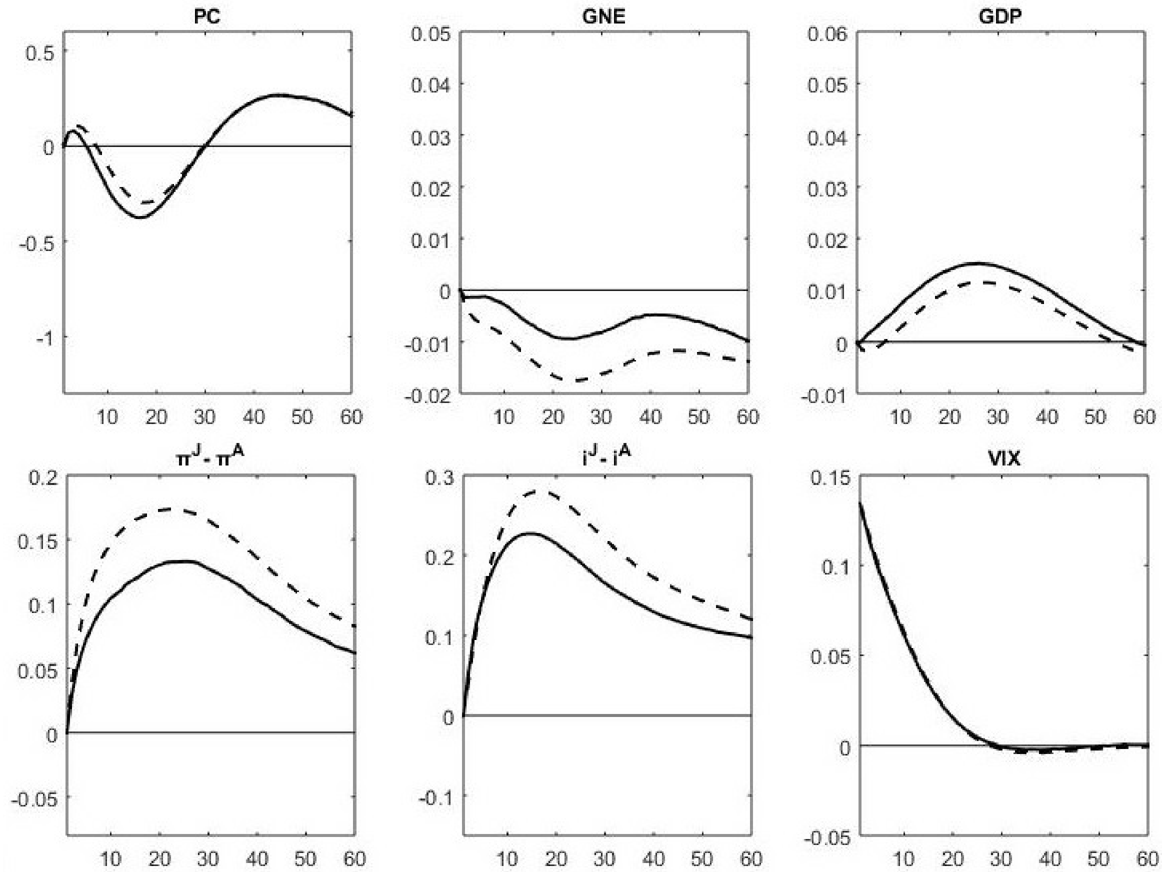

Figure 3: Comparison of shock size in the low pressure regime. Nonlinear impulse responses to a 1 standard deviation (solid line) and a 2 standard deviation (dashed line) shock to the VIX.

A one standard deviation shock to the VIX with the economy in the low pressure regime leads to an expansion in the interest rate differential between Japan and Australia. Given the increase in investor risk aversion, investors prefer safer assets resulting in a move to reverse higher risk investments such as those in Australia relative to Japan. This reversal has several effects. First, it increases relative borrowing costs given credit market imperfections (Brunnermeier, 2009; Menkhoff et al., 2012), as reflected in the expanding interest rate differential. Second, commodity prices inflation falls shortly thereafter which has the effect of increasing the Japanese-Australian inflation differential likely through a fall in Australian consumer prices. However, the fall in commodity price growth boosts growth in Australian production growth (GDP) as exports respond to declining commodity price inflation. It takes about four years for commodity prices inflation to recover before continuing to rise for a further two years and then returning to baseline. Domestic demand growth (GNE) rises simultaneously with the increase in national income from the export stimulus before domestic demand preferences abate, switching away from consuming imports after around two years.

The large shock in the low pressure regime as shown by the dashed line in Figure 3 reflects most of the dynamics of the one standard deviation shock. The main exception is in the response of domestic demand (GNE) and production (GDP) growth. Domestic demand growth declines faster in response to the two standard deviation shock to the VIX while the growth in GDP is more muted compared to its response to the smaller shock. With the difference between domestic demand and production reflecting the trade balance, the difference in adjustment between the two sized shocks is through a sustained fall in the growth of domestic demand and through the rise in exports in the external sector for the larger shock. The fall in domestic demand in response to the large shock is to be the main explanation of the relatively lower GDP growth outcome for the larger shock compared to the smaller shock.

3.2 High pressure regime

The carry trade unwinding is illustrated by a large shock to the VIX when the economy begins in a high pressure regime is shown in Figure 4. The figure also contains the impulse responses for the case of a normal sized shock. As before, the impulse responses of the two standard deviation shocks are scaled down by a factor of two.

In the high pressure regime there are distinct differences between the impulse re-

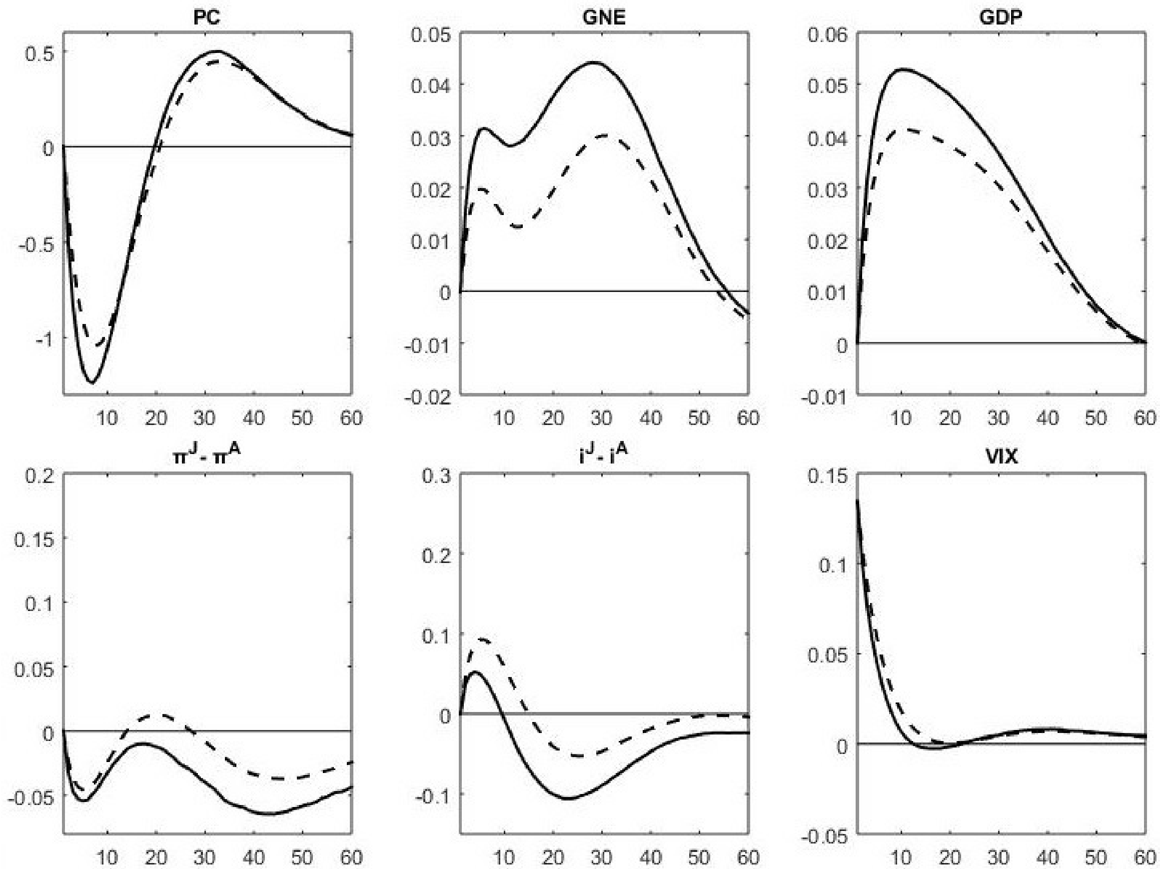

Figure 4: Comparison of shock size in the high pressure regime. Nonlinear impulse responses to a 1 standard deviation (solid line) and a 2 standard deviation (dashed line) shock to the VIX.

sponse functions for the normal and large magnitude shocks to the VIX, particularly for the the response of the interest rate differential. For the smaller shock the increase in investor risk aversion results in an increase in the interest rate differential between Japan and Australia which is also consistent with the response to the normal and large shocks in the low pressure regime. As before, investors reverse their investments in preference for safety, putting pressure on international borrowing costs resulting in a wider interest rate differential. In contrast, when there is a large shock and a more substantial increase in risk aversion during a high pressure period, this effect is still evident, but only for a very short period of time of around 6 months. The dominant effect is for a large fall in the interest rate differential, presumably as the Australian interest rate falls by more than the increasing upward pressure on world interest rates as the Australian economy responds more strongly to the anticipated effect of the reduction in commodity prices than when the shock is of a smaller magnitude. The inflation differentials respond commensurately to the interest rate diffentials in both cases. Again, in response to both the normal sized and large shocks, the fall in commodity price growth boosts growth in Australian production (GDP) as exports respond to declining commodity price inflation. In contrast to the low pressure regime, domestic demand growth (GNE) remains positive in response to the shocks of both magnitude.

To gain further insight into the effects of the carry trade unwinding on the Australian macroeconomy, Figure 5 illustrates the information presented so far in a different manner. Figure 5 compares the effects of a large shock in the low and high pressure regimes to compare the magnitude and direction of the responses. The solid line illustrates the two standard deviation shock to the VIX in the low pressure regime, while the dashed line illustrates the two standard deviation shock to the VIX in the high pressure regime. The impulse response functions show that the responses of all variables to the large shocks are magnified in the high pressure regime. In particular, the important response is the commodity price inflation fall in the high pressure regime which has a significant effect on domestic demand and production. This result confirms that the carry trade unwind and the subsequent stimulus to exports is beneficial to Australian growth when international financial markets are at their most stressed.

3.3 Probability of regime switching

Figure 6 presents the estimated empirical probability of transitioning from the low pressure to the high pressure regime and vice versa under three scenarios for shocks

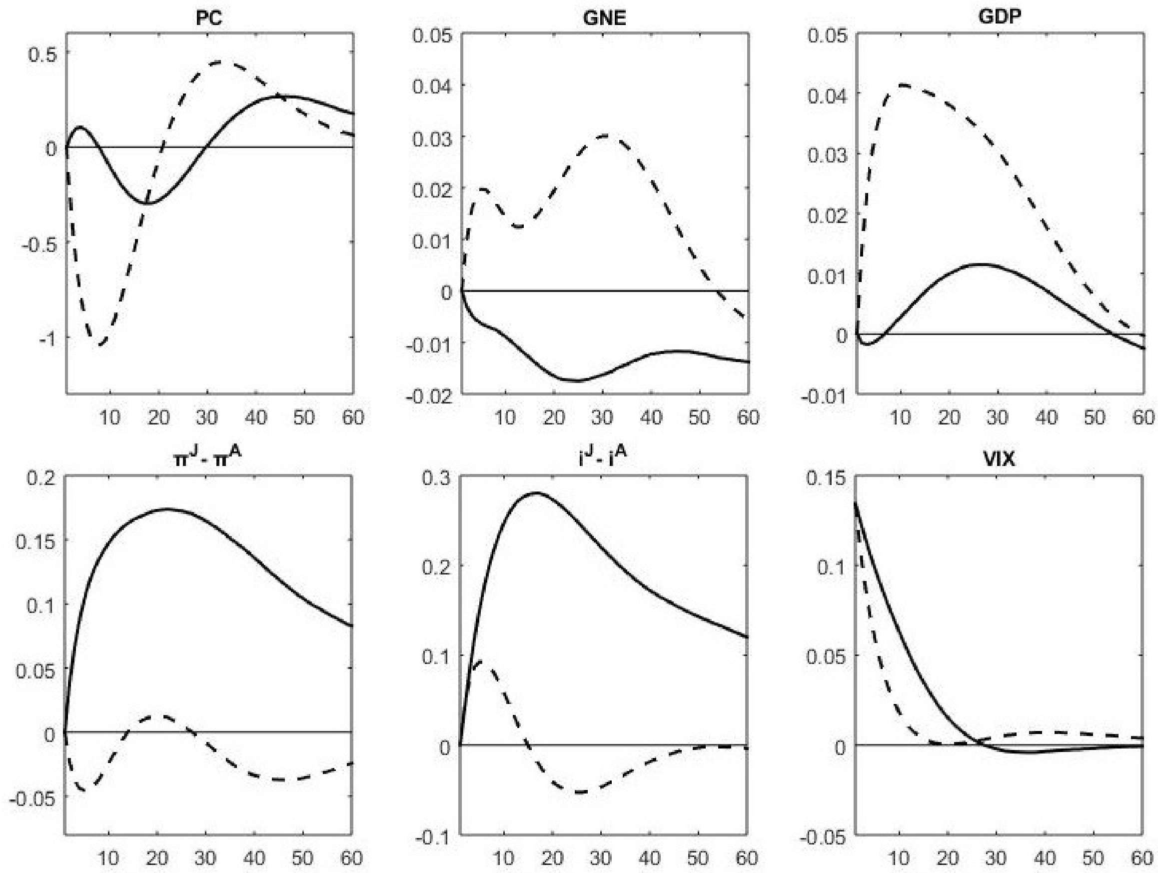

Figure 5: Nonlinear impulse responses to a 2 standard deviation shock to the VIX in the low pressure (solid line) and the high pressure (dashed lines) regimes.

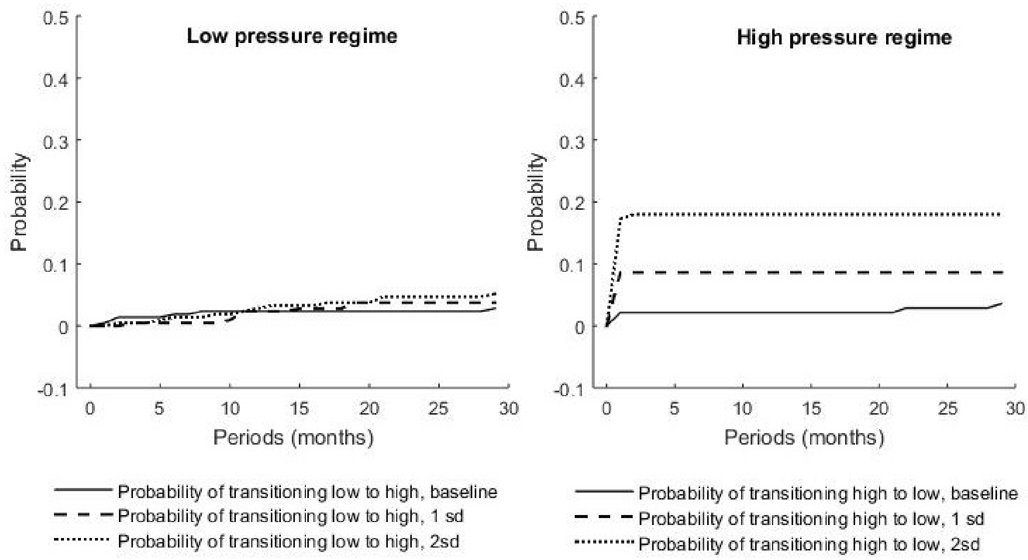

Figure 6: The empirical probability of switching from the low pressure regime to the high pressure regime and from the high pressure regime to the low pressure regime.

to the VIX. These are: i) the baseline case of no shock to the VIX; ii) a one standard deviation shock to the VIX; and iii) a two standard deviation shock to the VIX. Regime changes in the carry trade relationship between Australia and Japan are infrequent events, so it is anticipated that the probability of transitioning across regimes will be small. This is indeed the case. The probability of remaining in the low pressure regime rather than moving to the high pressure regime when in the low pressure regime is 97 percent. Accounting for shocks regardless of the size does not change this magnitude by any significant amount.

The estimated empirical probabilities of transitioning from the high pressure regime to the low pressure regime are plotted in the second panel of Figure 6. In contrast to the low pressure regime, the magnitude of the VIX level shocks does have an impact on the probability of regime switching from the high to the low pressure regimes. A two standard deviation shock to the VIX in the high pressure regime corresponds to a 30 percent probability of moving to a low pressure regime, while the normal shock results in a 15 percent probability. The baseline case (with no shocks) of switching from a high pressure regime to a low pressure regime is small at around 2 percent. The system is more likely to correct itself following large shocks in the high pressure regime, than it is to move from a stable system to the high pressure regime. This is consistent with the analysis of Melvin and Taylor (2009) of the crisis in the foreign exchange market

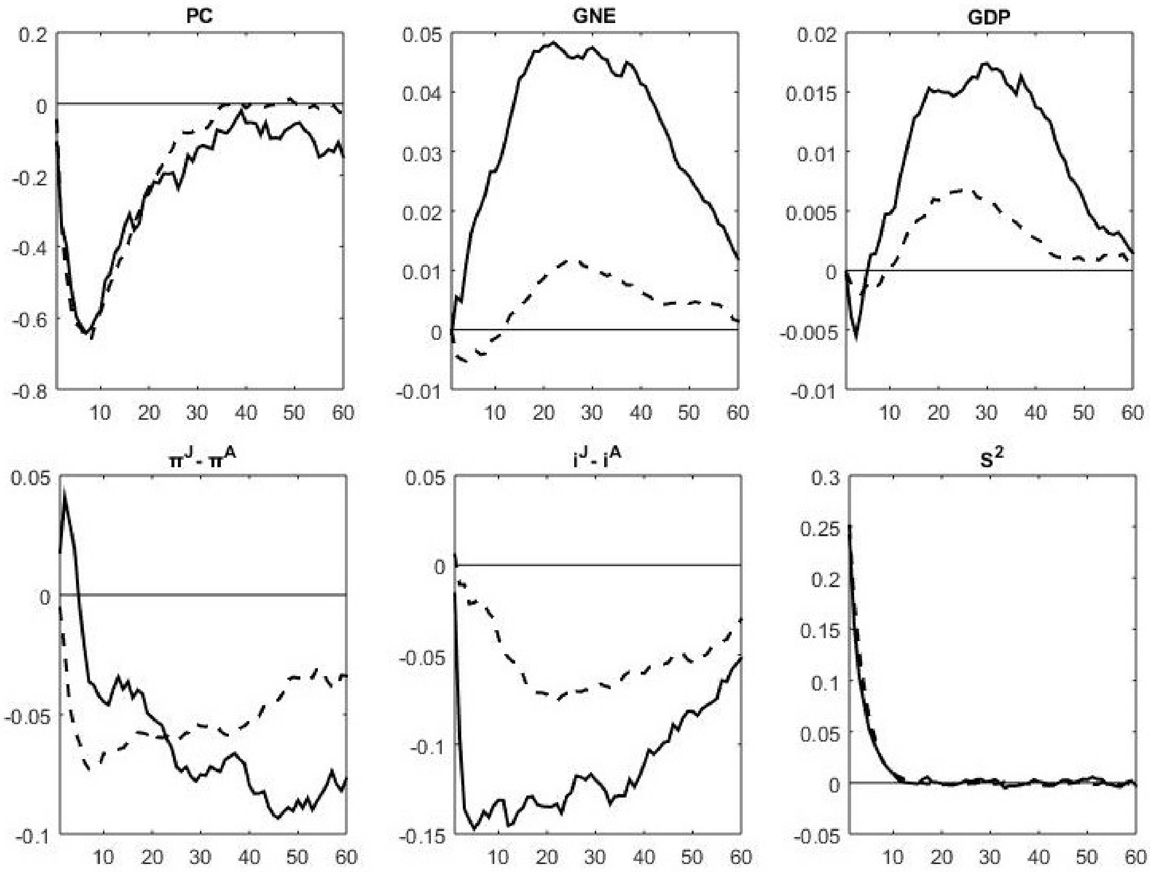

Figure 7: Comparison of shock size in the high pressure regime. Non linear impulse responses to a 1 standard deviation (solid line) and a 2 standard deviation (dashed line) shock to exchange rate volatility.

from 2007 onwards. They emphasize the role of the carry trade and the brevity of the unwinding of the carry trade observed despite high levels of risk aversion in the crisis period.

3.4 Alternative thresholds for the carry trade unwind

This section replaces the VIX index as the s_t variable in the TVAR with the alternative variables. Figures 7 and 8 present the comparisons of the normal and large shocks in the high pressure regime respectively for the alternative measures of the volatility of the JPY/AUD exchange rate followed by the skewness of the JPY/AUD exchange rate. These figures are comparable to Figure 4 which contains the corresponding impulse response functions for the model using the VIX variable in the high pressure regime. Again, the two standard deviation shocks are scaled to allow comparison with the one

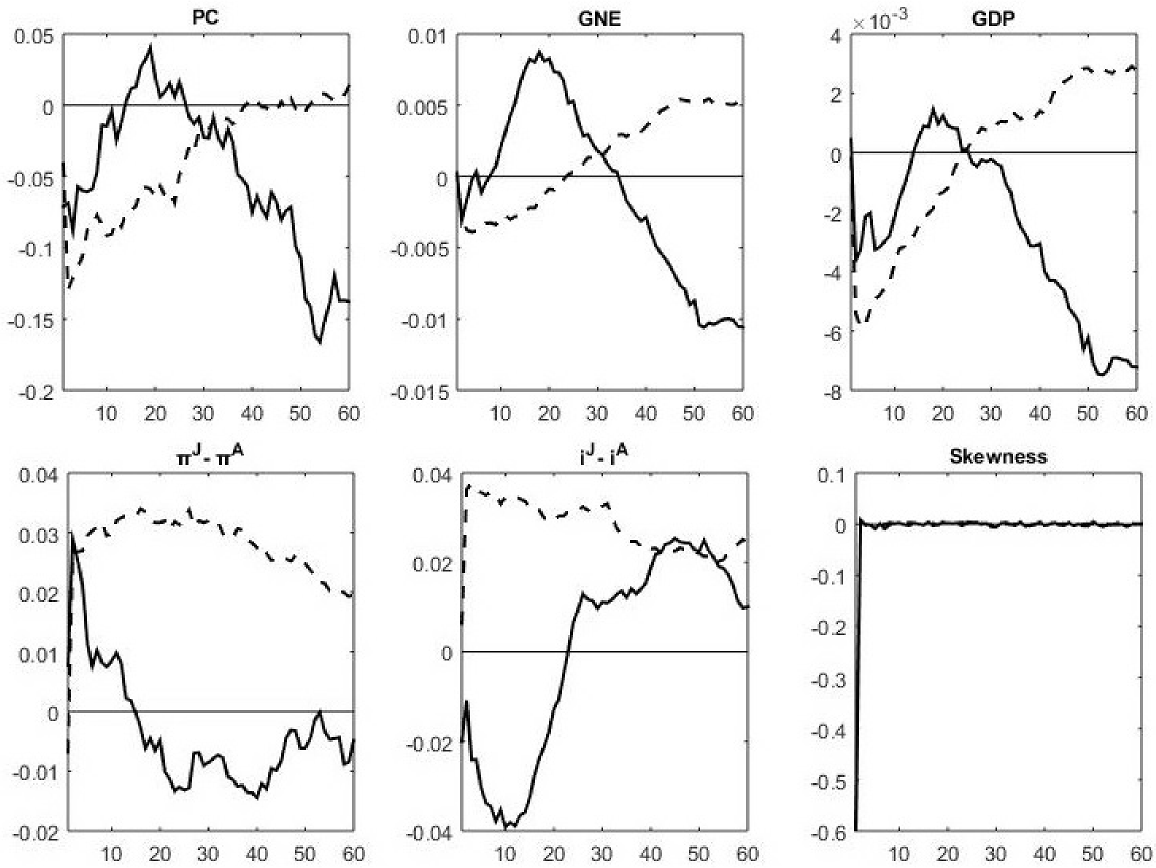

Figure 8: Comparison of shock size in the high pressure regime. Non linear impulse responses to a 1 standard deviation (solid line) and a 2 standard deviation (dashed line) shock to exchange rate skewness.

standard deviation shock.

Comparison of the models showing the unwinding of the carry trade for the model containing the exchange rate volatility variable (Figure 7) with the model containing the VIX (Figure 4) are generally qualitatively consistent. Like the model in Figure 4 showing the shocks to the VIX, the exchange rate volatility shocks lead to a similar fall in commodity price inflation for both sized shocks. This stimulates GDP growth via increased export and domestic demand growth (GNE) initially. The stimulus to domestic demand is smaller in response to the large shock than in comparison to the normal shock. Small differences arise in the responses of the Japanese and Australian relative variables of the interest rate and inflation rate differentials compared to the model containing the VIX, with the interest rate differentials in particular showing a sustained fall, indicating a relative monetary stimulus coming from Australia in response to the expected slowing of the economy through expected reduced commodity income.

The third model in Figure 3 shows the effects of a negative shock to the exchange rate skewness variable consistent with an increase in the potential loss of the carry trade. The impulse responses functions compared to the first two models are quite different. The first major difference is that the shock to skewness dies out particularly fast, lasting for one month only. This model also shows that the signs of the impulse responses for the different sized shocks are not always the same. Commodity price inflation falls in response to the smaller skewness shock, but rises in response to the larger version of the shock. In both cases demand and production growth initially decline. The stimulatory effect on exports does not appear to be present in this model. The change in the interest rate differentials is positive for the small shock, but falls slightly for the larger shock. The consistency of the impulse responses of the first two models makes the third model our least preferred model.

3.5 A shock to the interest rate differentials

The other key component of the carry trade in this model is the interest rate differential making it also of interest to examine the impacts of a shock to this variable. However, the stability of $r_t^J - r_t^A$ over our sample period indicates that pressure for the carry trade to unwind is likely to not originate in the interest rate differential component of the model but in the investor risk aversion component of the model as presented in the

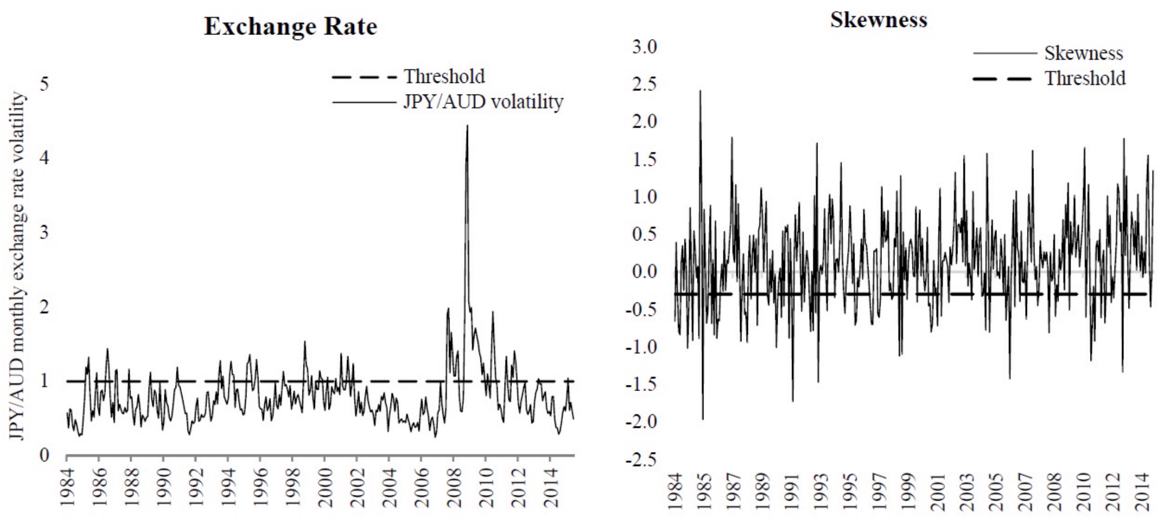

Figure 9: Alternatative threshold variables and their threshold values.

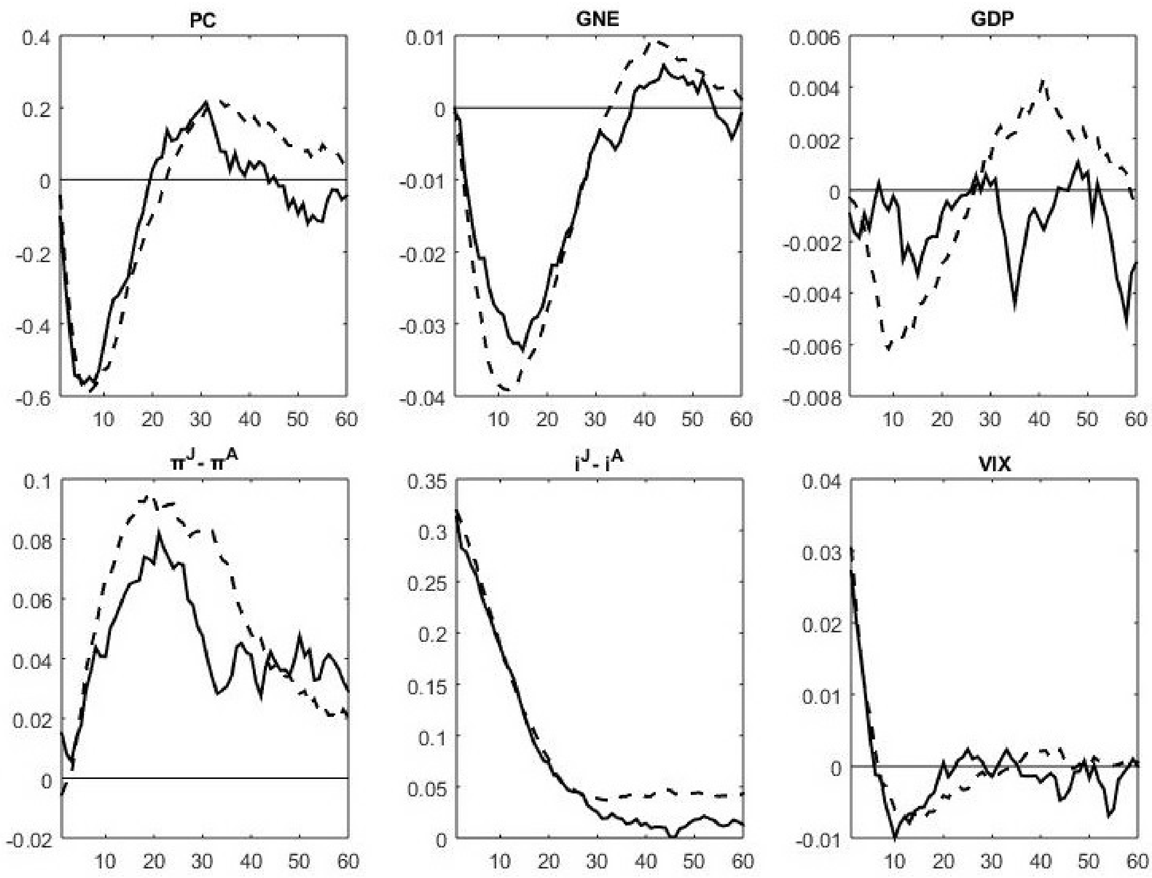

Figure 10: Comparison of shock size in the high pressure regime. Non linear impulse responses to a 1 standard deviation (solid line) and a 2 standard deviation (dashed line) shock to interest rate differential.

analysis so far.[7]

The qualitative impulse response function in the high pressure regime in response to the normal and large shocks are quite similar for all variables except for domestic GDP growth (GDP). The increase in global borrowing costs places downward pressure on commodity price inflation, but rather than leading to an improvement in domestic demand (GNE) and output (GDP) growth, global demand for Australia's exports falls leading to a drop in GDP growth. The growth rate of the economy recovers after two years when the shock is small, but fails to recover in response to the large shock. This model also shows evidence of supply side constraints, with the cost channel of global monetary policy operating as increased borrowing costs raise the cost of producing and investing, leading to a rise in the inflation differential and contributing to the reduction in demand (see Barth and Ramey, 2002).

4 Conclusion

The objective of this paper is to examine the macroeconomic effects of the unwinding of the carry trade using the example of the carry trade between the Australian dollar and the Japanese yen and the Australian macroeconomy as an example. Australia is of interest because despite the large financial market crises in the Asia-Pacific region and globally, it has performed remarkably well in terms of the economic growth. The Japanese Yen-Australian dollar carry trade and the commodity based nature of the Australian economy are features which may be the reason for its resilience. For this purpose a nonlinear TVAR model is used to capture the asymmetric effects of normal sized and large shocks to a range of variables capturing the unwinding of the carry trade. The model endogenously detects a regimes of low and high pressure on the carry trade. Drawing on recent finance literature on the carry trade, three candidate variables capturing the crossing of the threshold from the low to the high pressure regime are considered. These are investor risk aversion as measured through the VIX, the volatility of the JPY/AUD exchange rate and skewness of the same exchange rate. The VIX measure of risk aversion is the preferred measure.

The key findings from this paper are that in the low pressure regime, large shocks to the VIX have a contractionary effect on domestic demand growth and smaller effects on GDP growth in comparison to the normal sized shocks. In the high pressure regime

[7] This is in contrast to the complementary paper Anzuini and Fornari (2012) who examine shocks to the interest rate differential for explaining the macroeconomic determinants of carry trade activity.

where it is likely for the carry trade to unwind, the fall in the Australian interest rate relative to Japan, combined with a reduction in commodity price inflation leads the economy to favorably respond with the fall in commodity price growth boosting Australian production. This result confirms that the unwinding of the carry trade and the subsequent stimulus to exports is beneficial to Australian growth when international financial markets are at their most stressed.

The empirical model also gives the probability of remaining in the low pressure regime or moving to the high pressure regime and vice versa. The probabilities can be calculated under the scenario of no shocks, a one standard deviation shock and a two standard deviation shock. The probability of regime change is low as is expected as in the data the carry trade unwinding does not occur often. The probability of remaining in the low pressure regime rather than moving to the high pressure regime when in the low pressure regime is 97 percent. The occurrence of shocks does little to change this probability. The probability of moving to a low pressure regime from a high pressure regime is much more likely, indicating the ability for the system to correct itself. A two standard deviation shock to the VIX in the high pressure regime has a 30 percent probability of moving to a low pressure regime, while the one standard deviation sized shock results has a 15 percent probability.

Finally, an interest rate differential shock is also examined as an important part of the carry trade relationship. This model shows evidence of supply side constraints, with the cost channel of global monetary policy operating as increased borrowing costs raise the cost of producing and investing, leading to a rise in the inflation differential, a reduction in commodity price growth and contributes to the reduction in the growth of domestic demand.

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Appendix A: Data

Table 2: Data description

Variable	Data description	Source
Australia		
GNE	Real GNE in Australian dollars	RBA
GDP	Real GDP in Australian dollars	RBA
Inflation	Consumer price index 2014/15=100 annual percentage change	RBA
Interest rate	90 days bank accepted bills rate	RBA
Japan		
Inflation	Consumer price index, 2010=100, percent change over corresponding period of previous year	IMF IFS
Interest rate	Money market lending rate	IMF IFS
International variables		
Commodity prices	RBA index of commodity prices, 2014/15=100	RBA
Exchange rate	Mid-points of JPY-AUD buying and selling rates quoted around 4:00 p.m. Sydney time on each trading day	RBA
VIX	Historical daily closing prices	Chicago Board Options Exchange

Appendix B: Computation of the impulse responses

Following Koop, Pesaran, and Potter (1996), a nonlinear impulse response function is defined as the impact of a one-time shock on the variables Y_t, conditioned on history and/or the shock expressed as

$$IRF_y(n, u_t, \psi_{t-1}) = E[y_{t+n}|\psi_{t-1}, u_t] - E[y_{t+n}|\psi_{t-1}], \tag{8}$$

The response of a variable y at horizon n is the differences between two conditional expectations. First, the evolution of the VAR system conditional on a certain history

ψ_{t-1} following the shock u_t is simulated. Second, the evolution of the VAR system conditional on the same history, ψ_{t-1}, without imposing the shock u_t at time t is simulated and subtracted from the former computed conditional expectation. To obtain the impulse responses of the VAR system conditional on the regimes (above or below the threshold value), the simulations are repeated for a sufficient number of histories which correspond to the respective regime. Random shocks are allowed to hit the VAR system before and after the shock. The approach relies on the simulation of the VAR system under multiple sequences of the shocks. Taking an average of the conditional means of the generated nonlinear impulse responses evens out the shocks that are used to generate the simulations. The result is the response of the system with history ψ_{t-1} conditional on the shock u_t only. The steps are:

1. Pick a history, ψ^r_{t-1}, from the regime that is chosen. This history comprises the actual value of all the lagged endogenous variables in the VAR at the chosen date. This implies that the realization of the threshold variable, t^r_{t-1}, is also randomly drawn from the selected regime.

2. The shocks are drawn from the variance-covariance matrix of the residuals and are jointly distributed. A k-dimensional vector $u^b_{t+n}, n = 0, \ldots, p$ is drawn at each horizon, where k denotes the number of endogenous variables in the VAR. If a shock is drawn at horizon p, all k residuals for date p are collected.

3. The evolution of all variables in the VAR system over $n+1$ periods is simulated using the coefficients that are estimated for both the low and high nominal exchange rate volatility regimes and the shock process for $n+1$ periods. The model is allowed to switch regimes over the forecast horizon. The resulting baseline path is denoted as $Y_{t+n}(t^r_{t-1}, u^b_{t+n})$.

4. Step 4 is essentially similar to step 3, with the shock sequence at $t = 0$ replaced by a shock of size n_j for the variable j and the contemporaneous shocks of other variables in the system. This $k \times 1$ vector is denoted as u^*_j. The resulting path is denoted as $Y_{t+n}(t^r_{t-1}, u^b_{t+n}, u^*_j)$.

5. Steps 2 to 4 are repeated $R = 500$ times to allow the shocks to average out.

6. Steps 1 to 5 are repeated $B = 500$ times to compute an average over the history of each regime, and to even out the R times of shock sequences.

7. The nonlinear impulse response function is the difference between two simulated forecasts assuming the shock u_j^* and assuming zero respectively

$$IRF_y(n, \psi_{t-1}, u_j^*) = [Y_{t+n}(t_{t-1}^r, u_{t+n}^b, u_j^*) - Y_{t+n}(t_{t-1}^r, u_{t+n}^b)]/(B \times R). \qquad (9)$$

Appendix C: Regime specific impulses and confidence bands

The regime specific impulse response functions and their confidence intervals are presented in Figures 11 and 12 for completeness. The algorithm to compute the bootstrapped confidence intervals follows which applies to both the regime specific and non-linear cases follows (Fry-McKibbin and Zhang, 2016):

1. Compute centered residuals, $\hat{u} - \bar{u}$, and generate bootstrap residuals, u^*, by drawing randomly with replacement from the centered residuals.

2. Using the estimated parameters and errors from the TVAR structure, the data is generated recursively.

3. Using the recursive dataset, the regression coefficients B_1, $\gamma_1(L)$, B_2, $\gamma_2(L)$ and error terms are calculated from the TVAR with the assumption that threshold is equivalent to the estimated value ϕ.

4. Using the original dataset, but with the coefficients and errors from step 2, non-linear impulse response functions are calculated using the algorithm listed in the previous section for all combination of shocks and initial conditions.

5. Steps 1 to 3 are repeated Z times, set to$Z = 500$ bootstrap repetitions in this paper, to generate a sampling distribution of the impulse response functions. The confidence bands are then drawn from the ordered bootstrap estimates at the respective significance levels.

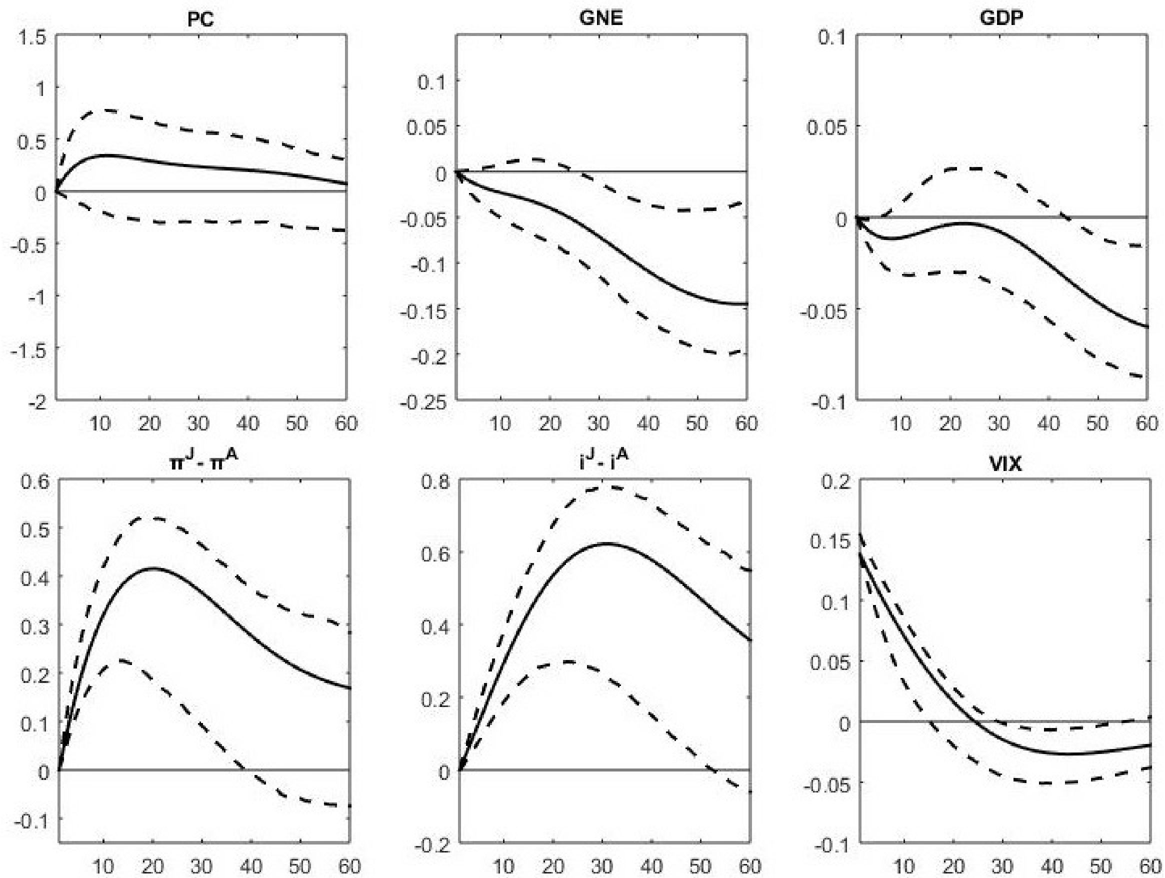

Figure 11: Regime-dependent impulse responses to a 1 standard deviation shock to the VIX in the low pressure regime with confidence intervals.

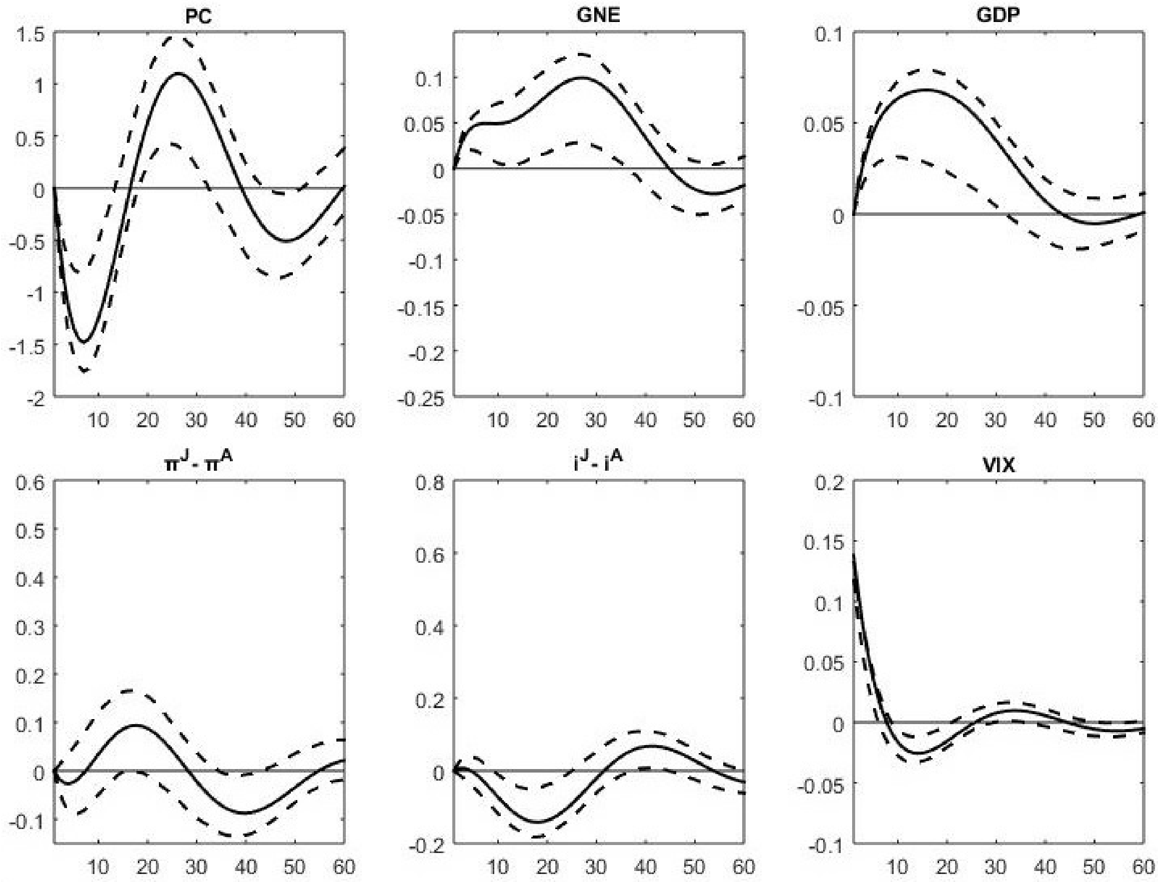

Figure 12: Regime-dependent impulse responses to a 1 standard deviation shock to the VIX in the high pressure regime with confidence intervals.

5 Appendix D: Low pressure regime responses with exchange rate volatility and skewness

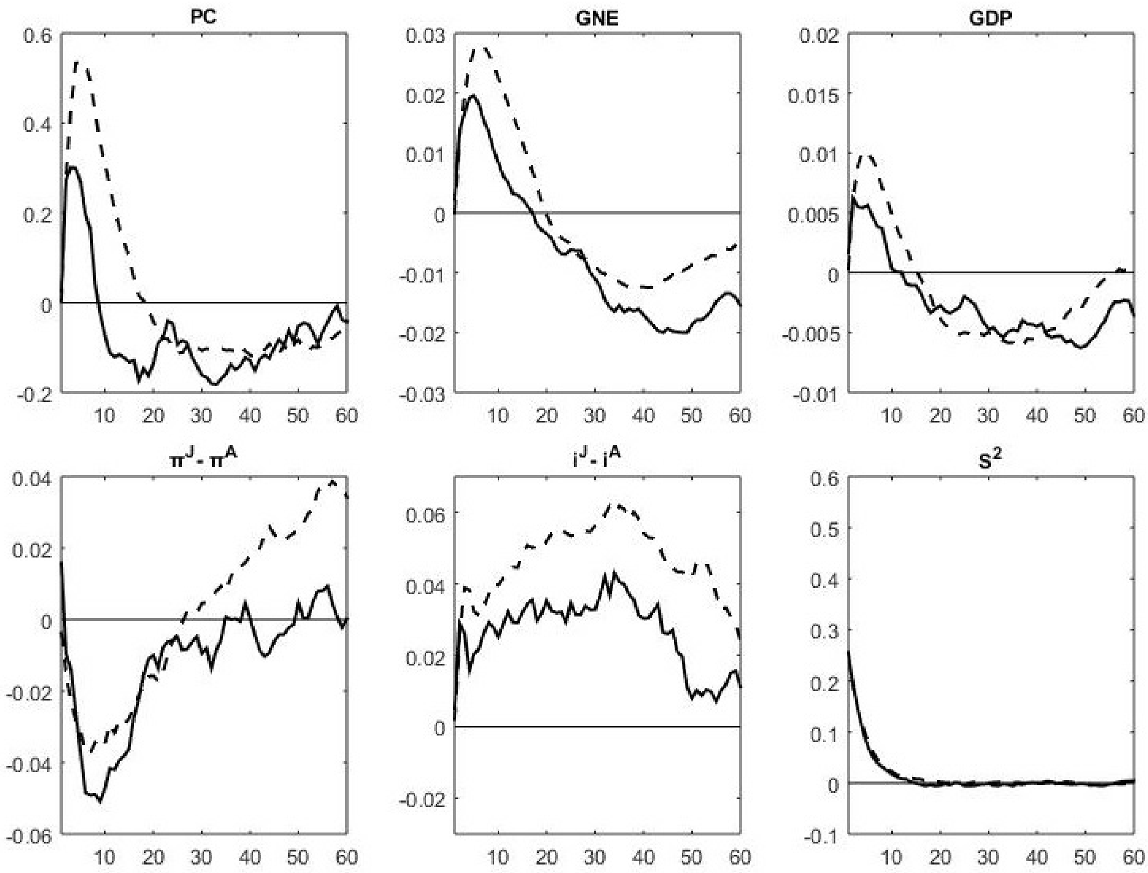

Figure 13: Comparison of shock size in the low pressure regime. Non linear impulse responses to a 1 standard deviation (solid line) and a 2 standard deviation (dashed line) shock to exchange rate volatility.

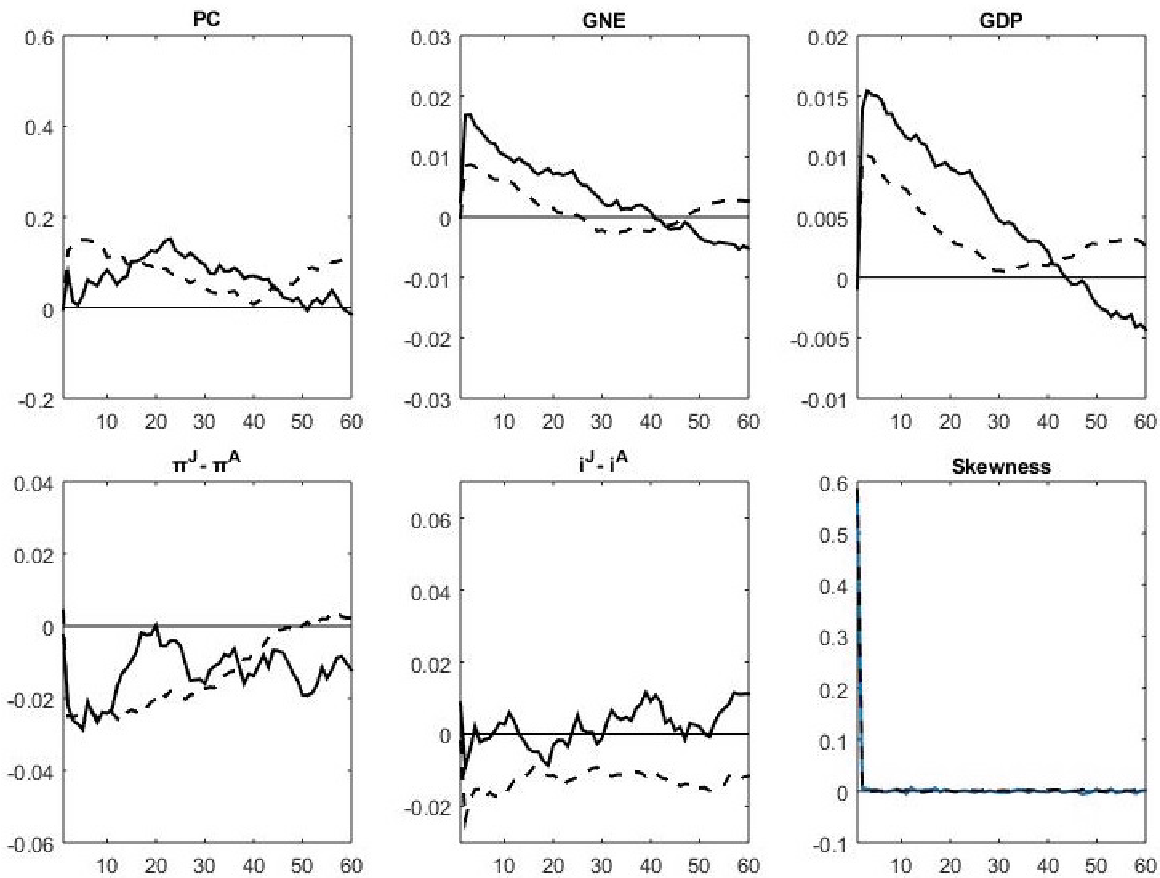

Figure 14: Comparison of shock size in the low pressure regime. Non linear impulse responses to a 1 standard deviation (solid line) and a 2 standard deviation (dashed line) shock to exchange rate skewness.