US sneezing and Australian colds: economic spillovers in both conventional and unconventional monetary policy times

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Abstract

We provide new evidence of international spillover of US monetary policy considering three transmission channels in an integrated framework. In this framework, we use a comprehensive dynamic time and frequency domain analysis and identify the main transmission channel (spillover) of US monetary policy to be through interest rates followed by asset prices (mainly through the consumer discretionary sector), and the exchange rate channels. We find that the most significant spillover was at the onset of the COVID-19 pandemic, with other peak transmissions being during the European sovereign debt crisis ($ESDC$) and the global financial crisis (GFC). As a novel contribution to the identification of monetary policy shocks, we show that these spillovers can be used as external instruments to remove the price puzzle for Australia. We further show that US monetary policy could undermine Australia's monetary policy. Our findings suggest international interest rate-channel as the dominant transmission channel for cross-country monetary policy spillovers.

Keywords: monetary policy spillovers, contagion, US, Australia, sectoral equities
JEL: E31, E44, E52, E58, G10

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1. Introduction

It is told that, "when the U.S. sneezes the world catches a cold", and this has over the years proven to be not only a folklore but an empirical fact in many areas including monetary policy transmission (Chen et al. 2014). The literature has identified three main channels of international transmission of monetary policy shocks, or *international monetary policy spillovers* from the US. These are the interest rate (Azad & Serletis 2022; Antonakakis et al. 2019; Nsafoah & Serletis 2019), asset price (bonds and equities)(Maurer & Nitschka 2023; Chiang 2021; Albagli et al. 2019; Jaccard 2018), and exchange rate channels (Ha 2021; Craine & Martin 2008; Faust et al. 2003). Most of these studies found evidence of some conventional or unconventional monetary policy spillovers from US to other countries while testing a single framework at a time. However, what is lacking in the literature is an integrated approach which considers all these channels during both conventional and unconventional monetary policy periods in a single framework. Also, the previous studies mainly focus on the uni-directional spillovers from the US to other countries. However, the net effect of US monetary policy spillovers which account for bi-directional spillovers has been ignored. Indeed, the Fed acknowledges the spillbacks of international markets to its monetary policy decisions (Fischer 2014; Yellen 2014). Moreover, we typically see that on the equity price channel, the literature have tended to use the overall aggregate stock market index to test the monetary policy transmission; we believe a more segregated approach is needed such that the transmission of monetary policy is tested on different sectors of the economy. In addition, while earlier studies like those of Romer & Romer (2004) and Cloyne & Hürtgen (2016) have provided approaches that successfully removed the "price puzzle" (i.e. the rise in inflation in response to monetary policy tightening contrary to macroeconomic theory) from US and UK data respectively, these approaches are not cast in stone as they do not apply to many countries like Australia (Bishop & Tulip, 2017). Indeed, under several specifications, current research by Bishop & Tulip (2017) at the Reserve Bank of Australia (*RBA*) use the approaches of Romer & Romer (2004) and Cloyne & Hürtgen (2016) along with several other suggested specifications like adding commodity prices in the VAR framework following studies like Bernanke

& Mihov (1998),Sims (1992) and Hanson (2004). However, Australia's price puzzle is still not removed, and Bishop & Tulip (2017) indicate that VAR models may not be appropriate for the analysis of monetary policy. Hence, this study seeks to provide a new approach that can help remove the price puzzle.

Against this backdrop, this study differs from the existing literature in three main ways. First, unlike previous studies, we provide empirical evidence of US monetary policy (both conventional and unconventional) spillover based on an integrated framework which captures all three channels: the interest rate, asset price, and exchange rate channels simultaneously. In this regard, we address the issue related to the net spillover effect(s) of US monetary policy stance on an open economy that has also used both conventional monetary policy (*CMP*) and unconventional monetary policy (*UMP*). We use Australia as an open economy that has also pursued UMP at the onset of COVID-19 pandemic. We choose Australia because the country has empirically been identified as an open economy whose financial markets are linked to events around the world especially from the US (Craine & Martin 2008; Ha 2021). In fact, the US is the largest investor in Australian economy taking about 24% share of total foreign direct investment (*FDI*) into Australia as of 2022 (DFAT, 2022).

The country also embarked on unconventional monetary policy from March 2020 when COVID-19 was declared a pandemic. As observed from Figure 1, prior to the *GFC*, the Fed used only *CMP* tools but started using UMP for a prolonged period till the later part of 2016 when it reverted to using *CMP* tools. Meanwhile, Australia had been using *CMP* for this period even though increased policy interest rate (*PIR*) after the *GFC*, the rate had seen a downward trend since 2011 until March 2020 when the *RBA* started using *UMP* tools as the US also reverted to *UMP* in the same period. For these reasons, Australia makes for an ideal 'case study' country to determine the effects of the evolution of monetary policy stance of the US. This has important policy implications given that the strength of the net spillover of US monetary policy on Australia's economy can inform the extent of RBA's monetary policy response to market changes. We use the time-varying VAR techniques based on (Diebold & Yilmaz, 2012; Diebold & Yılmaz, 2014) (hereafter, "DY (12,14)") as our main technique to estimate the net US monetary policy spillovers. This approach helps us to estimate spillovers across different time domains covering both *CMP* and *UMP* periods.

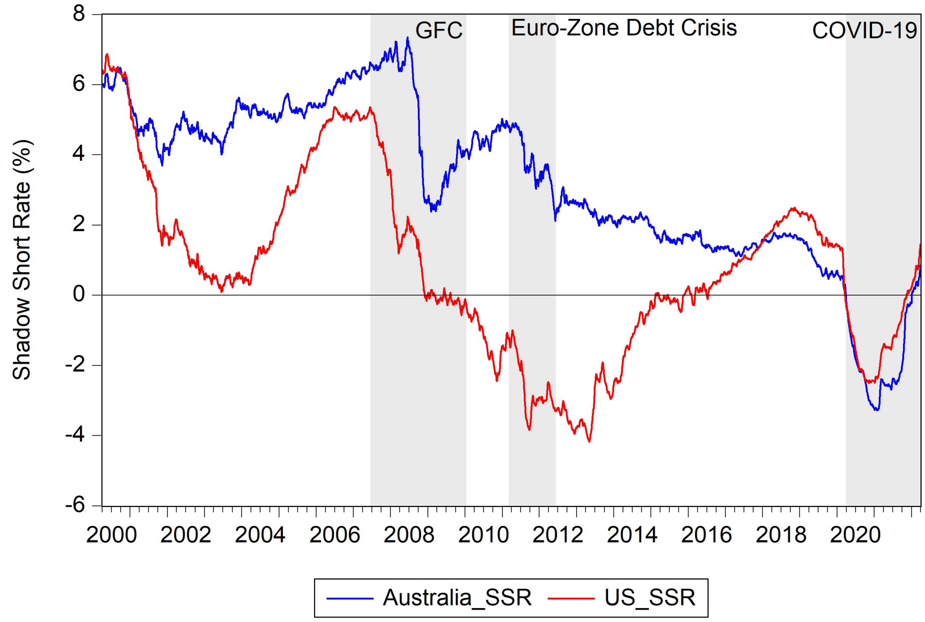

Figure 1: Time series plot of shadow short rate (SSR)

Second, unlike previous studies that have used the aggregate stock market index in analysing the equity price channel (Aastveit et al., 2023; Paul, 2020), we use sectoral indices in order to understand the heterogeneous impact of monetary policy on different sectors of the economy. This follows from the thinking of Carlino & DeFina (1998) who makes a case that different regions with strong backgrounds in some industries would have different responses to monetary policy shocks. Hence, we examine the monetary policy spillovers to different sectors in Australia.

Third, we estimate the response of Australia's output and inflation to the monetary policy shocks of the Fed and the RBA by using the spillovers from the DY(12,14) as external instruments. Indeed, instrumental variables (IV) methods have gained significant recognition in recent empirical macroeconomics as the leading approach to identify macroeconomic shocks (Miranda-Agrippino & Ricco, 2023; Cloyne et al., 2023; Gerko & Rey, 2017; Di Giovanni et al., 2009). As indicted earlier, current work by Bishop & Tulip (2017) at the RBA found that VAR models may not be able to remove the *price* *puzzle* from the Australian data. Hence, the authors indicate that VAR models may not be appropriate for the analysis of monetary policy. To remove the price puzzle, we explore other options by using the spillovers estimated from our DY(12,14) analysis as external instruments to identify monetary policy shocks. To the best of our knowledge, we are the first to add to the current literature on identification of monetary policy shocks by showing that net monetary policy spillovers within the economy considering spillovers from US can be used as external instruments to identify domestic monetary policy shocks. In this regard, as a novel solution, we show that the RBA can indeed rightly identify monetary policy shocks on inflation and output by using these spillovers as external instruments.

Our results show that spillovers from US monetary policy stance transmits mainly through the interest rate channel to the Australian economy. Importantly, we find that US monetary policy explains on average about 19% of the variation in Australia's monetary policy stance with a net effect of 6%. These spillovers are heterogeneous over time with the highest peak of spillovers observed during the COVID-19 pandemic. We also find that the consumer discretionary sector is the main sector through which US monetary policy transmits spillovers. We further show that, without accounting for these spillovers, the impact of Australia's monetary policy on inflation has signs which are contrary to macroeconomic theory. However, accounting for these spillovers, we see that Australia's monetary policy rightly predicts inflation and output with a contractionary monetary policy leading to a fall in output and inflation.

The remainder of the paper is organized as follows. In section 2, we review some related studies and discuss our contributions in detail. Section 3 shows a description of the data and specification of our empirical model. Section 4 provides the empirical results while section 5 presents the conclusion of the study.

2. Contributions and Review of Related Literature

There is limited literature that considers an integrated view of how US monetary policy (both conventional and unconventional) transmits to an economy looking at various channels (interest rate, asset price and exchange rate) together.

For instance, on the interest rate channel, Azad & Serletis (2022) examined how the monetary policies of some inflation-targeting emerging countries are affected by US monetary policy uncertainty and found evidence of spillover of US monetary policy to these emerging economies. Nsafoah & Serletis (2019) in a similar study examined the spillover of US monetary policy and found both positive and negative shocks of US Federal funds rate on the monetary policies of different countries including Canada, UK, Japan and the Eurozone. The evidence therefore suggests international spillovers of US monetary policy through the interest rate channel. Thus, central banks of other countries adjust their policy rates in response to changes in the Fed's monetary policy. However, most of these studies did not consider any possible spillback to US monetary policy. Antonakakis et al. (2019) is one study that examined the spillovers between the monetary policies of the US, UK, Japan and the Euro area and found heterogeneous spillovers of monetary policy among these countries. This shows the need to consider spillbacks to US monetary policy in a dynamic framework given that the Fed also acknowledges this fact (Yellen, 2014).

On the asset price channels, more recently, Maurer & Nitschka (2023) looked at the response of international stock market returns to US monetary policy surprise. The study found that US monetary policy surprise has a persistent impact on foreign stock markets. Chiang (2021) also examined the spillovers of US monetary policy uncertainty on international stock markets and found evidence of spillovers to international stock market returns even though the effect is less pronounced in Latin American and Asian stock markets. Albagli et al. (2019) examined the spillovers of US monetary policy on the international bond market. Using panel regressions, the study found significant spillover of US monetary policy on the international bond market with significant increases in spillovers after the GFC. The study identified the exchange rate as the main channel through which the impact of US monetary policy affects the bond market with different policy responses from developed and emerging markets. While developed countries predominantly focuses on the policy rate differential with the US, emerging markets focus more on intervention in the exchange rate market. This suggests that policy makers are faced with a trade-off between policy rate differential and currency adjustments. Chen et al. (2014) using an event study found US monetary policy to have an impact on the asset prices (bonds and equities) of emerging markets. Thus, changes in US monetary policy rate affect both bonds and equity prices of different emerging markets. Moreover, Lakdawala et al. (2021) also examined how US monetary policy uncertainty affect global bond yields. The authors found that the term premium of bond yields for advanced countries that respond to US monetary policy uncertainty while for emerging markets, it is the expected component of yields that respond to US monetary policy uncertainty.

Thus, from the literature, we typically observe that the channels are examined separately. An integrated framework which examines these channels together is lacking. Our study therefore differs from the previous studies by examining spillovers of US monetary policy considering all the channels together.

In a more related study, Ha (2021) using a structural vector autoregression ($SVAR$) approach also found that spillovers of US monetary policy shocks to other advanced economies are stronger and more persistent than the domestic monetary policy shocks of those countries. The main channels examined included US asset prices (equity and bonds) and exchange rate. Our study differs from that of Ha (2021) in three ways: First, we add interest rate channel in our framework given the recent call by central banks for a more coordinated international monetary policy (Liu & Pappa, 2008). Second, we also examine the spillover of monetary policy shocks on the real sector (output and inflation) using net monetary policy surprises or spillovers as external instruments.

Third, on the equity price channel, instead of considering the aggregate share indices, we examine sectoral indices to capture the heterogeneous response of different sectors to monetary policy shocks. As mentioned earlier, studies on spillovers of US monetary policy on equity prices or returns have only focused on the aggregate stock market by using measures of aggregate stock market or all share indices. This approach ignores valuable information on how these spillovers relate to different sectoral equities.

Indeed, we have learnt from the experience of the GFC, the recent COVID-19 pandemic and Russia-Ukraine war that different sectors have different levels of integration to the global market. For instance, the financial sector and housing markets were heavily exposed in the GFC, while anecdotal evidence suggests that transportation, energy and consumables sectors were highly affected by the COVID-19 pandemic when most countries implemented lockdown rules disrupting global supply chains. Likewise, the Russia-Ukraine war has affected the energy and commodities market given the world's dependence on the oil & gas and commodities from Russia and Ukraine.

We therefore postulate that the impact of monetary policy on the different sectors of the economy will be heterogeneous and will largely depend on the extent of connectedness of these sectors to monetary policy decisions. For instance, the financial sector especially the banking sector is likely to be highly connected to monetary policy decisions than say the retail sector given the traditional role of banks in the interest rate and credit channel of monetary policy. Interestingly, Kent (2018) observed that the offshore borrowings of Australian banks have dwindled over the years because of the higher share of domestic deposits in banks' funding. Kent (2018) further indicated that the hedging abilities of Australian banks insulates them from external monetary policy shocks especially from the US, even though Australian banks have large offshore borrowings with about 15% in US dollars. Meanwhile, there is a lack of empirical literature that tests the level of integration and spillover of international monetary policy to the financial and other sectors of an open economy in an integrated framework. In this regard, it is important to understand the transmission of US monetary policy stance on the Australian Stock Exchange (ASX) which would inform investors' decision to follow the herd to the money market or the equity market or to move to the international financial market. In so-doing, it is important to segregate the spillover of US monetary policy on Australia's sectoral equities. To the best of our knowledge, this is the first study to look at international monetary policy spillover that considers sectoral equities in an integrated framework.

In-light of all of the above, our study makes three key contributions to the literature. First, the study combines CMP and UMP of US in a single framework to study monetary policy spillovers to different markets of an open economy that also uses CMP and UMP tools. This has been ignored in the literature. Second, while previous studies have examined the various channels in isolation, the current study examines all the channels in a unified framework. Hence, our study uses a new technique that estimates spillover effects in a unified framework where the direction of spillovers is not only from the US but bi-directional. This technique also helps to track the dynamic nature of these spillovers to observe whether the spillovers are heterogeneous over time and their behaviours during periods of crisis such as the GFC and COVID-19 pandemic. Third, concerning the equity price/returns channel, the study uses sectoral equities instead of the aggregate equity indices that have been used in previous studies. Fourth, using spillovers as external instruments for monetary policy shocks, the study is able to properly identify the monetary policy shocks of Australia (i.e. remove the price puzzle for Australia).

3. Data and Empirical Methodology

3.1. Data description and sources

The present study uses the SSR series for US and Australia which are sourced from Krippner (2020).[1] We take daily data from 31st March 2000 to 31st March 2022.[2] As we discussed earlier, the SSR estimates capture both conventional and unconventional monetary policy when the policy target is at the ZLB. As Krippner (2020) observes, during periods of UMP, assessing monetary policy stance using the short rates or the policy interest rate will not be adequate given that there are additional UMP tools that are used. Hence, the overall monetary policy stance will be influenced by the additional stimulus provided by the UMP which cannot be properly captured by the policy interest rates or short-term rates alone. Therefore, studies that use official policy rates, such as the federal funds rate of the Fed and the cash rate of the Reserve Bank of Australia (RBA), covering periods of ZLB using VAR models will not be able to provide meaningful interpretation (Wu & Xia, 2016) given that the policy interest rate becomes ineffective at the zero-lower bound. The SSR, therefore, can capture the overall monetary policy stance in periods of CMP and UMP. The SSR is based on the shadow rate term structure model first proposed by Black (1995).

We also use a total of 13 sectoral indices from the ASX. The indices are developed by Standard & Poor's (S&P) Dow Jones indices and Morgan Stanley Capital International (MSCI) based on the Global Industry Classification Standard (GICS) which provides

[1]Data is sourced from: `https://www.ljkmfa.com/visitors/` [Accessed on August 21, 2022]

[2]Time span is selected due to data availability. The data for SSR ends on 31st March 2022 while 31st March 2000 is when all the sectoral indices taken together have available data.

definitions of 11 standardized industries used by stock markets around the world. The ASX adopted the GICs in 2002. The GIC has 11 sectors which are: Energy, Materials, Industrials, Consumer Discretionary, Consumer Staples, Health Care, Financials, Information Technology, Communication Services, Utilities and Real Estate. The ASX in collaboration with the S&P Dow Jones Indices developed five additional sector indices to reflect the specialized characteristics of the Australian market. These are: All Ordinaries Gold Index, Metals and Mining Index, Agribusiness Index, Financials Index excluding A-Real Estate Investment Trust (REIT) and the REIT Index. Hence, instead of the financial index, we rather use the Financial Index excluding A-Real Estate Investment Trust (REIT)-(FINEXA-REIT) and include the Real Estate Investment Trust (REIT) Index as an additional index. Instead of the additional Resources Index which classifies whether a company belongs to either Energy sector or the Metals & Mining sector, we include the Index for the Metals and Mining Sector. Thus, we use a total of 13 indices which include: (1) Energy, (2) Materials, (3) Industrials, (4) Consumer Discretionary, (5) Consumer Staples, (6) Health Care, (7) FINEXA-REIT, (8) A-REIT (9) Information Technology (IT), (10) Communication Services, (11) Utilities, (12) Real Estate and (13) Minerals & Metals. Data is taken from the Thomson Reuters Datastream Database.

We also include the US stock market by using the MSCI-US index which captures over 600 large and medium firms in the US unlike the 500 companies measured by the S&P500 index. This US measure can also be considered as a global measure of financial market conditions. Daily data of MSCI-US index are also obtained from the Thomson Reuters Datastream Database. Time spans from 31st March 2000 to 31st March 2022. Following Antonakakis et al. (2019), we take the first difference in the shadow short rate which captures the spillovers of monetary policy given that fully anticipated monetary policy announcements show no immediate impact on the shadow short rate (Claus et al., 2016). We however use the percentage change for equity indices and FX. The use of growth rates are consistent with previous literature (Caggiano et al., 2017).

From Figure 2, we see variations in the changes in US & Australia's SSR and the returns series of FX & equity indices over the period with spikes and peaks during periods of crises. We observe that these return series appears to be persistent over time. We see from the figure that, changes in US and Australia's SSR follow similar pattern with the Dotcom, GFC and ESDC periods showing the most volatile changes. We see similar jumps during the GFC and ESDC for the stock returns, especially for the materials, financial (FINAEXAREIT), real estate (REALESTATE and REIT), industrial (INDUS) and metals sectors.

3.2. Descriptive statistics

In Table 1, it can be observed from the summary statistics that the average change in SSR rate and variance of US and Australia are the same showing similar policy stance over the period. With the sectors, the health sector has the largest return of 0.05% with the communication sector being the only sector with a negative mean return of -0.005%. Also, all the series are stationary based on the ERS unit root test (Elliott et al., 1992). Hence, the estimation of time-varying variances by the DY (12,14) technique is suitable for the nature of the series given the time-varying nature of monetary policy reactions (Davig & Doh, 2014).

3.3. Model specification

To estimate international spillovers from the US and the consequent domestic spillovers within Australia, we follow the flowchart as shown in Figure 3. The figure captures dynamics of the monetary policy transmission of the Fed and RBA in the Australian economy. After controlling for the dynamics in US stock market, the dynamics of shocks from the US monetary policy stance to Australian economy creates a rippling effect where we observe policy response of Australia's RBA and responses from the equity and foreign exchange markets. The results in a feedback effects or spillbacks in the system. Therefore, the net transmission of spillovers (net US and Australia monetary policy spillovers, net foreign exchange spillovers and net equity spillovers) can then be estimated on output and inflation. The figure captures the contribution of the study to existing literature by estimating US monetary policy spillovers within the Australian economy considering the interest rate, exchange rate and stock price/return channels in an integrated framework.

Therefore, unlike Albagli et al. (2019) and other studies that use linear panel regressions and/or generalized autoregressive conditional heteroskedasticity (GARCH)

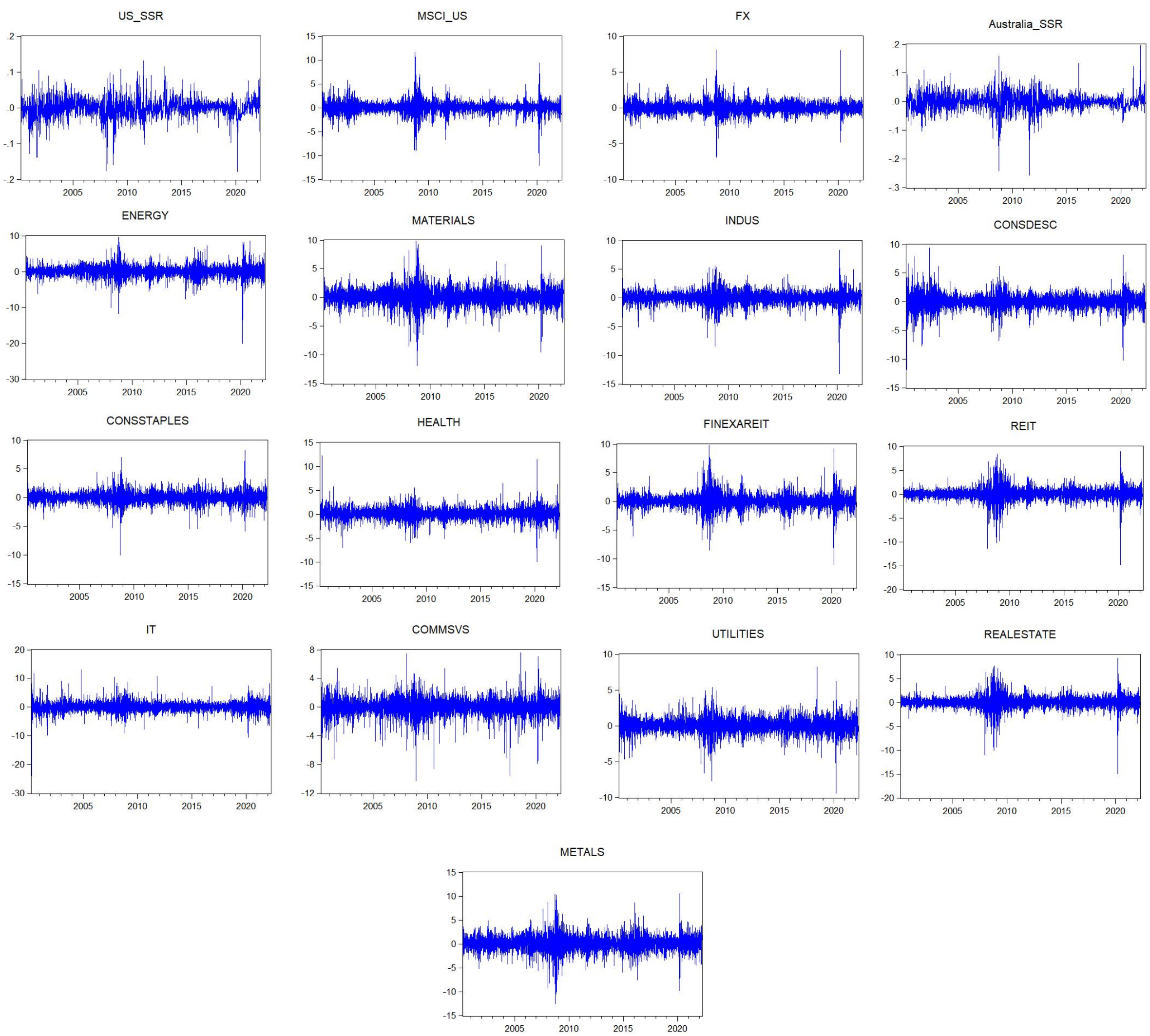

Figure 2: First difference of US & Australia SSR and returns series of FX and stock indices

Table 1: Summary Statistics

Variable	**Mean**	**Variance**	**Skewness**	**Kurtosis**	**JB**	**ERS**
US_SSR	-0.001	0.001	-0.363***	4.115***	4175.446***	-12.595***
			(0.000)	(0.000)	(0.000)	(0.000)
US_MSCI	0.026	1.477	-0.190***	11.334***	30751.800***	-22.370***
			(0.000)	(0.000)	(0.000)	(0.000)
FX	-0.001	0.586	0.488***	9.572***	22137.746***	-26.283***
			(0.000)	(0.000)	(0.000)	(0.000)
Australia_SSR	-0.001	0.001	-0.645***	9.033***	19907.172***	-22.591***
			(0.000)	(0.000)	(0.000)	(0.000)
ENERGY	0.032	2.371	-0.642***	10.207***	25304.267***	-6.458***
			(0.000)	(0.000)	(0.000)	(0.000)
MATERIALS	0.042	2.202	-0.238***	5.097***	6267.265***	-5.860***
			(0.000)	(0.000)	(0.000)	(0.000)
INDUS	0.018	1.172	-0.614***	8.451***	17437.460***	-6.965***
			(0.000)	(0.000)	(0.000)	(0.000)
CONSDESC	0.008	1.586	-0.441***	6.932***	11675.716***	-10.002***
			(0.000)	(0.000)	(0.000)	(0.000)
CONSSTAPLES	0.03	0.926	-0.086***	6.895***	11374.157***	-8.518***
			(0.008)	(0.000)	(0.000)	(0.000)
HEALTH	0.052	1.421	0.151***	7.777***	14485.452***	-10.705***
			(0.000)	(0.000)	(0.000)	(0.000)
FINEXAREIT	0.023	1.512	-0.107***	8.696***	18093.918***	-9.613***
			(0.001)	(0.000)	(0.000)	(0.000)
REIT	0.013	1.622	-0.937***	14.208***	49108.762***	-12.472***
			(0.000)	(0.000)	(0.000)	(0.000)
IT	0.005	2.926	-0.475***	11.675***	32810.815***	-8.099***
			(0.000)	(0.000)	(0.000)	(0.000)
COMMSVS	-0.005	1.454	-0.591***	5.683***	8056.556***	-12.226***
			(0.000)	(0.000)	(0.000)	(0.000)
UTILITIES	0.021	1.066	-0.200***	4.888***	5751.075***	-28.214***
			(0.000)	(0.000)	(0.000)	(0.000)
REALESTATE	0.011	1.566	-0.993***	14.603***	51935.643***	-24.185***
			(0.000)	(0.000)	(0.000)	(0.000)
METALS	0.046	2.684	-0.179***	4.501***	4875.921***	-6.413***
			(0.000)	(0.000)	(0.000)	(0.000)

Note: *** Significance at 1%. ** Signficance at 5% , Skewness: D'Agostino (1970) test; Kurtosis: Anscombe and Glynn (1983) test; JB: Jarque and Bera (1980) normality test; ERS: Stock, Elliott, and Rothenberg (1996) unit-root test; US_SSR: Shadow short rate of US; US_MSCI: the MSCI share index of US; FX: Australia-US dollar exchange rate; Australia_SSR: Shadow short rate of Australia; ENERGY: share index of the energy sector; MATERIALS: share index of the materials sector; INDUS: share index of industrials sector; CONSDESC: share index of the Consumer Discretionary sector; CONSSTAPLES: share index of the consumer staples sector; HEALTH: share index of the health sector; FINEXAREIT: Financial Index excluding A-Real Estate Investment Trust (REIT); REIT: the share index of Real Estate Investment Trust (REIT) sector: IT: share index of Information Technology sector; COMMSVS: share index of communication Services sector; UTILITIES: share index of utilities sector; REALESTATE: share index of real estate sector; METALS: share index of Minerals & Metals sector. The SSR's are in first-differences (%) while the indices are percentage changes (%).

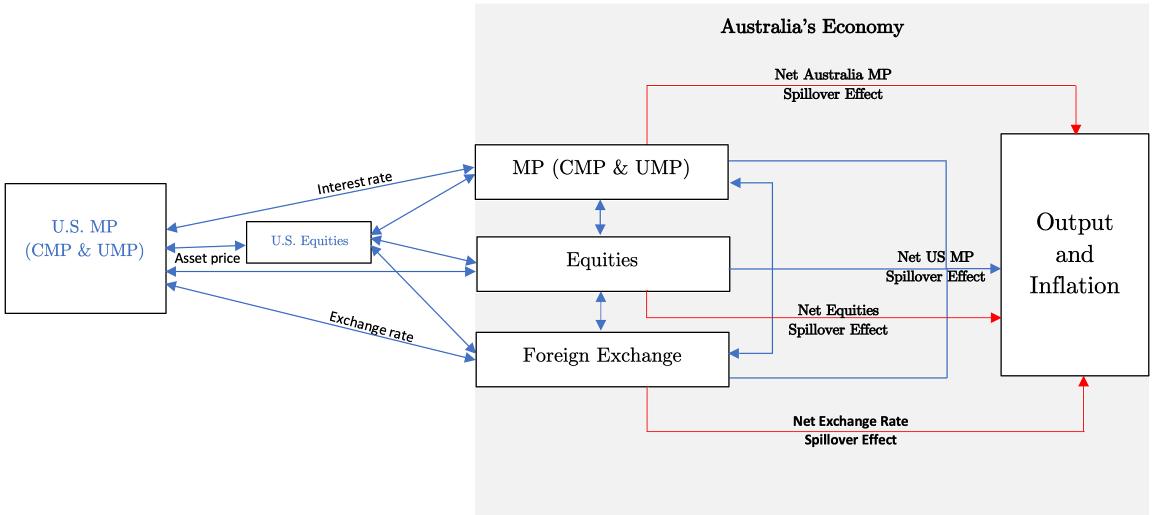

Figure 3: Flowchart of monetary policy spillovers

Source: Authors' Conceptualization

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and/or unstructural VARs and global VAR models (Dekle & Hamada 2015; Georgiadis 2016; Nsafoah & Serletis 2019), the current study differs by employing the newly developed time-frequency technique of Diebold and Yilmaz (Diebold & Yilmaz 2012; Diebold & Yılmaz 2014) to estimate total, net and directional spillovers. Unlike other VAR methods that are sensitive to element ordering in their estimation of variance decompositions, the VAR technique of DY (12,14) is irrelevant to element ordering. Again, other VAR models typically estimate impulse responses that are static in nature over the whole sample period (Diebold & Yilmaz, 2012). These static measures of spillovers however mask the dynamics of the heterogeneous nature of spillovers over time (Diebold & Yilmaz 2012; Diebold & Yılmaz 2014).

Importantly, the international monetary policy spillovers from the US to Australia and spillovers within Australia's economy may be time-varying. The time-varying nature of the DY(12,14) technique is appropriate to observe spillovers across time covering major global events like the GFC, ESDC, COVID-19 pandemic and the Russia-Ukraine war. The DY(12,14) technique addresses these limitations by estimating directional spillovers across time. Hence, this technique provides a comprehensive and complete measures of spillovers to include: i) total spillovers, ii) directional spillovers, iii) net spillovers, and iv) net pairwise spillovers within the system. In this way, the study can have an integrated approach where estimates of the total spillovers between US monetary policy and Australia's markets (monetary policy, exchange rate and sectoral equities) can be obtained in addition to obtaining estimates of the unique spillovers from US monetary policy to each of the markets. As a policy implication, the RBA could understand how different markets within the economy respond to US and its own monetary policy decisions. For other financial participants, understanding of these different spillovers to the different sectors can help them make informed investment decisions given the link between these markets or sectors to monetary policy decisions. We also use the technique of Baruník & Křehlík (2018) in order to understand the spillovers at different frequencies (short-term, medium-term and long-term). As robustness to our main technique, we use the time-varying parameter vector autoregression (TVP-VAR) technique of Antonakakis et al. (2019) which overcomes the loss of valuable data that arises from choosing a rolling-window size in the DY (12,14) technique. We proceed to discuss our main estimation technique.

3.4. Diebold-Yilmaz method: spillover analysis in the time domain

Our major aim in the empirics is to examine the international spillovers of US monetary policy to Australia's economy. In doing so, we first use the time domain spillover analysis of Diebold & Yilmaz (2012) and Diebold & Yılmaz (2014) which extends the Diebold & Yilmaz (2009). Here, we summarize the technique as follows. Consider a covariance stationary N-variable (variables are change in the series of SSR and return of stock indices and FX) VAR(p):

$$\mathbf{Y}_t \ = \ \sum_{k=1}^{p} \Phi_k \mathbf{Y}_{t-k} + \varepsilon_t \ , \tag{1}$$

where $\varepsilon_t \ \sim (0, \ \Sigma)$ is a vector of independently and identically distributed (*i.i.d.*) disturbances. The moving average representation is $Y_t \ = \sum_{k=0}^{\infty} A_k \varepsilon_{t-k}$ where A_k is an $N \times N$ coefficient matrix which obeys the recursion: $A_k = \ \Phi_1 \ A_{k-1} + \ \Phi_2 \ A_{k-2} + \ldots + \ \Phi_p \ A_{k-p}$ with A_0 being an identity matrix of size N and $A_k = 0$ for $k < 0$.

As documented in Diebold & Yilmaz (2012), the dynamics of the system are explained by the coefficients in the moving average process which is key to understanding the system. The various system shocks are decomposed into components which explain the forecast error variances of each variable. In this case, the variance decompositions help to explain the fraction of the F step-ahead error variance in forecasting Y_k that is due to shocks to Y_l where $\forall l \neq k$, for each k. Here, unlike the Cholesky factorization which whilst achieving orthogonality, its variance decompositions depends on the ordering of the variables, the advantage of the Diebold & Yilmaz (2012)'s approach is that it follows the generalized variance decomposition (GVD) framework framework of Koop et al. (1996) and Pesaran & Shin (1998) that helps to produce variance decompositions, which are invariant to variable ordering.

Defining Variance and Spillovers

The share of variances are separated into own and the cross-variances, which is the variance from other variables in the system or spillovers. The own variance share is the fraction of the F step-ahead error variances in forecasting Y_k that are due to shocks in Y_k, for $k = 1, 2, \ldots, N$, and the cross-variance shares are the F step-ahead error variances in forecasting Y_i that are due to shocks in Y_l, for $l = 1, 2, \ldots, N$, such that $k \neq l$. Here, the F step-ahead forecast error variance is represented by $\theta^g_{kl}(F)$ for $F = 1, 2, \ldots$, and is specified as follows:

$$\theta_{kl}(F) = \frac{\sigma_{ll}^{-1} \sum_{f=0}^{F-1} \left(e'_k A_f \Sigma e_l\right)^2}{\sum_{f=0}^{F-1} \left(e'_k A_f \Sigma A'_f e_k\right)} \tag{2}$$

where σ_{ll} is the standard deviation of the error term for the lth equation and e_l is the selection vector with unity as the lth element and zeros otherwise. Σ is the covariance matrix of the shock vector in the non-orthogonalized VAR. Given the shocks to each variable is not orthogonalized, the sum of the contributions to the variance of the forecast error is not necessarily equal to one, $\sum_{l=1}^{N} \theta_{kl}(F) \neq 1$. The elements of the variance decomposition matrix are normalized to help calculate the spillover index by using the row sum as follows:

$$\widetilde{\theta}_{kl}\left(F\right)=\frac{\theta_{kl}\left(F\right)}{\sum_{l=1}^{N}\theta_{kl}\left(F\right)} \tag{3}$$

where $\sum_{l=1}^{N}\theta_{kl}\left(F\right)$ is the sum of the total spillovers from l to k while $\theta_{kl}\left(F\right)$ is the spillover of l to k for each k where $k \neq l$. Hence, $\sum_{l=1}^{N}\widetilde{\theta}_{kl}\left(F\right) = 1$ and the sum of all elements $\widetilde{\theta}_{kl}\left(F\right)$ is equal to N, by construction. $\widetilde{\theta}_{kl}\left(F\right)$ is therefore a standard measure of pairwise spillovers which is the share of variance contributed by the cross prediction errors. This is then aggregated to the total spillovers index expressed as a percentage as follows.

Total spillover index (TSI)

$$TSI\left(F\right)=\frac{\sum_{k,l=1,\ k\neq l}^{N}\widetilde{\theta}_{kl}\left(F\right)}{\sum_{l=1}^{N}\widetilde{\theta}_{kl}\left(F\right)}\times 100=\frac{\sum_{k,l=1,\ k\neq l}^{N}\widetilde{\theta}_{kl}\left(F\right)}{N}\times 100 \tag{4}$$

This is the total spillover index which measures the total contribution of spillovers across all the variables to the total forecast error variance. Hence, $S^{g}\left(F\right)$ can be interpreted as the total spillovers of the entire system. To measure the directional spillovers, we measure the directional spillover from all other markets/variables l to k as follows:

Directional spillover 'From' all variables $\boldsymbol{l}$ to $\boldsymbol{k}$

$$DSI_{k\leftarrow\bullet}\left(F\right)=\frac{\sum_{l=1,\ k\neq l}^{N}\widetilde{\theta}_{kl}\left(F\right)}{\sum_{k,l=1}^{N}\widetilde{\theta}_{kl}\left(F\right)}\times 100=\frac{\sum_{l=1,\ k\neq l}^{N}\widetilde{\theta}_{kl}\left(F\right)}{N}\times 100 \tag{5}$$

We similarly measure the directional spillovers transmitted from variable k to all other markets l as follows:

Directional spillover by variable k 'To' all variables l

$$DSI_{k\to\bullet}(F) = \frac{\sum_{l=1,\ k\neq l}^{N} \widetilde{\theta}_{lk}(F)}{\sum_{k,l=1}^{N} \widetilde{\theta}_{lk}(F)} \times 100 = \frac{\sum_{l=1,\ k\neq l}^{N} \widetilde{\theta}_{lk}(F)}{N} \times 100 \tag{6}$$

Hence, **net spillovers index (NSI) can be calculated as:**

$$NSI_k(F) \ = \ DSI_{k\to\bullet}(F) \ - \ DSI_{k\leftarrow\bullet}(F) \tag{7}$$

To calculate the net pairwise spillover which is net spillover between two variables thus how much each variable or series contributes to the other variable in net terms. This can be defined as below:

Net pairwise spillover index (NPSI)

$$NPSI_{kl}(F) = \left(\frac{\widetilde{\theta}_{lk}(F)}{\sum_{k,m=1}^{N} \widetilde{\theta}_{km}(F)}\right) - \left(\frac{\widetilde{\theta}_{kl}(F)}{\sum_{l,m=1}^{N} \widetilde{\theta}_{lm}(F)}\right) \times 100 = \left(\frac{\widetilde{\theta}_{lk}(F) \ - \ \widetilde{\theta}_{kl}(F)}{N}\right) \times 100 \tag{8}$$

Therefore, net pairwise spillover is the difference between the gross spillover from market k to market l and spillover from market l to market k.

3.5. Spillover analysis in the frequency domain

Building upon the seminal work of Diebold & Yilmaz (2012), Baruník & Křehlík (2018) have introduced a method that allows for heterogeneous frequency responses to shocks. This method employs a spectral representation of generalized forecast error variance decompositions (GFEVD) to disaggregate spillovers into various time horizons using Fourier transformations of the frequency responses, which are the impulse responses. This approach is particularly relevant when the variables of interest may have varying responses to shocks at different frequencies and strengths.This approach is relevant given that our variables of interest may have varying responses to the shocks in the system at different frequencies and strengths.

This allows us to check the the short-, medium- and long-term frequency responses to shocks. Baruník & Křehlík (2018) considers a frequency response function, $\Psi\left(\mathrm{e}^{-\mathrm{i}\omega}\right) = \sum_b \mathrm{e}^{-\mathrm{i}\omega h}\Psi_b$, which can be obtained as a Fourier transform of the coefficients Ψ_b, with $i = \sqrt{-1}$. The generalized causation spectrum over frequencies $\omega \in (-\pi, \pi)$ is defined as[3]:

$$(f(\omega))_{j,k} \equiv \frac{\sigma_{kk}^{-1}\left|\left(\Psi\left(e^{-i\omega}\right)\Sigma\right)_{j,k}\right|^2}{\left(\Psi\left(e^{-i\omega}\right)\Sigma\Psi'\left(e^{+i\omega}\right)\right)_{j,j}}, \tag{9}$$

where $\Psi\left(e^{-i\omega}\right) = \sum_b e^{-i\omega h}\Psi_b$ is the Fourier transform of the impulse response Ψ_b. $(f(\omega))_{j,k}$ is the portion of the spectrum of the jth variable at the given frequency, ω, due to shocks to the kth variable. Following that denominator holds the spectrum of the jth variable under frequency ω, Equation (9) above can be deduced as the quantity within the frequency causation. The generalized decomposition of the variance is converted to frequencies by weighting the function $(f(\omega))_{j,k}$ by the frequency share of the jth variable. Following the above, the weighting function is:

$$\Gamma_j = \frac{\left(\Psi\left(e^{-i\omega}\right)\sum\Psi'\left(e^{+i\omega}\right)\right)_{j,j}}{\frac{1}{2\pi}\int_{-\pi}^{\pi}\left(\Psi\left(e^{-i\lambda}\right)\sum\Psi'\left(e^{+i\lambda}\right)\right)_{j,j}d\lambda}, \tag{10}$$

Equation (10) shows the jth variable power in the system under frequency ω and sums the frequencies to a constant value of 2π. It is noteworthy that even though the Fourier transformation of the impulse response is a complex number, the generalized spectrum is the squared coefficient of the weighted complex number and, as result, is a real number. To make meaningful economic application where the short-, medium- and long-term connectedness or spillovers can be assessed, the frequency band formally

[3]See Baruník & Křehlík (2018) for a full proof.

as: $d = (a, b) : a, b \in (-\pi, \pi), a < b$. This is defined as the amount of forecast error variance created on a convex set of frequencies given by integrating only over the desired frequencies $\omega \in (a, b)$. Hence, the generalized variance decomposition under the frequency band d is given in Equation (11):

$$(\Theta_d)_{j,k} = \frac{1}{2\pi} \int_d^{\infty} \Gamma_j(\omega)(f(\omega))_{j,k} d\omega. \tag{11}$$

The generalized variance decomposition is scaled under the frequency band $d = (a, b) : a, b \in (-\pi, \pi), a < b$ to obtain Equation (12):

$$\left(\tilde{\Theta}_d\right)_{j,k} = (\Theta_d)_{j,k} \,/ \sum_k (\Theta_\infty)_{j,k} \tag{12}$$

The within connectedness is formulated under the frequency band d as:

$$C_d^W = 100 \times \left(1 - \frac{\mathrm{Tr}\left\{\tilde{\Theta}_d\right\}}{\sum \tilde{\Theta}_d}\right) \tag{13}$$

Finally, we estimate the frequency connectedness or spillovers under the frequency band d as:

$$C_d^F = 100 \times \left(\frac{\sum \tilde{\Theta}_d}{\sum \tilde{\Theta}_\infty} - \frac{\mathrm{Tr}\left\{\tilde{\Theta}_d\right\}}{\sum \tilde{\Theta}_\infty}\right) = C_d^W \frac{\sum \tilde{\Theta}_d}{\sum \tilde{\Theta}_\infty} \tag{14}$$

3.6. Monetary policy transmission to output and inflation

We use the DY(12,14) to obtain the net monetary policy spillovers for US and Australia. We then proceed to estimate how these monetary policy spillovers transmit to output and inflation in Australia. The use of this small model follows from previous empirical literature (Benati & Surico, 2008; Primiceri, 2005; Stock & Watson, 2001; Cogley & Sargent, 2001; Boivin & Giannoni, 2006). However, for our study, we use the net Australia and US monetary policy spillovers obtained from the DY(12,14) as monetary policy surprises. Given that they are the net spillover of monetary policy after their transmission within the economy through the various channels, the net effect gives us the 'surprise' component that will further have a 'true' effect on the real sector.

Therefore, these must be accounted for in the transmission mechanism. We take two approaches to address this: first, we estimate the response of output and inflation to monetary policy shocks following the standard Cholesky Identification in a VAR framework. Second, as a novel contribution, we use the DY(12,14) spillover estimates as external instrument to identify monetary policy shocks following the approach of Gertler & Karadi (2015). These are discussed below:

3.6.1. VAR approach – Cholesky identification

Here, we first follow the standard recursive VAR framework to examine the dynamic relationship between inflation, output and monetary policy as follows:

$$\mathbf{A}(L)\mathbf{Y}_t = \varepsilon_t, \tag{15}$$

where $A(L) = I - A_0 - A_1L - ... - A_pL^p$ is the lag polynomial and ε_t is a vector of orthogonalized disturbances. Vector Y_t is:

$$Y_t = \begin{bmatrix} RealOutput_t \\ Inflation_t \\ Policy_t \end{bmatrix} \tag{16}$$

where real output is real industrial production index in log terms (Gertler & Karadi, 2015; Hanson, 2004) and inflation is the inflation rate (percentage change in consumer prices). Our monetary policy variable is either the shadow short-rate of the RBA or Fed.

For our three-variable VAR, the Cholesky restrictions result in the following exclusion restrictions on contemporaneous responses in the matrix A to fit a just-identified model:

$$A = \begin{bmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \tag{17}$$

Here, we order the variables as: real output, inflation, and policy respectively. This recursive form implies that contemporaneous shocks to the other variables do not affect the variable with index 1 (Output). On the other hand, variable 2 (Inflation) is affected by the contemporaneous shock to variable 1 but not variable 3 (policy) but the contemporaneous shocks to variables 2 and 1 affect variable 3. However, in the estimations for US spillover, we order the Fed monetary policy as the first variable.

3.6.2. VAR approach – external instrument approach

As we discussed earlier, we note the current research by Bishop & Tulip (2017) who found the price puzzle in Australia's data and indicate that VAR models may be inappropriate for the estimation of Australia's monetary policy. As a major contribution to identify Australia's monetary policy shocks, we employ the use of external instruments identification approach proposed by Mertens & Ravn (2013) and Stock & Watson (2012, 2018) following the procedure of Gertler & Karadi (2015) by using the DY(12,14) net monetary spillovers or surprises as external instruments. Described briefly, let the general structural VAR be:

$$\mathbf{A}\mathbf{Y}_t = \sum_{k=1}^{p} \mathbf{B}_k \mathbf{Y}_{t-k} + \epsilon_t \ , \tag{18}$$

where $\mathbf{Y}_t$ is a vector of economic variables (real output, inflation, and policy), $\mathbf{A}$ and $\mathbf{B}_k$ are vectors of conformable coefficient matrices, and ϵ_t is a vector of structural shocks. The reduced form representation of our structural VAR therefore is:

$$\mathbf{Y}_t = \sum_{k=1}^{p} \Phi_k \mathbf{Y}_{t-k} + \mu_t \ , \tag{19}$$

where $\mathbf{\Phi_k} = \mathbf{A^{-1}}\mathbf{B}_k$. μ_t is the reduced form structural shock which follows the below structural shock function (where $\mathbf{S} = \mathbf{A^{-1}}$):

$$\mu_t = \mathbf{S}\varepsilon_\mathbf{t}. \tag{20}$$

Following from Gertler & Karadi (2015), we only need to compute the coefficients of monetary policy shocks. Hence, we are interested in estimating the impact of structural policy shock. Let $Y_t^p \in Y_t$ be the monetary policy indicator (Australia or US shadow-short rate) in the structural equation 18 with the associated policy shock, ϵ_t^p. If $\mathbf{s}$

corresponds to the the vector of the impact of the ϵ_t^p on each element of the **S**, then the impulse responses of these variables to a policy shock can be represented as:

$$\mathbf{Y}_t \;=\; \sum_{k=1}^{p} \mathbf{\Phi}_k \mathbf{Y}_{t-k} + \mathbf{s}\epsilon_t^p \; . \tag{21}$$

In the instrumental variables approach, let Z_t be a vector of the instrumental variables in this case the spillovers or monetary policy surprises from the DY(12,14) approach and let ϵ_t^q be a vector of the other structural shocks aside the policy shock, ϵ_t^p. The validity of the instrument for the policy shocks relies on the condition that Z_t be correlated with ϵ_t^p but orthogonal to ϵ_t^q:

$$\begin{aligned} E\left[\mathbf{Z}_t \epsilon^{p'}\right] &= \boldsymbol{\phi} \\ E\left[\mathbf{Z}_t \epsilon^{q'}\right] &= \mathbf{0}. \end{aligned} \tag{22}$$

We therefore estimate the VAR models first following the Cholesky identification procedure (based on equations 16 and 17) consistent with literature and second using the instrumental variables approach following Gertler & Karadi (2015) by using the net monetary spillover estimates from the DY(12,14) as external instrument to identify monetary policy shocks.

As we previously mentioned, our instrument (net monetary policy spillovers) represents surprises around monetary policy stance. Hence, similar to the IV literature like Gertler & Karadi (2015) that use surprises around the federal funds futures, net monetary spillover can be considered to be surprises around the monetary policy decision given its transmission throughout the economy.

4. Empirical Results

In this section, we discuss results obtained from our main estimation technique - DY(12,14) as well as the frequency analysis of Baruník & Křehlík (2018) [4]. The study then proceeds to estimate the impact of the Fed and RBA's monetary policy Australia's

[4]The results from the TVP-VAR analysis are provided in the Online Appendix.

output and inflation using the net Fed and RBA monetary policy spillovers as external instruments.

4.1. Time domain analysis

Here, we present results of dynamic spillovers following DY(12,14). We use 100-day rolling window samples following from Diebold & Yilmaz (2012) and Diebold & Yılmaz (2014) in order to assess the variation of spillovers over time. We discuss the dynamic total spillovers and average dynamic spillovers (based on equation 4), the directional (based on equations 5 and 6) and net spillovers (based on equation 7) over the period. These spillovers measure the level of connectedness or integration between the markets in the framework. Hence, higher values indicate high connectedness or spillovers between the variables. The implication of these spillovers is that, if for instance US monetary policy is highly connected to Australia's financial markets than Australia's own monetary policy, then the RBA may underestimate it's monetary policy response. This means that Australia's financial markets would be more aligned to developments in the US, hence would tend to react more to changes in US monetary policy than to Australia's monetary policy. For our discussion purposes, we refer to a positive net spillover as net spillover or net contributor/transmitter of spillovers while we refer to a negative net spillover as net receiver of spillovers or net *"spillbacks"*.

4.1.1. Dynamic total spillovers

The dynamic total spillover shows how total spillover index (TSI) evolves over the sample period. This is shown in Figure 4. We can see oscillating spillovers across time. Starting from spillovers below 65%, we see the spillovers going over 85% close to 90%. We observe several cycles between these extreme spillovers. The early 2000s saw the Dot-com or Tech bubble that shot spillovers from around 50% to around 67% before falling back to the initial levels after which the spillover index reached below of 50% by the end of 2005. After that, we see upward and downward spillovers between 60% and 70% prior to the 2007/2008 GFC. The spillovers reached unprecedented heights close to 80% during the financial crisis. Since then, the highest spillovers reaching around 88% have been seen in 2011 during the ESDC and in early 2020 around March when COVID-19 was declared as a pandemic. Thus, COVID-19 pandemic, ESDC and the GFC were periods where spillovers between US monetary policy, stock market and Australia's market reached notable heights.

4.1.2. Average dynamic spillovers effects

We proceed to discuss the average dynamic spillovers for the sample period in Table 2. From the table, the kl^{th} entry shows the estimated contribution *to* the forecast error variance of market k *From* shocks to market l. The Spillovers *To Others* column shows the off-diagonal sums of the *to* spillovers while the column, *Spillovers From Others*, shows the off-diagonal row sums which indicate the from spillovers. The gross sum of the *From* spillovers as a percentage of the gross sum of the *To* spillovers plus the diagonals (own spillovers) gives the total spillover index. From the table, the average TSI is 64.72% indicating relatively high spillovers between monetary policy and stock market from the US and the monetary policy and financial markets of Australia.

Moving on to discussion on the monetary policy spillovers, we find that US monetary policy explains about 18% of variations in Australia's monetary policy with a net spillover of about 6% (*i.e.*, 17.83%-11.86%). This shows that about 6% of the variations in the monetary policy stance of the RBA can be attributed to the monetary policy decisions of the Fed. In the entire system, we find that US monetary policy is a net contributor of spillovers (12%) to Australia while Australia's monetary policy is a net receiver of spillovers (-11%). This shows the dominance of US monetary policy over Australia's monetary policy in influencing Australia's financial markets. On the other hand, US monetary policy explains about 3.79% of the exchange rate with a net spillover of about 2.03% (i.e. 3.79%-1.76%) while Australia's monetary policy contributes a net spillover of 0.9% (i.e. 4.41%-3.51%) to the exchange rate. Again, this shows US's monetary policy to be the highest contributor of spillovers to the exchange rate between the two countries.

In regards to the contribution of monetary policy spillovers to Australia's stock market, we find that spillovers of US monetary policy to all of Australia's sectoral equity returns is higher than the spillovers from Australia's monetary policy. Taken together (last three rows of Table 2), the results show that US monetary policy is a net contributor of spillovers to Australia's sectoral equities with a spillover of 4.21%

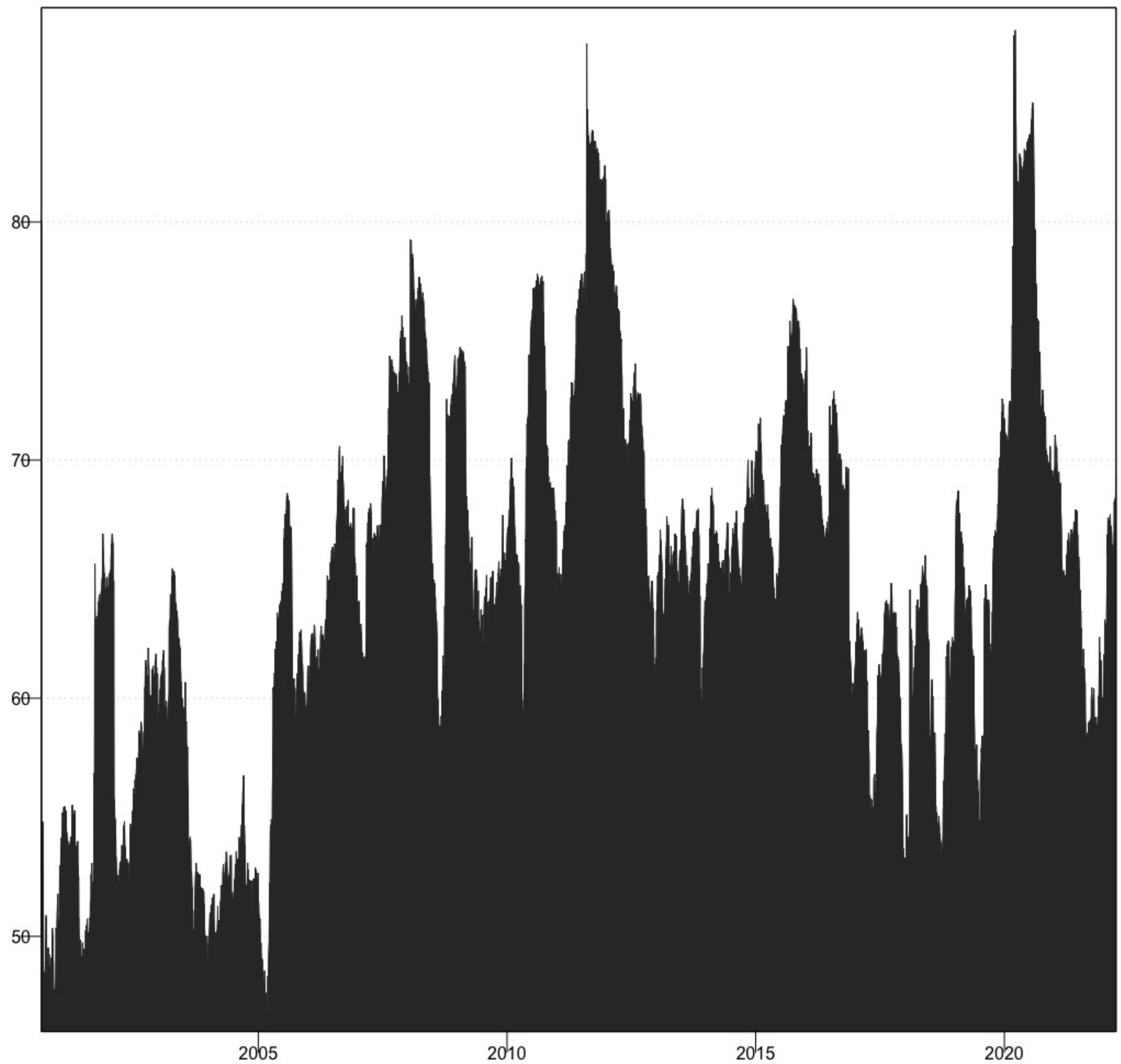

Figure 4: Dynamic total spillovers (TSI)

Note: Results are based on Diebold and Yilmaz (2012, 2014) technique with lag length of order one (Bayesian information criterion, BIC) and a 10-step-ahead generalized forecast error variance decomposition.

while Australia's monetary policy is a net receiver of spillovers of about 4.10% from its own sectoral equities. This shows the dominance of the US monetary policy in explaining the sectoral equity returns of Australia. The consumer discretionary sector is the highest net receiver of 0.71% spillovers (*i.e.*, 2.60%-1.89%) from US monetary policy followed by 0.58% to the IT (*i.e.*, 2.33%-1.75%) and 0.41% to the financial sectors (FINEXREIT: 2.47%-2.06%) respectively. The sector that receives the least net spillover from US monetary policy is the real estate industry with both REIT (1.63%-1.50%) and real estate (1.58%-1.45%) measures receiving about 0.13% spillovers. This shows that, there is high connectedness between US monetary policy and Australia's consumer discretionary sector with the least connectedness with the real estate sector. On the other hand, as indicated earlier, Australia's monetary policy is a net receiver of spillovers from its sectoral equities with the financial sector being the dominant sector contributing net spillovers of about 1.46%. The sector with the least contribution of net spillovers to Australia's monetary policy is the IT sector.

Overall, these results show that US monetary policy is a net transmitter of spillovers to Australia's financial markets while Australia's monetary policy is a net receiver of spillovers. The main transmission channel of US monetary policy spillovers is through the interest rate channel with a net spillover of about 6% to Australia's SSR. This is followed by the asset price channel with US monetary policy contributing about 4.2% of net spillovers to Australia's sectoral equity returns with the consumer discretionary sector receiving the most spillovers followed by the IT and financial sectors respectively. The exchange rate channel follows with a net spillover of 2% from US' monetary policy.

We now proceed to highlight the key findings of the average return spillovers for US stock market, FX, and sectoral indices. From Table 2, we see high levels of return spillovers from US stock market to Australia's market. Indeed, US stock market is the largest contributor of spillovers in the entire system with a net spillover of about 53.46%. This is mainly attributed to the high net spillover of about 45.77% to Australia's sectoral equites showing the high connectedness between US and Australia's stock markets. The remaining 7.69% spillovers is mainly to the FX market, 5.51% (i.e., 7.59%-2.08), Australia's monetary policy, 1.85%, and to US monetary policy, 0.33%.

Again, the FX market is on average a net receiver of about 21.13% of spillovers in the system with Australia's stock market contributing majority of the spillovers of about 12.68%. This is followed by net spillovers of 5.51%, 2.03% and 0.9% from US stock market, US monetary policy and Australia's monetary policy respectively. These results show that Australia's stock market explains most of the variations in its AUD/USD exchange rate. Among the sectors however, the largest net contributor of spillovers to the exchange rate is the materials sector with net spillover of 1.82%.

Concerning the sectoral equity indices, the results show that the industrial sector is the dominant net contributor of spillovers with a net spillover of 9.41%. The sector contributes its highest net spillovers to the IT and Utilities sectors with net spillovers of 1.99% (i.e. 6.56%-4.57%) and 1.98% (i.e. 6.65%-4.67%) respectively. However, the net spillbacks to the sector is only from the US, with 4.16% spillbacks from the US stock market and 0.24% from US monetary policy. Meanwhile, the second and third highest contributors of net return spillovers to the system are the financial and materials sectors contributing net spillovers of 5.82% and 5.2% respectively in the system. For the financial sector, the sector's highest net spillover is to the utilities sector with a net spillover of 1.62%. However, the highest net spillback to the sector is from the US stock market with net spillback of 3.31% followed by net spillback of 0.42% and 0.41% from the industrial sector and US monetary policy respectively. On the other hand, the materials sector contributes its highest spillover of 1.82% to the exchange rate while the sector receives its highest net spillback of 4.99% from the US stock market followed by net spillbacks of 0.24% and 0.16% from US monetary policy and industrials sector respectively. From the table, the results show that the IT sector is the highest net receiver of spillovers in the system with a net spillback of 15.25%. The highest contributor of net spillovers to the IT sector is from the industrial sector (1.99%) as indicated above. However, the IT sector is a net contributor of spillovers to only the foreign exchange and communication services sector with spillovers of 0.38% and 0.29% respectively. This shows the connectedness of the IT sector and the communication services sector.

Table 2: Average dynamic spillovers: DY(2012,2014)

Variable	US_SSR	US_MSCI	FX	Australia_SSR	ENERGY	MATERIALS	INDUS	CONSDESC	CONSSTAPLES	HEALTH	FINEXAREIT	REIT	IT	COMMSVS	UTILITIES	REALESTATE	METALS	Spiilovers FROM Others
US_SSR	**55.42**	8.65	1.76	11.86	1.99	2.03	1.71	1.89	1.32	1.49	2.06	1.50	1.75	1.71	1.43	1.45	1.99	44.58
US_MSCI	8.32	**56.37**	2.08	3.97	2.58	2.69	2.55	2.72	1.80	1.92	2.91	1.79	2.02	1.97	1.82	1.92	2.58	43.63
FX	3.79	7.59	**49.11**	4.41	3.60	4.29	2.74	2.92	2.33	2.11	2.82	1.93	1.97	2.00	1.87	2.05	4.46	50.89
Australia_SSR	17.93	5.82	3.51	**50.02**	1.82	1.89	1.75	1.92	1.52	1.56	2.00	1.57	1.67	1.61	1.98	1.58	1.84	49.98
ENERGY	2.35	6.18	2.46	1.68	**31.77**	9.09	5.70	4.72	4.12	3.24	5.53	2.69	2.81	2.30	3.69	3.21	8.46	68.23
MATERIALS	2.27	7.68	2.47	1.49	7.57	**23.77**	5.14	4.36	3.32	2.32	4.71	2.09	2.74	2.15	2.43	2.33	23.15	76.23
INDUS	1.95	6.71	1.65	1.32	4.84	4.98	**24.83**	7.56	6.15	5.51	7.40	4.86	4.57	3.43	4.67	5.43	4.14	75.17
CONSDESC	2.60	8.97	1.63	1.53	4.18	4.53	8.00	**25.94**	6.13	5.13	6.91	3.94	4.79	3.55	3.98	4.40	3.79	74.06
CONSSTAPLES	1.58	4.12	1.47	1.17	4.20	3.94	7.50	7.37	**30.48**	5.72	7.40	4.38	4.25	3.73	4.67	4.78	3.25	69.52
HEALTH	1.86	5.45	1.62	1.28	3.63	3.13	7.19	6.64	6.32	**33.62**	5.67	3.95	5.05	3.28	4.40	4.36	2.55	66.38
FINEXAREIT	2.47	6.22	1.64	1.45	4.81	4.77	7.82	6.92	6.50	4.46	**25.93**	5.13	4.12	3.66	4.27	5.94	3.90	74.07
REIT	1.63	3.65	1.23	1.26	2.68	2.37	5.53	4.35	4.11	3.34	5.59	**27.35**	2.44	2.95	4.12	25.40	1.99	72.65
IT	2.33	7.18	1.59	1.73	3.57	3.93	6.56	6.25	5.09	5.13	5.47	3.11	**34.53**	3.38	3.37	3.45	3.32	65.47
COMMSVS	1.93	3.85	1.48	1.38	3.00	3.06	5.20	4.89	5.00	3.67	5.24	3.72	3.67	**43.45**	3.74	4.01	2.71	56.55
UTILITIES	1.72	3.77	1.24	1.59	4.45	3.25	6.65	5.54	5.52	4.55	5.89	5.24	3.29	3.27	**35.62**	5.63	2.78	64.38
REALESTATE	1.58	3.95	1.24	1.24	2.94	2.54	5.94	4.67	4.28	3.51	6.15	24.13	2.62	2.98	4.25	**25.87**	2.10	74.13
METALS	2.26	7.31	2.69	1.49	7.59	24.94	4.59	3.89	2.92	2.01	4.14	1.86	2.45	2.00	2.21	2.05	**25.60**	74.40
Spillovers TO Others	56.59	97.09	29.76	38.84	63.46	81.43	84.58	76.60	66.44	55.66	79.90	71.90	50.22	43.97	52.90	77.98	73.00	**TSI**
Net Spillovers/Spillback	***12.01***	***53.46***	***-21.13***	***-11.13***	***-4.77***	***5.20***	***9.41***	***2.54***	***-3.07***	***-10.72***	***5.82***	***-0.76***	***-15.25***	***-12.58***	***-11.48***	***3.85***	***-1.40***	**64.72%**
Sectoral equity analysis																		
Spillovers to Sectoral Indices	*26.53*	*75.04*	*22.41*	*18.61*	*53.46*	*70.53*	*75.82*	*67.16*	*59.46*	*48.59*	*70.10*	*65.10*	*42.80*	*36.68*	*45.80*	*70.99*	*62.14*	
Spillovers From Sectoral Indices	*22.32*	*29.27*	*35.09*	*22.71*	*55.56*	*62.31*	*63.54*	*59.33*	*61.19*	*56.17*	*62.3*	*64.87*	*52.63*	*47.91*	*56.06*	*66.11*	*60.65*	
Net Spillovers/Spillback to Sectoral Indices	***4.21***	***45.77***	***-12.68***	***-4.10***	***-2.10***	***8.22***	***12.28***	***7.83***	***-1.73***	***-7.58***	***7.80***	***0.23***	***-9.83***	***-11.23***	***-10.26***	***4.88***	***1.49***	

Note: All Variables are as defined earlier.

4.1.3. Dynamic directional and net spillovers effects

Figures 5 and 6 show the evolution of directional spillovers, thus, the to and from spillovers respectively. Consequently, we discuss net spillovers which are shown in Figures 7 and 8. From the figures, positive values show that the variable in question is a net contributor of spillover in the specific period while negative values indicate that the variable is a net receiver of spillovers in the system in the specific period.

From Figures 5 and 6, we observe that spillovers to all other variables are heterogeneous over time. Particularly, from Figure 5, we see that US monetary policy exhibit higher spillovers to all other variables than Australia's monetary policy. We however observe that over time, Australia's monetary policy receives higher spillovers from all other variables than do US' monetary policy. This is evident in Figure 7 where we observe that over the sample period, US monetary policy exhibit net positive spillovers in the system over extended periods compared to Australia's monetary policy even though the monetary policy stance of both countries receives net spillovers in some periods. Specifically, we observe that in the early 2000s up to 2005, monetary policy of the US was a net contributor of spillovers in the system while at the same time, Australia's monetary policy was a net receiver of spillovers. We note that the US monetary policy was a net transmitter of spillovers during the GFC while Australia's monetary policy was a net receiver of spillovers in the same period up until 2009/2010 when the country's monetary policy began to transmit spillovers. We also observe that in 2011 to 2012 during the ESDC, Australia's monetary policy was a net receiver of spillovers while US' monetary policy only briefly received spillovers at the onset of the crisis. Again, from Figure 7, US monetary policy saw its highest transmission of net spillovers when COVID-19 was declared a pandemic in March 2020 while at the same time Australia recorded its highest net monetary policy spillback. These results, in general, show that comparatively, US monetary policy transmits shocks to Australia's economy more than Australia's monetary policy and that periods of high transmission of US monetary policy spillovers are when Australia's monetary policy also receives its highest spillovers. From Figure 7, US stock market is generally a net transmitter of spillovers to Australia's economy in almost the entire sample period. Notably, US stock market received net spillbacks briefly from March 2020 when COVID-19 was declared a pandemic until August 2020. The exchange rate was a net receiver of spillovers in almost the entire sample period.

We now move on to discuss the net spillovers of the sectoral equity indices as shown in Figure 8. From the figure, we observe that over the period, the industrial sector is the dominant sector contributing net spillovers in most of the sample period. Notably, the sector received net spillbacks in the early 2000s with extended spillbacks from 2002 to 2004 with occasional net spillbacks in 2006, 2008, 2009, 2011 and 2012. The materials and financial sectors followed respectively as next dominant sectors transmitting spillovers in the system. These sectors also observe occasional spillbacks as the industrial sector. The sectors that received the most net spillbacks over the entire period are the IT, communication services, utilities, and health sectors. These sectors received net spillovers over extended period indicating that the vulnerability of these sectors to market shocks.

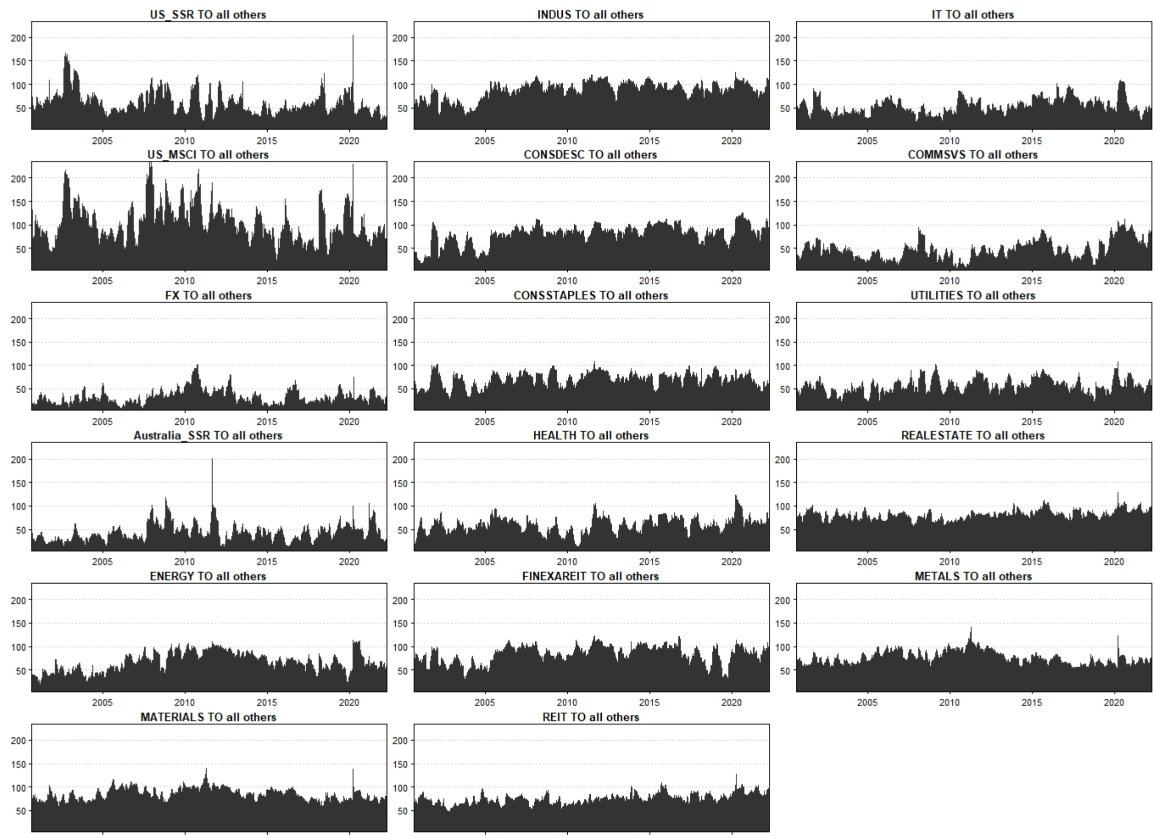

Figure 5: Dynamic spillovers To all others

Note: Results are based on Diebold and Yilmaz (2012,2014) technique with lag length of order one (Bayesian information criterion, BIC) and a 10-step-ahead generalized forecast error variance decomposition.

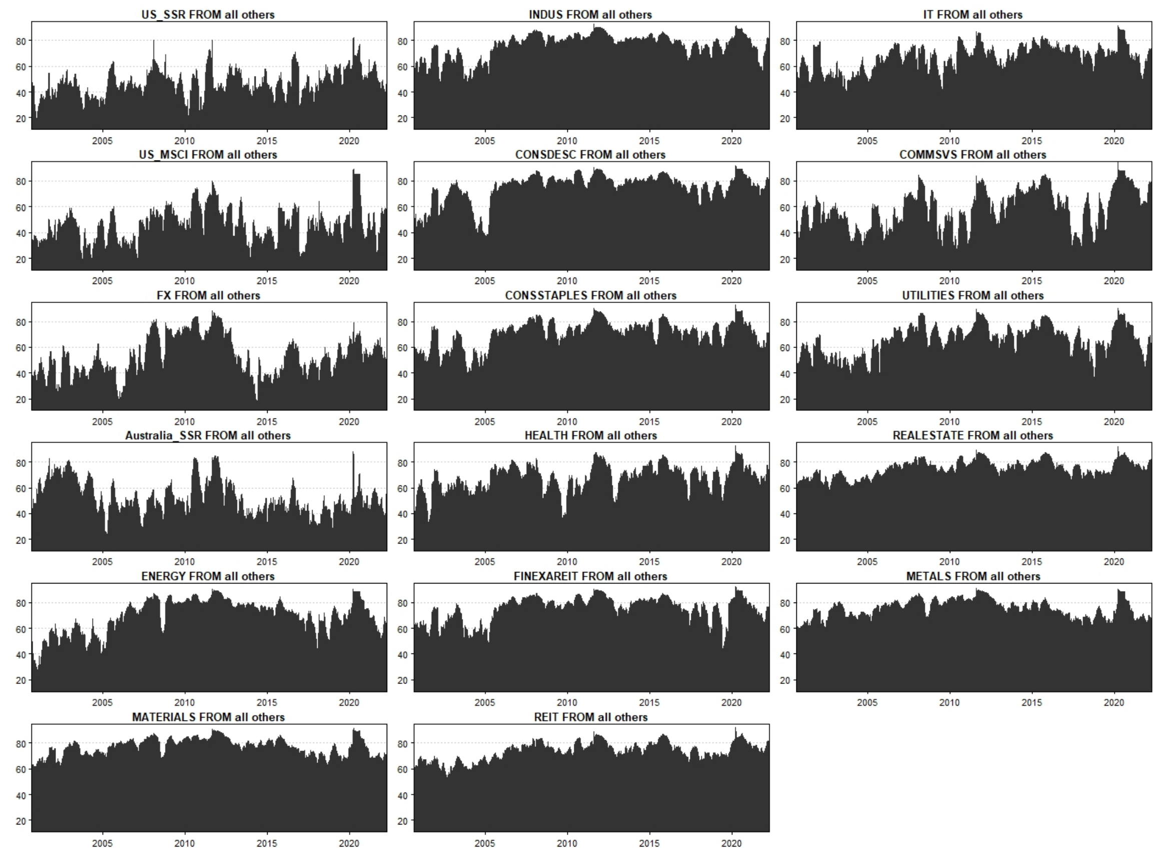

Figure 6: Dynamic spillovers From all others

Note: Results are based on Diebold and Yilmaz (2012,2014) technique with lag length of order one (Bayesian information criterion, BIC) and a 10-step-ahead generalized forecast error variance decomposition.

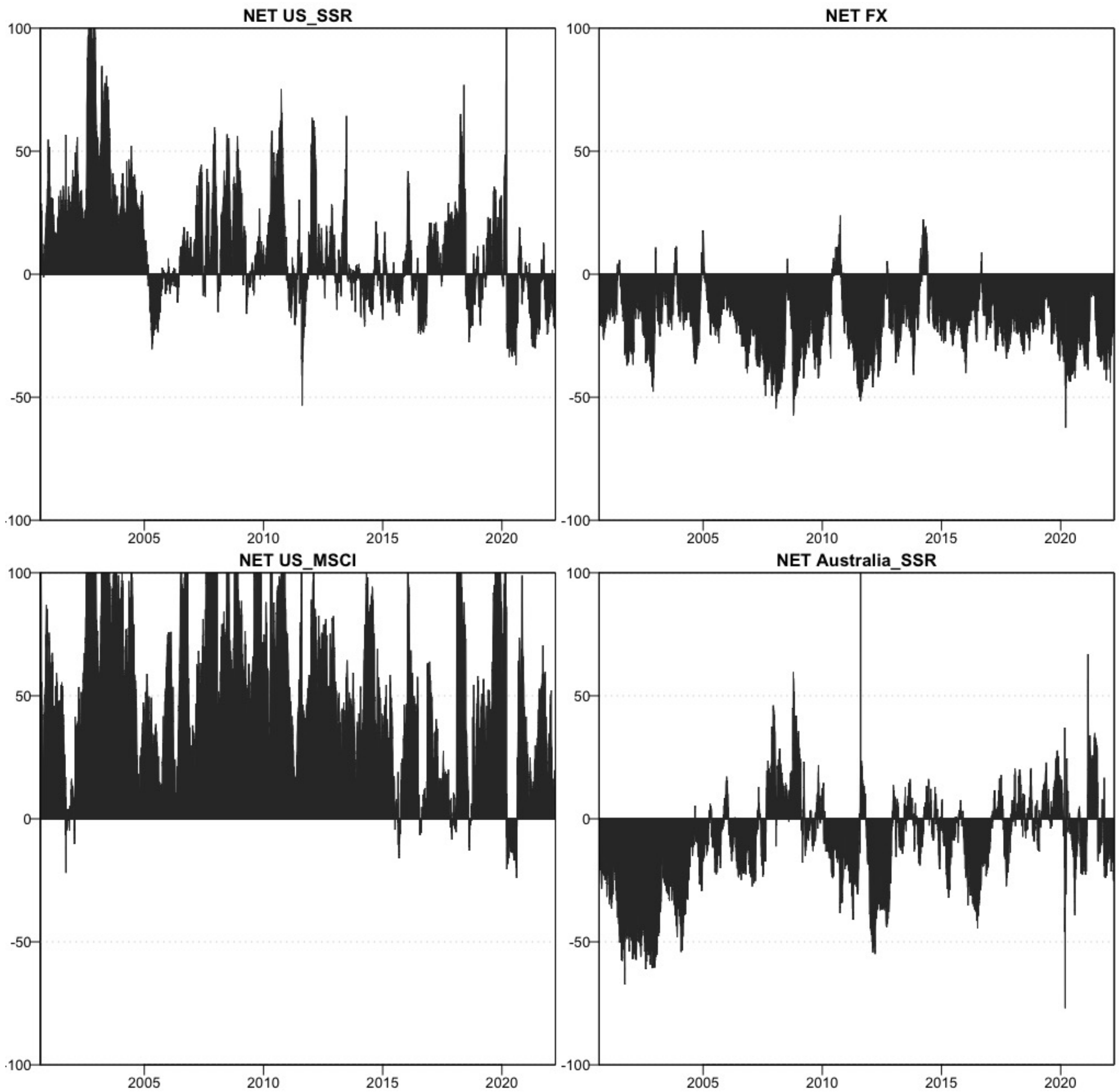

Figure 7: Dynamic net spillovers/spillbacks (NSI) – interest rate, FX and MSCI-US

Note: Results are based on (Diebold & Yilmaz, 2012; Diebold & Yılmaz, 2014) technique with lag length of order one (Bayesian information criterion, BIC) and a 10-step-ahead generalized forecast error variance decomposition.

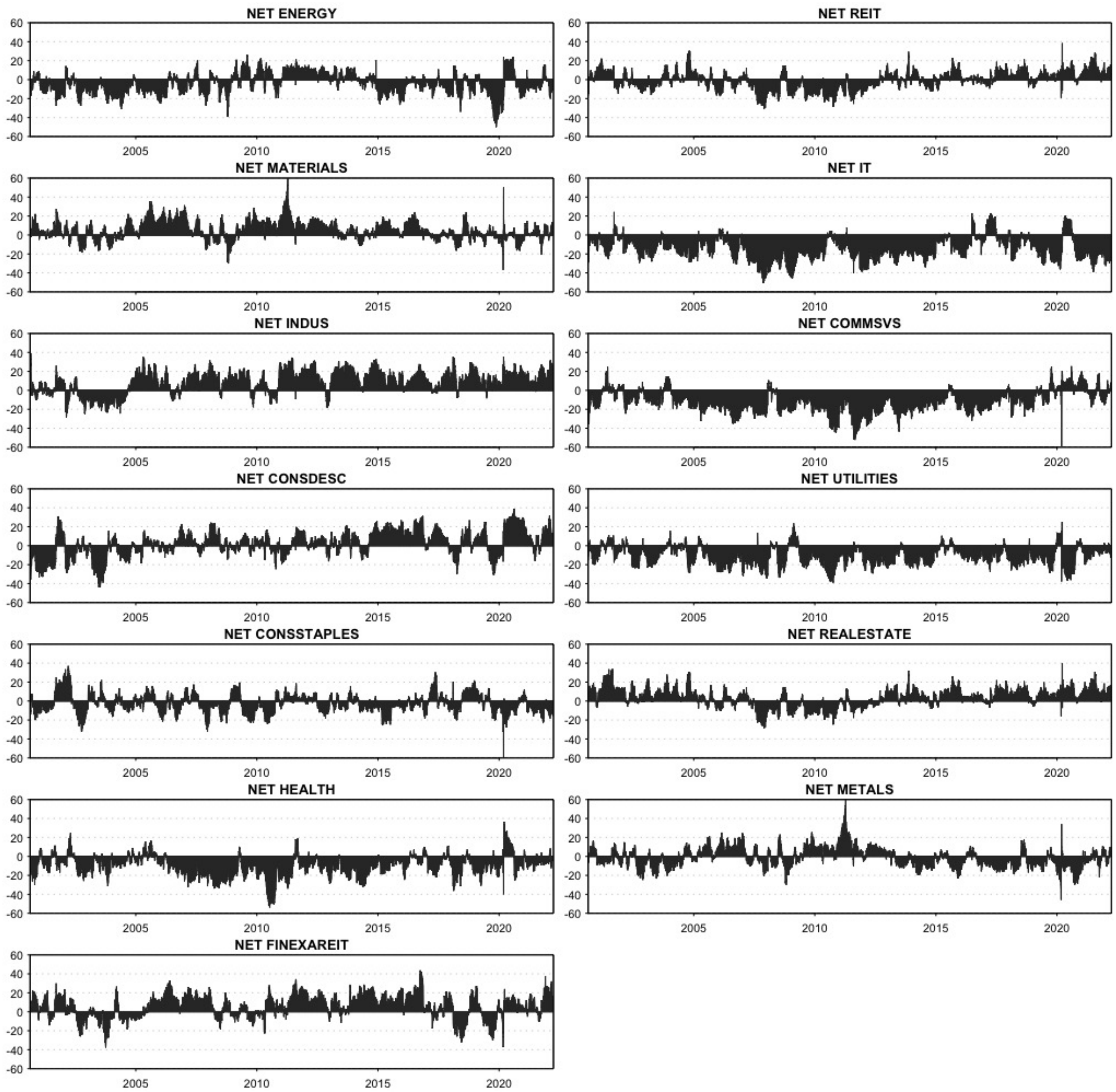

Figure 8: Dynamic net spillovers/spillbacks (NSI) – Australia's sectoral indices

Note: Results are based on Diebold and Yilmaz (2012, 2014) technique with lag length of order one (Bayesian information criterion, BIC) and a 10-step-ahead generalized forecast error variance decomposition.

4.1.4. Frequency domain analysis

Here, based on the Baruník & Křehlík (2018) technique, we present the time-frequency dynamics of the monetary policy and return spillovers. Following Baruník & Křehlík (2018), we use three frequency bands: 1 to 5 days (1 week) to represent the short-term frequencies, 5 to 20 days (1 month) to represent the medium-term and over 20 days to represent the long term. From Tables 3 to 5 we observe that the TSI increases from 48.67% in the short-term to 55.31% in the medium-term, and then reduces to 51.30% in the long-term. This shows that on the average, total spillovers between monetary policy and financial markets are highest in the medium-term.

We move on to observe the dynamic spillovers in the frequency domain. As we see in Figure 9 in the total dynamic frequency, the immediate short-term drive spillovers followed by the medium-term and long-term respectively indicating that the short-term responses drive the overall spillovers in the system. This shows that higher frequencies (in the short-term) drive the spillovers in the system. Hence, market participants normally foresee future uncertainties to be short-lived and thus are more long-term oriented. We however observe that, periods of high uncertainties or peaks particularly during the ESDC and COVID-19 pandemic are observed at lower frequencies (long-term) with observable spikes during these periods.

As we observed earlier, in these periods, there is high market uncertainties hence monetary authorities usually pursue unconventional monetary policies to restore market confidence. These high uncertainties coupled with the unconventional policy stands increases the systematic risk, thus the spillovers. These spikes are however not persistent hence short-lived. As we clearly see, the peaks are occasional and quickly become stable as market participants show less fear. The results in Tables 3 to 5 are largely qualitatively consistent with our earlier results. We see that compared to Australia's monetary policy, US monetary policy is the dominant transmitter of international monetary policy in all frequency bands with positive net spillovers. We, however, see that Australia's monetary policy is a net receiver of spillovers over all frequency bands except in 1-5 days. This shows that Australia's monetary policy is only effective at transmitting spillovers in the system in the first week of monetary policy changes. When we summarize the net spillovers to sectoral equities, we again confirm the US monetary

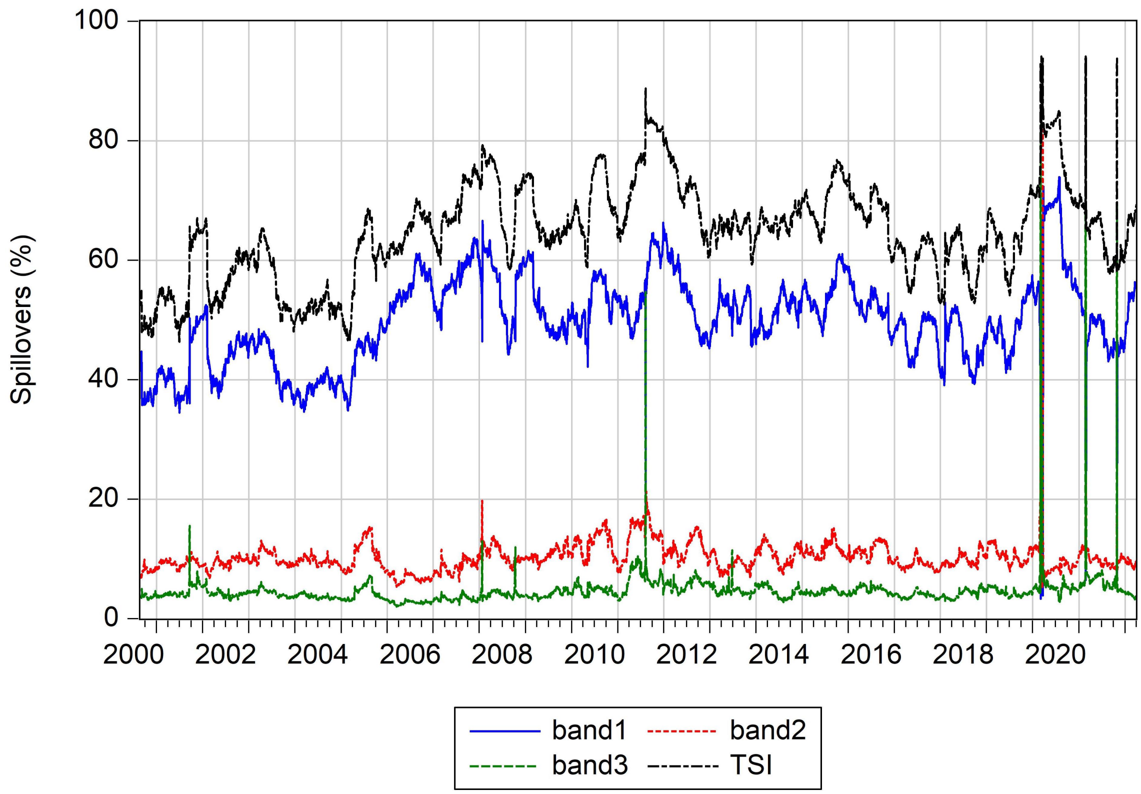

Figure 9: Dynamic total and frequency spillovers

Note: Results are based on Baruník & Křehlík (2018) technique with lag length of order one (Bayesian information criterion, BIC) and a 10-step-ahead generalized forecast error variance decomposition. Band1: 3.14 to 0.63 that roughly corresponds to 1–5 days (1 week); Band2: 0.63 to 0.16 that roughly corresponds to 5–20 days (1 month); Band3: 0.16 to 0 that roughly corresponds to 20 days–infinity (over 1 month); TSI refers to total spillover index which is the sum of frequency spillovers.

policy to have positive net spillover in all frequencies except for in the long-term, while Australia's monetary policy has only a positive net spillover in the first week. This shows the dominance of US monetary policy in Australia's financial markets especially up to the medium-term, while the dominance of Australia's monetary policy on the financial markets is only seen in the first week. Concerning the sectors, we again see that the industrial and materials sectors are the dominants transmitters of sectoral spillovers while the utilities, IT and communication services sectors remain the top receivers of spillovers.

Table 3: Frequency 1: The spillover table for band 3.14 to 0.63 that roughly corresponds to 1–5 days

	US_SSR	US_MSCI	FX	Australia_SSR	ENERGY	MATERIALS	INDUS	CONSDESC	CONSSTAPLES	HEALTH	FINEXAREIT	REIT	IT	COMMSVS	UTILITIES	REALESTATE	METALS	Spillovers FROM Others
US_SSR	**23.87**	2.98	0.06	3.01	0.28	0.21	0.22	0.25	0.07	0.09	0.33	0.07	0.12	0.05	0.09	0.09	0.19	0.48
US_MSCI	6.39	**50.6**	0.69	3.16	2.51	2.11	3.07	2.95	1.21	1.56	3.35	1.2	1.51	1.07	1.03	1.43	1.92	2.07
FX	0.55	7.1	**48.57**	1.73	3.85	3.92	2.24	0.55	0.49	0.32	2.12	1.2	0.28	0.27	0.3	1.25	3.82	1.77
Australia_SSR	3.63	2	0.57	**27.56**	0.24	0.52	0.28	0.3	0.13	0.07	0.36	0.06	0.05	0.03	0.13	0.08	0.5	0.53
ENERGY	0.6	3.37	1.76	0.35	**22.82**	9.03	5.84	3.08	3.82	2.44	5.95	2.82	1.77	1.39	3.16	3.22	8.28	3.35
MATERIALS	0.71	4.81	1.57	0.55	7.93	**19.3**	5.24	2.96	3.73	1.75	4.65	2.02	1.66	1.21	2.3	2.26	18.82	3.66
INDUS	0.6	4.13	0.77	0.29	4.76	4.72	**17.91**	5.84	5.65	4.19	7.78	4.75	3.43	2.51	4.53	5.27	3.75	3.7
CONSDESC	0.92	5.83	0.08	0.45	3.09	3.49	7.36	**22.45**	5.49	4.54	6.52	3.25	4.05	3	3.13	3.73	2.81	3.4
CONSSTAPLES	0.27	1.98	0.21	0.16	4.03	4.47	7.26	5.7	**23.97**	5.64	7.43	3.55	3.32	3.59	4.72	3.95	3.6	3.52
HEALTH	0.35	2.27	0.01	0.13	3.21	2.51	7.01	5.88	6.98	**29.98**	5.65	3.04	4.27	3.27	4.09	3.4	1.85	3.17
FINEXAREIT	0.61	3.44	0.77	0.35	5.11	4.48	8.27	5.43	6.07	3.6	**19.05**	5.54	2.77	2.47	3.89	6.15	3.61	3.68
REIT	0.33	2.42	0.53	0.11	2.66	2.03	5.84	3.18	3.36	2.21	6.5	**21.87**	1.39	1.55	3.35	21.43	1.5	3.43
IT	0.68	4.42	0.11	0.22	2.6	2.93	6.26	5.84	4.67	4.78	4.86	2.12	**31.64**	3.1	2.98	2.53	2.37	2.97
COMMSVS	0.23	2.01	0.03	0.1	2.43	2.43	5.16	5.1	5.56	4.02	4.96	2.76	3.48	**36.26**	3.25	3.12	1.97	2.74
UTILITIES	0.29	1.96	0.15	0.11	4.08	3.28	7.21	4.19	5.79	4.2	5.97	4.3	2.58	2.55	**29.27**	4.7	2.55	3.17
REALESTATE	0.38	2.58	0.52	0.13	2.87	2.17	6.13	3.47	3.51	2.35	6.81	20.23	1.58	1.67	3.44	**20.75**	1.61	3.5
METALS	0.69	4.66	1.68	0.56	7.95	20.6	4.59	2.6	3.3	1.44	4.11	1.67	1.46	1.06	1.99	1.87	**21.04**	3.54
Spillovers TO Others	1.01	3.29	0.56	0.67	3.39	4.05	4.82	3.37	3.52	2.54	4.55	3.45	1.98	1.69	2.49	3.79	3.48	
Net Spillover/Spillback	0.54	1.22	-1.21	0.15	0.04	0.40	1.12	-0.03	0.00	-0.63	0.87	0.01	-0.99	-1.05	-0.68	0.30	-0.06	TSI = 48.67%
Sectoral equity analysis																		
Spillovers to Sectoral Indices	*6.66*	*43.88*	*8.19*	*3.51*	*50.72*	*62.14*	*76.17*	*53.27*	*57.93*	*41.16*	*71.19*	*56.05*	*31.76*	*27.37*	*40.83*	*61.63*	*52.72*	
Spillovers From Sectoral Indices	2.06	24.92	20.61	2.75	50.8	54.53	57.18	50.46	57.26	51.16	57.39	55	45.04	44.24	51.4	55.84	52.64	
Net Spillovers/Spillback to Sectoral Indices	***4.60***	***18.96***	***-12.42***	***0.76***	***-0.08***	***7.61***	***18.99***	***2.81***	***0.67***	***-10.00***	***13.80***	***1.05***	***-13.28***	***-16.87***	***-10.57***	***5.79***	***0.08***	

Note: All Variables are as defined earlier.

Table 4: Frequency 2: The spillover table for band 0.63 to 0.16 that roughly corresponds to 5-20 days

	US_SSR	US_MSCI	FX	Australia_SSR	ENERGY	MATERIALS	INDUS	CONSDESC	CONSSTAPLES	HEALTH	FINEXAREIT	REIT	IT	COMMSVS	UTILITIES	REALESTATE	METALS	Spillovers Others FROM
US_SSR	**30.87**	2.86	0.06	3.76	0.18	0.18	0.11	0.25	0.05	0.06	0.39	0.04	0.16	0.11	0.04	0.06	0.17	0.5
US_MSCI	0.93	**6.67**	0.09	0.39	0.21	0.23	0.29	0.34	0.08	0.09	0.31	0.13	0.2	0.14	0.06	0.14	0.2	0.22
FX	0.08	1.64	**8.13**	1.16	0.76	0.97	0.5	0.11	0.07	0.01	0.51	0.24	0.09	0.06	0.04	0.26	0.96	0.44
Australia_SSR	9.03	2.72	0.56	**24.5**	0.16	0.41	0.02	0.28	0.02	0.01	0.19	0	0.04	0.04	0.01	0.01	0.41	0.82
ENERGY	0.3	1	0.4	0.17	**4.07**	1.77	1.07	0.56	0.52	0.32	0.97	0.46	0.35	0.27	0.45	0.52	1.63	0.63
MATERIALS	0.21	1.05	0.36	0.18	1.28	**3.49**	0.74	0.48	0.45	0.18	0.62	0.22	0.27	0.18	0.25	0.25	3.44	0.6
INDUS	0.21	1.05	0.15	0.09	0.72	0.77	**3.23**	1.05	0.74	0.62	1.24	0.91	0.64	0.37	0.66	0.99	0.61	0.64
CONSDESC	0.36	1.48	0.02	0.14	0.52	0.53	1.3	**4.07**	0.75	0.66	1.03	0.66	0.82	0.51	0.48	0.76	0.41	0.61
CONSSTAPLES	0.06	0.37	0.04	0.06	0.48	0.56	1.02	0.79	**3.75**	0.73	1.02	0.52	0.44	0.48	0.6	0.56	0.45	0.48
HEALTH	0.1	0.47	0	0.02	0.36	0.31	0.89	0.83	0.92	**4.52**	0.64	0.45	0.68	0.41	0.58	0.5	0.23	0.43
FINEXAREIT	0.3	0.9	0.14	0.11	0.71	0.65	1.29	0.91	0.81	0.45	**3.32**	0.94	0.49	0.35	0.52	1.02	0.52	0.6
REIT	0.09	0.62	0.12	0.02	0.49	0.41	1.09	0.64	0.47	0.41	1.02	**3.96**	0.28	0.32	0.51	3.83	0.3	0.62
IT	0.24	1	0.03	0.05	0.37	0.34	0.96	0.99	0.52	0.66	0.66	0.3	**5.54**	0.48	0.36	0.37	0.26	0.45
COMMSVS	0.04	0.43	0.01	0.01	0.29	0.26	0.7	0.67	0.74	0.54	0.55	0.37	0.61	**6.35**	0.48	0.43	0.2	0.37
UTILITIES	0.08	0.36	0.01	0.02	0.52	0.44	1.09	0.51	0.75	0.51	0.75	0.73	0.4	0.4	**4.73**	0.78	0.35	0.45
REALESTATE	0.11	0.66	0.12	0.02	0.53	0.43	1.13	0.68	0.5	0.43	1.07	3.68	0.32	0.33	0.54	**3.73**	0.32	0.64
METALS	0.2	1.03	0.39	0.19	1.3	3.76	0.62	0.41	0.39	0.13	0.54	0.16	0.24	0.16	0.21	0.19	**3.89**	0.58
Spillovers TO Others	0.73	1.04	0.15	0.38	0.52	0.71	0.75	0.56	0.46	0.34	0.68	0.58	0.35	0.27	0.34	0.63	0.62	TSI = 55.31%
Net Spillover/Spillback	0.23	0.81	-0.29	-0.44	-0.11	0.11	0.12	-0.05	-0.02	-0.09	0.08	-0.05	-0.09	-0.10	-0.11	-0.01	0.03	
Sectoral equity analysis																		
Spillovers to Sectoral Indices	*2.30*	*10.42*	*1.79*	*1.08*	*7.57*	*10.23*	*11.90*	*8.52*	*7.56*	*5.64*	*10.11*	*9.40*	*5.54*	*4.26*	*5.64*	*10.20*	*8.72*	
Spillovers From Sectoral Indices	1.8	2.42	4.58	1.6	8.89	8.36	9.32	8.43	7.65	6.8	8.66	9.77	6.27	5.84	7.23	9.96	8.11	
Net Spillovers/Spillback to Sectoral Indices	***0.50***	***8.00***	***-2.79***	***-0.52***	***-1.32***	***1.87***	***2.58***	***0.09***	***-0.09***	***-1.16***	***1.45***	***-0.37***	***-0.73***	***-1.58***	***-1.59***	***0.24***	***0.61***	

Note: All Variables are as defined earlier.

Table 5: Frequency 3: The spillover table for band 0.16 to 0 that roughly corresponds to 20 days-infinity

	US_SSR	US_MSCI	FX	Australia_SSR	ENERGY	MATERIALS	INDUS	CONSDESC	CONSSTAPLES	HEALTH	FINEXAREIT	REIT	IT	COMMSVS	UTILITIES	REALESTATE	METALS	Spillovers FROM Others
US_SSR	**22.58**	2.04	0.04	2.73	0.13	0.13	0.07	0.18	0.03	0.04	0.28	0.03	0.12	0.08	0.02	0.04	0.12	0.36
US_MSCI	0.35	**2.36**	0.03	0.14	0.07	0.08	0.1	0.12	0.03	0.03	0.11	0.04	0.07	0.05	0.02	0.05	0.07	0.08
FX	0.03	0.63	**2.97**	0.55	0.27	0.36	0.17	0.04	0.02	0	0.18	0.08	0.03	0.02	0.01	0.09	0.36	0.17
Australia_SSR	7.8	1.88	0.31	**14.04**	0.11	0.25	0.01	0.19	0.01	0.01	0.15	0	0.04	0.03	0	0.01	0.25	0.65
ENERGY	0.17	0.4	0.15	0.08	**1.47**	0.65	0.38	0.21	0.19	0.11	0.36	0.16	0.13	0.1	0.16	0.18	0.6	0.24
MATERIALS	0.09	0.39	0.13	0.07	0.45	**1.25**	0.26	0.17	0.16	0.06	0.22	0.07	0.1	0.06	0.09	0.08	1.24	0.21
INDUS	0.1	0.39	0.05	0.03	0.25	0.28	**1.16**	0.38	0.26	0.22	0.44	0.33	0.23	0.13	0.23	0.36	0.22	0.23
CONSDESC	0.18	0.56	0.01	0.06	0.19	0.19	0.47	**1.47**	0.27	0.23	0.37	0.24	0.3	0.19	0.17	0.28	0.14	0.23
CONSSTAPLES	0.03	0.14	0.02	0.03	0.17	0.2	0.36	0.28	**1.33**	0.26	0.36	0.18	0.15	0.17	0.21	0.2	0.16	0.17
HEALTH	0.04	0.17	0	0	0.12	0.11	0.31	0.29	0.32	**1.6**	0.22	0.16	0.24	0.15	0.21	0.18	0.08	0.15
FINEXAREIT	0.17	0.35	0.05	0.05	0.25	0.23	0.46	0.33	0.29	0.16	**1.21**	0.34	0.18	0.13	0.18	0.37	0.19	0.22
REIT	0.03	0.22	0.04	0	0.17	0.14	0.39	0.23	0.16	0.15	0.36	**1.42**	0.1	0.11	0.18	1.37	0.11	0.22
IT	0.12	0.37	0.01	0.02	0.13	0.12	0.34	0.36	0.18	0.24	0.24	0.11	**2**	0.18	0.13	0.13	0.09	0.16
COMMSVS	0.01	0.14	0	0	0.1	0.09	0.25	0.23	0.26	0.19	0.19	0.13	0.22	**2.27**	0.17	0.15	0.07	0.13
UTILITIES	0.03	0.13	0	0	0.18	0.15	0.39	0.18	0.26	0.18	0.26	0.26	0.14	0.14	**1.69**	0.28	0.12	0.16
REALESTATE	0.04	0.24	0.04	0	0.19	0.15	0.41	0.24	0.17	0.15	0.38	1.32	0.11	0.12	0.19	**1.34**	0.11	0.23
METALS	0.08	0.38	0.14	0.07	0.46	1.35	0.22	0.15	0.13	0.04	0.19	0.05	0.08	0.06	0.07	0.06	**1.4**	0.21
Spillovers TO Others	0.55	0.49	0.06	0.23	0.19	0.26	0.27	0.21	0.16	0.12	0.25	0.21	0.13	0.1	0.12	0.22	0.23	TSI = 51.3%
Net Spillover/Spillback	0.19	0.41	-0.11	-0.42	-0.04	0.05	0.04	-0.02	-0.01	-0.03	0.03	-0.01	-0.03	-0.03	-0.04	0.00	0.02	
Sectoral equity analysis																		
Spillovers to Sectoral Indices	*1.09*	*3.88*	*0.64*	*0.41*	*2.66*	*3.66*	*4.24*	*3.05*	*2.65*	*1.99*	*3.59*	*3.35*	*1.98*	*1.54*	*1.99*	*3.64*	*3.13*	
Spillovers From Sectoral Indices	1.27	0.84	1.63	1.06	3.23	2.96	3.33	3.04	2.7	2.39	3.11	3.47	2.25	2.05	2.54	3.54	2.86	
Net Spillovers/Spillback to Sectoral Indices	***-0.18***	***3.04***	***-0.99***	***-0.65***	***-0.57***	***0.70***	***0.91***	***0.01***	***-0.05***	***-0.40***	***0.48***	***-0.12***	***-0.27***	***-0.51***	***-0.55***	***0.10***	***0.27***	

Note: All Variables are as defined earlier.

5. Monetary Policy Transmission to Inflation and Output

In this section, we discuss the results of the response of output and inflation to monetary policy shocks. We first discuss the VAR results based on the Cholesky identification following previous literature (Stock & Watson, 2001) and compare the results to our IV approach. We provide further robustness by adding commodity prices to our VAR model. We also provide additional robustness by using US net monetary policy surprises as the external instrument for Australia's monetary policy. BIC suggests two lags, and the results are presented using impulse response functions (IRFs).

5.1. Recursive VAR based on Cholesky identification

Here, we discuss our results based on the Cholesky identification. From the right panel of Figure 10, we see that a contractionary US monetary policy leads to an insignificant increase in Australia's output and inflation. Inflation however increases but peaks around 5 months. While weak, these results may suggest that a contractionary US monetary policy leads to an appreciation of the US dollar, resulting in a rise in imports of Australia's goods, leading to a rise in Australia's output and inflation.

From the left panel of Figure 10, we see that a monetary policy shock leads to marginal but insignifcant fall in output but an initial increase in inflation confirming the price puzzle. This is not surprising given that the literature shows that half of the papers in a survey of related studies using similar VAR framework showed the presence of the price puzzle (Rusnák et al., 2013). This result is consistent with the earlier studies of Beechey & Österholm (2008), Phan (2014) and Bishop & Tulip (2017) for Australia. Indeed, Bishop & Tulip (2017) finds the price puzzle for Australia's monetary policy in different VAR specifications and conclude that VAR models may not be appropriate for analysing Australia's monetary policy. It is therefore necessary as a policy relevance to be able to have an appropriate VAR model that is able remove the price puzzle in Australia's data. We proceed to discuss the results from our IV approach which is able to remove this puzzle.

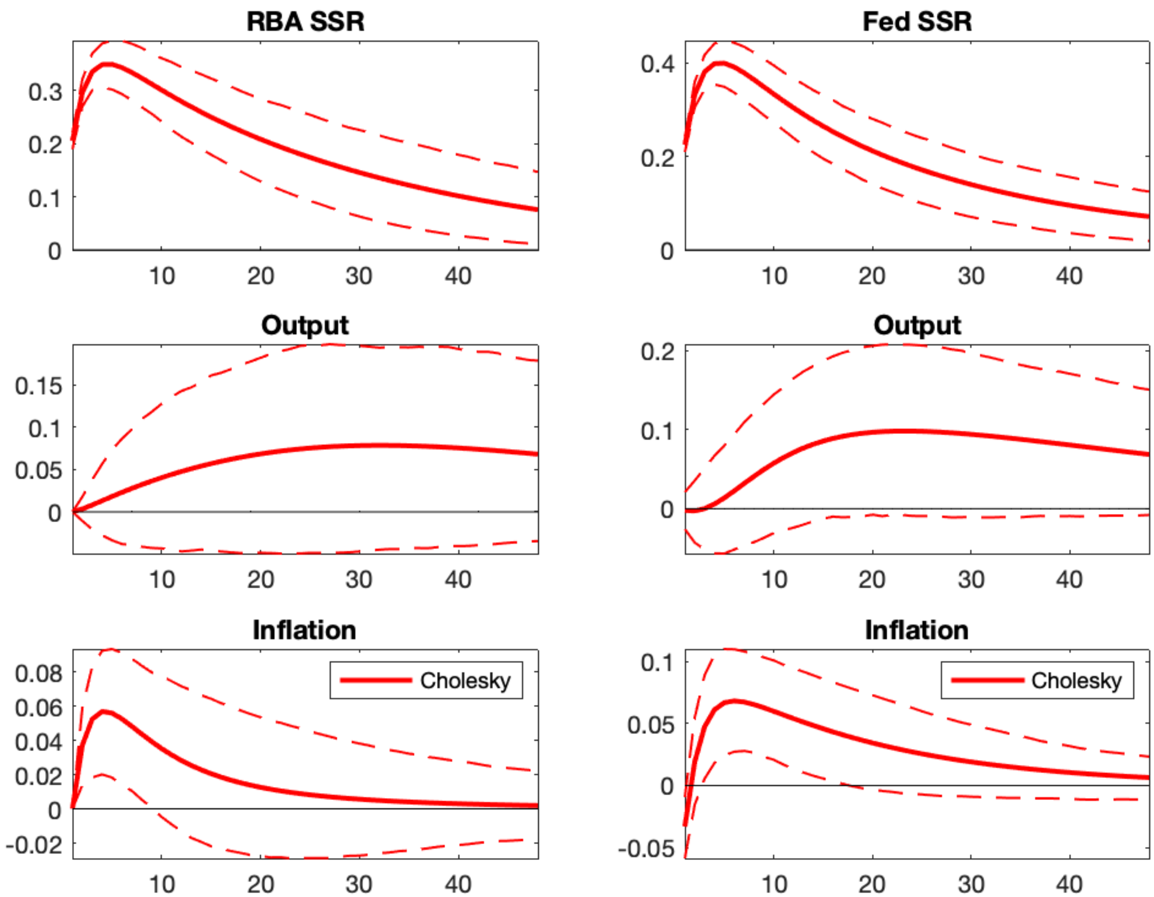

Figure 10: Impulse response functions (response to policy [RBA and Fed. SSR] shocks) of inflation and real output (industrial production) in a Cholesky identification and instrumental VAR approach based on Gertler & Karadi (2015) with 68% wild bootstrapped confidence intervals for the model with two lags, based on 1,000 replications. Horizontal axis are in months.

5.2. External instruments approach

Having found the price puzzle in the Cholesky Identification, we proceed to compare our results with our IV approach which rightly identifies our VAR. Here, the study follows Gertler & Karadi (2015) and combines the traditional "money shock" VAR analysis with a high-frequency identification (HFI) using net spillovers generated from daily data through the DY(12,14) approach to examine the effect of policy surprises on inflation and output. This hybrid approach following from Gertler & Karadi (2015) employs HFI measures of policy surprises/spillovers as external instruments in a set of VARs to identify the effects of monetary policy. This approach requires an identification of policy surprises/spillovers that can be considered exogenous to our economic variables. This is also similar to the identification strategy employed by Elliott et al. (2024) and Jarociński & Karadi (2020), who also employ monetary policy shocks as an instrument for the monetary policy variable in the second stage. Given the unique net monetary spillovers of the DY(12,14) in terms of the NET($To - From$ spillovers) spillovers of both US and Australia's monetary policy (SSR), these spillovers are plausible instruments for our monetary policy variables as they represent surprises only attributed to our monetary policy variables. Even though we do acknowledge the limitation of the DY(12,14) technique which employs the GIRF – that the shocks may have some noise – the GIRF provides a comprehensive framework where the monetary policy surprises estimated from the DY(12,14) can give us a good evolution of the monetary policy variables, SSR. This provides useful information for us to identify our monetary policy shocks.

In Table 6, we test the validity of our instruments using a two-stage least squares (2SLS) where we regress inflation or real output on the SSR of either Australia or US but instrument for the SSR with the net monetary policy surprises. We summarize the first stage results, which regresses the SSR on the monetary policy surprises as is the convention of the HFI literature (Gertler & Karadi, 2015). From the Table, we see that net monetary policy surprises of both Australia (AUS_SPILL) and US (US_SPILL) are correlated with Australia's monetary policy stance with a 1% significance level. Also, net US monetary policy surprise (US_SPILL) positively correlates with US monetary policy stance. These results satisfy the relevance condition for our instruments.

Also, the Sanderson & Windmeijer (2016) F and χ^2 tests reject the null hypothesis of under- and weak identification, respectively. Again, the Cragg & Donald (1993) *Wald* F-statistic test of weak identification is generally rejected as the values are greater than the Stock-Yogo (2005) weak ID test critical values from 5.53 (25% critical value) to 16.38 (10% critical value) albeit some noise for net US monetary policy surprises. These findings, along with the fact that net monetary policy surprises (AUS_SPILL and US_SPILL) can only impact output and inflation via monetary policy stance (Shadow short rate), suggest that our instruments are appropriate.

Table 6: First Stage results - Dependent variable SSR

Variable	AUS_SSR		US_SSR
	(1)	(2)	(3)
AUS_SPILL	-0.029***		
	(0.007)		
US_SPILL		0.041***	0.014***
		(0.006)	(0.005)
Observations	260	260	260
Sanderson-Windmeijer F Test	16.17***	54.11***	7.86***
Sanderson-Windmeijer χ^2 Test	16.29***	54.53***	7.92***
Cragg-Donald F-stats	15.19	51.45	5.02

Note: *** Significance at 1%. Robust Standard errors in parenthesis. The table represents the first-stage results of a two-stage least squares (2SLS) estimation of the impact of Australian SSR or US SSR on inflation/Output (gives the same first-stage results) using our monetary policy spillovers or surprises as instruments for the SSR series. AUS_SPILL is the net Australia monetary policy spillovers or surprises. US_SPILL is the net US monetary policy spillover or surprises.

We proceed to discuss the IRFs as shown in Figure 11. From the left column in Figure 11 (IRFs in black), a one standard deviation increase in RBA's monetary policy shock (instrumented with an exogenous monetary policy spillover) leads to a marginal fall in output and a significant fall of about 0.20% in inflation which lasts for about 20 months. Hence, instrumenting for Australia's monetary policy shocks eliminates the price puzzle. In addition to our test of instrument validity earlier, following Cesa-Bianchi & Sokol (2022) and Mertens & Ravn (2013), we report two other reliability statistics for the validity of the instrument: similar to those of Cesa-Bianchi & Sokol

(2022), the R^2 of the first-stage regression is 0.02, while the eigenvalues of the reliability matrix is 0.98. Both statistics indicate that the instruments provide useful information for identifying our structural shocks, albeit with a fair amount of noise.

When we look at the spillover from US monetary policy in the right column of Figure 11, we see that for the IV approach, a Fed monetary policy shock (tightening) leads to a marginal but insignificant fall in output. We, however, see that US monetary policy shock leads to an initial rise in Australia's inflation around 0.20%, which is around the fall from the response to Australia's monetary policy shock as seen earlier. The increase lasts for about the same period as was for the response to Australia's monetary policy. Indeed, US is Australia's second major trading partner in terms of Australia's imports. Hence, a tightening of US monetary policy will make the dollar stronger–this is the exchange rate channel. This makes imports denominated in US dollars expensive, leading to a rise in Australia's inflation. Moreover, US importers will increase their imports from Australia considering the strengthening of the US dollar, while other importers will also shift to Australia for their imports. These results are consistent with the results of Caldara et al. (2022).

5.3. Further robustness: including commodity prices

The literature on the price puzzle in VAR models usually attributes this puzzle to the inability of variables in the VAR model to capture the central bank's information set about future inflation (Bernanke & Mihov, 1998; Sims, 1992). Studies like Hanson (2004), Bernanke & Mihov (1998) and Sims (1992) suggest the use of commodity price index as a proxy to capture the central bank's additional information set about future inflation. The argument is that commodity prices are sensitive to changes in information about future inflation hence represent a good measure of supply shocks that can capture any anticipatory policy movements. We follow the previous literature and include commodity price index [5] in our VAR specification. From the left panel of Figure 12, where we use the standard Cholesky identification, we see that similar to the findings of Bishop & Tulip (2017) at the Reserve Bank of Australia, the price puzzle is not removed.

[5]Commodity prices index is the natural log of index of all monthly average commodity prices (2020/2021 = 100) provided by the Reserve Bank of Australia (RBA).

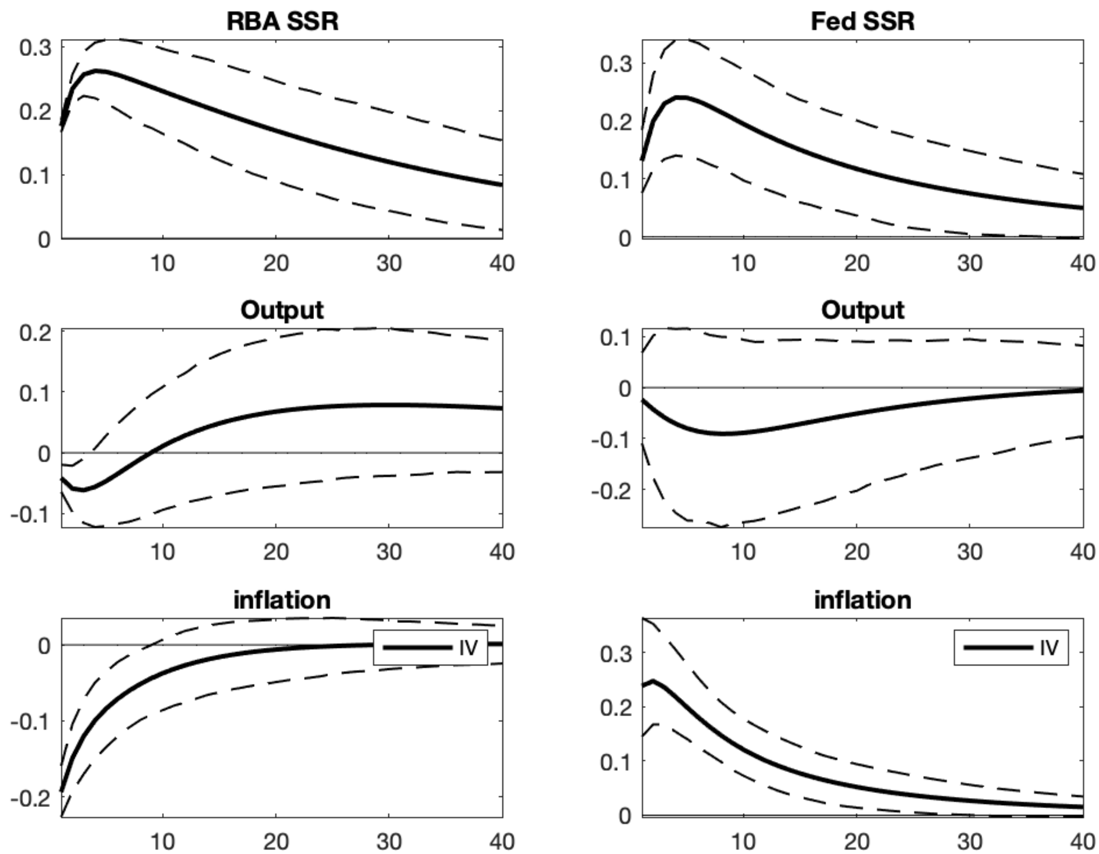

Figure 11: Impulse response functions (response to policy [RBA and US SSR] shocks) of inflation and real output (industrial production) in an instrumental VAR approach following Gertler & Karadi (2015) with 68% wild bootstrapped confidence intervals for the model with two lags, based on 1,000 replications. Horizontal axis are in months.

We, however, notice that adding commodity prices reduces the duration of the price puzzle. While initially, the response of inflation to Australia's monetary policy shock in the Cholesky identification took over 40 months to return to equilibrium, adding commodity prices reduces this duration to about 20 months but its unable to remove the price puzzle.

However, from the right column of the figure, when we instrument for our monetary policy shocks and add commodity prices, we see that both the response of output and inflation are significant, and the price puzzle is eliminated. Thus, a contractionary monetary policy leads to a fall in output and inflation, confirming the theoretical interpretation. We observe here that adding commodity prices to the model leads to a significant drop in output in response to policy shocks compared to the model without commodity prices. Though the response of commodity prices to policy shocks is weak, the response is negative and sustained, suggesting that contractionary monetary policy shocks are deflationary. These results further confirm that our instruments can be useful in eliminating the price puzzle.

We then proceed to discuss the results of the response of Australia's output and inflation to US monetary policy shocks, including commodity prices. The results are presented in Figure 13. Similar to the earlier findings, we see that the response of Australia's output and inflation to US monetary policy shocks is opposite to the policy shocks of the RBA. We see that a contractionary monetary policy in the US leads to a rise in output, inflation and commodity prices in Australia. These results can be explained through the exchange rate channel. Here, the argument is that a contractionary US monetary policy leads to an appreciation of the US dollar, leading to lower US exports. This leads importers to shift to Australia for their imports while US importers increase their imports from Australia. Higher demand for Australia's goods leads to a rise in output and, consequently, prices. Hence, the response of Australia's real sector to US monetary policy is opposite to the response to Australia's own monetary policy.

6. Conclusion

The first contribution of our paper lies in applying time and frequency-domain analysis of monetary policy spillovers to track the transmission of monetary policy

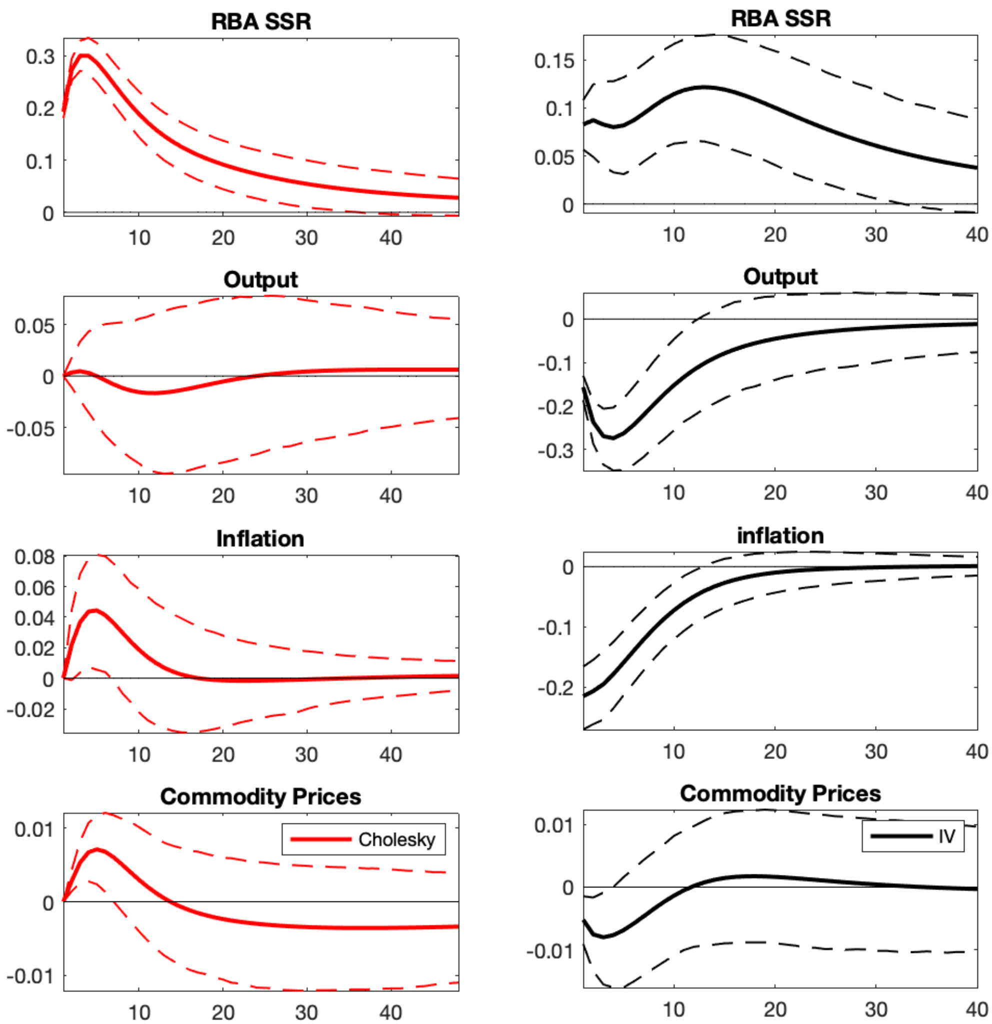

Figure 12: Impulse response functions (response to policy [RBA. SSR] shocks) of inflation and real output (industrial production) with Commodity Prices in a Cholesky identification and instrumental VAR approach based on Gertler & Karadi (2015) with 68% wild bootstrapped confidence intervals for the model with two lags, based on 1,000 replications. Horizontal axis are in months.

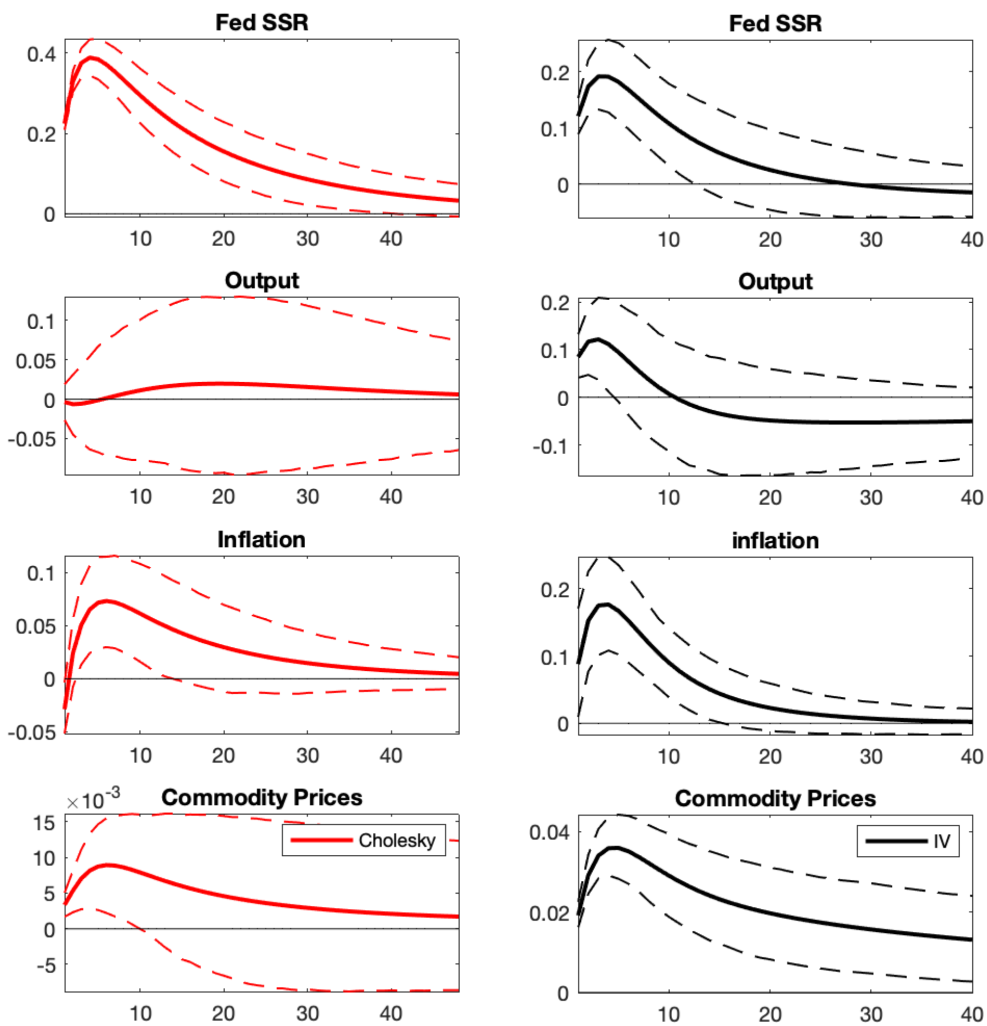

Figure 13: Impulse response functions (response to policy [Fed. SSR] shocks) of inflation and real output (industrial production) with Commodity Prices in a Cholesky identification and instrumental VAR approach based on Gertler & Karadi (2015) with 68% wild bootstrapped confidence intervals for the model with two lags, based on 1,000 replications. Horizontal axis are in months.

through three different channels in an integrated framework. Through this, we examined both the international transmission of US monetary policy on Australia's economy and Australia's own monetary policy transmission, all in the same framework. We find high spillovers of up to an average of 64% between US monetary policy and Australia's monetary policy and financial markets. This shows a relatively high connectedness between the Fed's monetary policy decisions and Australia's market. Indeed, we find that US monetary policy plays a dominant role in Australia's financial markets than Australia's own monetary policy.

We find that while US monetary policy is a net transmitter of spillovers to Australia's financial markets, Australia's monetary policy is a net receiver of spillovers from its own markets. The main transmission channel of US monetary policy is the interest rate channel, followed by the asset price and exchange rate channels, respectively.

Again, we add to the literature by considering the consequences of these spillovers on the real sector: inflation and output. We first compare a recursive monetary policy VAR with and without considering these spillovers and find that, without accounting for these spillovers, we are unable to properly identify monetary policy shocks in a VAR framework for Australia's monetary policy consistent with literature. However, using the spillovers between Australia's monetary policy and its financial markets and the Fed's monetary policy as an instrument to identify monetary policy shocks rightly predicts inflation and output in conformity to theory. We, however, find that US monetary policy shocks generally exert an opposite impact on Australia's real sector, which may undermine the monetary policy objectives of the RBA. Therefore, without properly accounting for US monetary policy spillovers, the RBA may over or under-tighten its monetary policy. Given the policy relevance of rightly estimating international spillovers in monetary policy decisions of central banks, we show that the spillover analysis we use can provide the right estimates of US monetary policy spillovers to the Australian economy.

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