# Can we use high-frequency yield data to better understand the effects of monetary policy and its communication? Yes and no!

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## Abstract

*We examine the effects of three facets of monetary policy in Australia using high-frequency yield changes around RBA announcements: current policy; signalling/forward guidance; and changes in premia. Shocks to current policy have similar effects to those identified using conventional approaches, but the effects of signalling and premia shocks are imprecisely estimated. Still, the approach provides evidence that: forward guidance shocks raised future rate expectations in the mid-2010s as the RBA highlighted housing risks; Covid-era policy mainly affected term premia, unlike pre-COVID policy; shocks to the expected path of rates are predictable, suggesting markets misunderstand the RBA's reaction to data.*

# 1.     Introduction

To set monetary policy appropriately, it is important for the central bank to understand how monetary policy affects the economy. However, it can be difficult to quantitatively assess the effects of monetary policy. One reason is that monetary policy is not set randomly, but rather in response to expected future economic outcomes. For instance, if the central bank forecasts that inflation and activity are going to increase, it will tend to raise rates to keep inflation from rising too far. As such, it could look like inflation is rising in response to higher interest rates, but in fact interest rates are responding to future (expected) inflation: the relationship is endogenous. A second complicating factor is that central banks not only affect the economy by changing current short-term interest rates, but also through their communication about current and potential future policy. However, quantifying the nature and effects of communication is difficult. Moreover, 'unconventional' policy such as the yield-curve targeting and bond purchase programs used during the COVID-19 pandemic work by affecting longer-term interest rates and expectations, and not just current short-term interest rates.

To get around the first issue, economists often try to identify monetary policy 'shocks'. These are 'exogenous' changes in policy that are unrelated to current and expected economic conditions. As such, these shocks should give a cleaner read of the causal effects of monetary policy on the economy compared to simply looking at rate changes. There is a large literature trying to identify policy shocks, and to quantify their effects, using various approaches (see Section 2 and Ramey 2016 for more details). This includes several papers looking at the Australian economy, including work by Bishop and Tulip (2017), Beckers (2020) and Hartigan and Morley (2020).

To get around the second issue, more recent work has begun incorporating information about longer-term interest rates when constructing measures of monetary policy shocks. In particular, the recent literature has looked at high-frequency changes in interest rates with different maturities just before and after a policy announcement.  These high-frequency changes are interpreted as shocks to current and expected future interest rates as they are above and beyond what market participants expected based on their understanding of systematic monetary policy and the available information. This allows for a more holistic examination of the different facets of monetary policy and its communication, and how these different facets affect the economy.

In this paper we adopt one such approach put forward by Kaminska, Mumtaz and Sustek (2021) (KMS) and apply it to the Australian data. The approach involves combining high-frequency data on changes in yields around policy announcements with an Affine Term Structure Model (ATSM), which decomposes the yields into expected future interest rates and term premia. This allows us to further decompose monetary policy shocks into three different components: (i) shocks to the current short-term policy rate - 'Action' shocks; (ii) shocks to the expected path of rates due to communication about future conditions or policy intentions – 'Path' shocks (iii) and changes in required term premia due, for example, to the effect of communication on uncertainty or, in the case of unconventional policy, on the supply of government bonds – 'Premia' shocks. We then examine the effects of these different shocks on the Australian economy, using them as instruments in a proxy structural vector autoregression (SVAR).

This approach offers three key advantages over previous work. First, as each facet of policy could affect the economy differently, this decomposition potentially allows us to get a cleaner read on

each one, rather than lumping them all together. Second, the approach allows us to try to quantify the effects of the RBA's communication about the outlook for rates and the economy. And third, we can apply this approach to COVID-era monetary policy to better understand the channels through which it affected the economy.

We apply this approach to monetary policy announcements, while also considering other events, such as speeches, release of Board Minutes, and release of the *Statement on Monetary Policy*. This makes our paper the first to identify the macroeconomic effects of monetary policy shocks around a broad set of different monetary-policy related announcements in Australia.

To preview the results, we find that the KMS approach provides an intuitive lens through which to examine monetary policy and its communication. It allows us to understand how policy and its communication affected expectations for rates and risk during certain historical periods, and more generally. For example:

- During the mid-2010s, Path shocks tended to raise expectations about future interest rates as the Bank communicated concerns around risks in the housing market.

- Monetary policy announcements are more likely to be associated with increased term premia during periods of uncertainty, like the Global Financial Crisis.

- Changes in term premia were the key channel through which policy affected interest rates during the Covid-era, while changes in expected future interest rates played a smaller role. This contrasts with pre-COVID policy announcements, which mainly affected expected interest rates. This finding is similar to overseas findings comparing conventional and non-conventional policy periods (e.g. Kaminska and Mumtaz 2022)

- Speeches and other events mainly contain information about future interest rates, though on average they have a much smaller effect on yields compared to policy announcements.

We also find some evidence that shocks to the path of interest rates were predictable based on information at the time. This suggests that markets systematically misunderstand how the RBA reacts to data, potentially because they are learning about this reaction function over time. This highlights the importance of clear communication.

Regarding the effects of monetary policy on the macroeconomy, the KMS high-frequency approach provides broadly similar estimates of the effects of monetary policy to earlier papers in the literature. Positive shocks to current policy (Action shocks) are associated with an appreciation of the exchange rate and an eventual rise in unemployment. These effects are similar to those found using other simpler approaches, such as using high-frequency yield changes directly, including the fact that the 'price puzzle' is still evident, with Action shocks tending to preceded higher inflation. In addition, the macroeconomic effects of both path and premia shocks turn out to be imprecisely estimated. As such, the approach adds little to our understanding of the effects of monetary policy on the macroeconomy.

In the context of the broader literature, we also find evidence that the specification of the ATSM can have substantial effects on the estimated shocks. This is consistent with other papers, such as Kim

and Orphanides (2012), but is important to highlight in the context of interpreting the effects of monetary policy. In particular, if we follow KMS and use statistical methods to adjust the ATSM, rather than augmenting it with surveys, the approach attributes a much larger share of shocks to changes in the path of interest rates, rather than premia. In turn, this can influence the interpretation of the effects of path and premia shocks.

The rest of the paper proceeds as follows. Section 2 provides an overview of the literature on monetary policy shocks. Section 3 describes the KMS approach and shows the corresponding decomposition of yield curve changes. Section 4 examines the effects of the different identified shocks over the pre-COVID period, with robustness of the results examined in Section 5. Section 6 applies the KMS approach to COVID-era policy, and finally Section 7 concludes.

## 2.      Related literature

Our paper relates to the large literature that tries to identify monetary policy 'shocks' – movements unrelated to economic conditions (see Ramey 2016 for detailed reviews of the literature). One of the most common approaches to identifying shocks and their effects is to use SVARs along with some identifying restrictions about the timing, magnitude, or direction of the effects that shocks have on other economic variables. Numerous papers have applied these approaches to Australian data (e.g. Berkelmens 2005; Beechey and Osterholm 2008; Jaaskela and Jennings 2010; Jaaskela and Smith 2011; Read 2022).  A common finding in the Australian literature is that while increases in interest rates tend to be contractionary for the economy, they also tend to be associated with increases in inflation: the so-called 'price puzzle'.

More recently, papers have tried to identify monetary policy shocks using other types of data. For example, Romer and Romer (2004) estimate how the Federal Reserve sets interest rates based on current and expected future conditions, and then use this to identify movements that appear unrelated to these conditions. Bishop and Tulip (2017) and Beckers (2020) both apply this approach to the Australian data. The latter, by also incorporating indicators of financial conditions into the reaction function, is able to overturn the price puzzle. In a somewhat similar vein, some papers have tried to account for this additional information by increasing the information set included in the SVAR (Gambetti 2021). For example, Hartigan and Morley (2020) are able to overturn the price puzzle by including factors extracted from a large macro dataset into the VAR.

Our paper relates more directly to a more recent stream of the literature that has used high-frequency changes in interest rates around policy or other central bank announcements. Using these 'surprises' as monetary policy shocks relies on three assumptions:

1) during the short-window under examination the announcement is the only economic news, so any change can be fully attributed to the announcement;

2) the market has priced in all information about future economic conditions, and so the surprise reflects only information about monetary policy that is unrelated to economic outcomes.

3) the market understands how the central bank will react to the available information.

One key advantage of the high-frequency approach is that it allows us to incorporate information from across the yield curve. This opens up the possibility of understanding not only the transmission of monetary policy through changes in the current policy rate, but also how policy and its communication can affect the economy by changing expectations about future rates, as well as peoples' views about risks and therefore the premia they require to invest.

Early papers in this literature focus on a single short-term interest rate to identify shocks to current rates – action shocks (Kuttner 2001; Gurkaynak, Sack and Swanson 2005a). Gurkaynak, Sack and Swanson (2005b) extend this analysis while focusing on shocks to both current and future expected rates – action and path shocks – by looking at high-frequency changes in interest rates with maturities up to one year.

More recent papers on identification using high-frequency policy surprises point out that the second assumption noted above is likely to be violated in many cases, and that the surprises are likely to combine true policy shocks with additional information about the state of the economy – an information shock. In particular, an unexpected increase in the policy rate could indicate that the central bank expects economic conditions to improve, reflecting additional information held by the central bank and not available to the market. This reintroduces the standard endogeneity issue that shocks are meant to avoid. Jarockinski and Karadi (2020) and Miranda-Agrippino and Ricco (2021) show that ignoring these information shocks leads to biased estimates of the effects of monetary policy. He (2021) explores the information shocks in the Australian content, finding some evidence that speeches contain such information, but little evidence for other communication.

An alternative explanation of the information shocks is the 'news channel' proposed by Bauer and Swanson (2021, 2022). They show that their empirical results are consistent with a "Fed response to news" channel, in which incoming, publicly available economic news causes the Federal Reserve to change monetary policy, but the private sector systematically underestimate the Fed's response. This leads to a violation of the third assumption. They provide substantial new evidence that distinguishes between these two channels and strongly favours the response to news channel. They also outline a model where market participants learn about the Fed's reaction function, which can explain systematic misunderstanding of the Fed's response.

Another recent debate in the literature revolves around the role of term premia and financial conditions in the transmission of monetary policy shocks. Using high-frequency changes in interest rates around announcements for the US, Gertler and Karadi (2015) find that monetary policy shocks transmit through the economy largely by affecting term premia, with expected future interest rates left almost unaffected. To this end, they highlight the importance of including financial variables in models to capture the transmission of monetary policy through the credit markets.[1] Consistent with this, Caldara and Herbst (2019) find that US monetary policy has a strong and systematic response to financial conditions, underlining the importance of including financial variables such as credit spreads in the VAR or when constructing shock measures using the Romer and Romer (2004) approach.

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[1] Doko Tchatoka and Haque (2021) point out that the real effects of U.S. monetary policy shocks identified using Gertler and Karadi's (2015) approach are sensitive to the sample period. They find that once the Volcker disinflation period is left out and one focuses on the post-mid-1980s period, policy shocks have no significant effects on output, despite large movements in credit costs.

Gertler and Karadi's (2015) finding that monetary policy transmits to the economy almost exclusively through changes in term premia presents a challenge to theoretical models used for monetary policy analysis. This, alongside the earlier noted debate around information shocks motivated KMS to revisit the relevance of action, path and term premia shocks using a more structural approach.

Specifically, KMS apply an ATSM to high-frequency data on changes in the yield curve around FOMC announcements. This allows them to decompose these changes into changes in expected rates and term premia. Using additional restrictions in a second step, they further decompose these surprises into three different facets of monetary policy and its communication: changing current short-term rates - Actions shocks; changes in the expected path of rates - Path shocks; and changes in term premia or uncertainty - Premia shocks. They then study the macroeconomic effects of the different facets of monetary policy using a local projections model. Overall, they find that action shocks affect the economy like textbook monetary policy shocks. Path shocks appear to capture signalling about future economic conditions, while premia shocks are hard to interpret, but have some hallmarks of uncertainty shocks.

Our paper also relates to the literature on ATSMs. In particular, several papers have highlighted that ATSMs tend to produce unreasonably stable estimates of expected rates in the far future. This reflects small-sample biases in these models. Some papers have suggested using statistical approaches to address this bias (e.g. Malik and Meldrum 2016), as used in KMS. In contrast, other papers have argued for the incorporation of surveys to provide additional information on the expected path of short-term interest rates (e.g. Kim and Orphanides 2012 and Guimaraes 2016). As we show in Appendix A and B, the choice of approach can affect the identified shocks in the KMS framework and therefore alter the interpretation of the shocks.

## 3.     Documenting shock measures pre-COVID

As discussed above, KMS suggest a new approach to identifying monetary policy shocks using high-frequency data that is able to separate out the effects of action, signalling/forward guidance, and effect on term premia. Specifically, KMS suggest a three-step approach to constructing more interpretable monetary policy shocks:

1.  Gather high-frequency measures of surprise yield changes.
2.  Decompose changes in yields into changes in expected policy rates, and changes in premia.
3.  'Reshape' these changes in expected rates and premia to capture shocks to the current policy rate, to the expected future path of policy rates, and to premia or uncertainty.

### 3.1     Gathering high-frequency yield changes

As noted above, the KMS approach builds off the high-frequency identification literature, taking changes in yields over tight windows around events as exogenous monetary policy shocks. For this, we use data on Overnight Indexed Swaps (OIS) at fixed maturities of 1 week, 1-6 months, 9 months, and 12 months, as well as yields on all outstanding nominal Australian Government securities with at least 1-year to maturity. These are measured in a reasonably tight window of 30 minutes before the relevant event, and 60 minutes after. We use these data to fit a zero-coupon yield curve just before and after the announcement, following the approach of Finlay and Chambers (2008).

Our main focus is on monetary policy announcements, which is consistent with much of the literature. We collect data on meetings covering the period from 2002 to 2019.

We also consider the broader set of events examined in He (2021), though we only incorporate data from 2006-2019 (as earlier data were not available). This includes speeches, release of the Board Minutes, and release of the *Statement on Monetary Policy*. Considering these extra events not only broadens our information set in general, but may also be particularly useful in identifying shocks to the path of expected interest rates if these longer-form releases provide a more detailed assessment of the likely path for interest rates.

Table 1 provides some statistics on these changes. Variation in yields tends to be higher on monetary policy announcement days, particularly for shorter maturities, with much of the variation occurring during the tight event window. On average across the sample, other event days look fairly similar to the full sample, with the events themselves being associated with relatively minimal variation in yields. This is consistent with the findings in He (2021), though as he notes and we discuss below, some have had larger effects, particularly around the GFC.

**Table 1: Variation in rates over Event Windows**
Average absolute yield change, basis points , by yield maturity

|  | 1-year | 3-year | 5-year | 10-year | Observations |
|---|---|---|---|---|---|
| Full sample[a] | 0.033 | 0.043 | 0.044 | 0.046 | 3,714 |
| Monetary Policy Announcement day[a] | 0.050 | 0.051 | 0.051 | 0.047 | 199 |
| Other event day [a] | 0.029 | 0.042 | 0.042 | 0.042 | 523 |
| Monetary Policy Announcement window [b] | 0.035 | 0.039 | 0.031 | 0.023 | 199 |
| Other event announcement window[b] | 0.013 | 0.018 | 0.015 | 0.015 | 523 |

Note:　(a) Daily change
　　　　(b) Change during window around announcements

## 3.2    Decomposing yield curve changes into changes in expected rates and premia

Following KMS, we decompose changes in the yield curve into changes in the expected path of interest rates and changes in premia by employing a standard ATSM, which is designed to model the future path of interest rates and premia based on data on yields. Our ATSM differs slightly from KMS (for details see Appendix A). First, we use a slightly different estimation procedure, suggested by Adrian, Crump and Moench (2013). But more importantly, we incorporate surveys into the model to avoid small sample biases, similar to Kim and Orphanides (2012) and Guimaraes (2016), rather than using statistical techniques as in KMS. As discussed in Appendix A, this leads to a more plausible path for expected interest rates and term premia. It also affects what the model assigns as shocks Path and Premia shocks, affecting our estimates of the effects of these shocks.

Having estimated the model parameters, we can then apply the ATSM to look at the estimated path of interest rates and term premia, before and after monetary policy announcements or other events.[2] For example, Figure 1 and Figure 2 show the yields, expected policy rates and premia just before and after the May 2016 Monetary Policy Announcement where a 25 basis point cut in the cash rate to 1.75 per cent was announced. Yields fell after the announcement with much of the decline reflecting lower current and expected policy rates. Premia also declined, potentially suggesting some decline in uncertainty about future rates.

**Figure 1: Yield Curve**
Before and after May 2016 Board
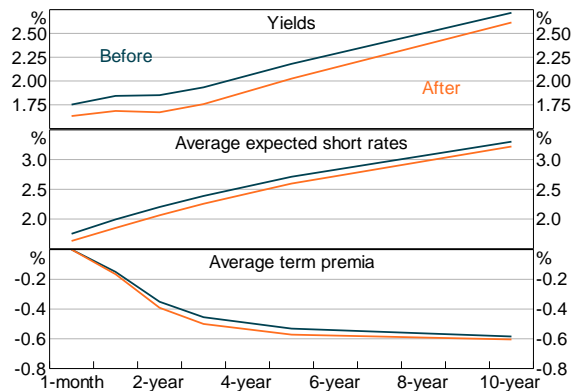


**Figure 2: Yield Curve**
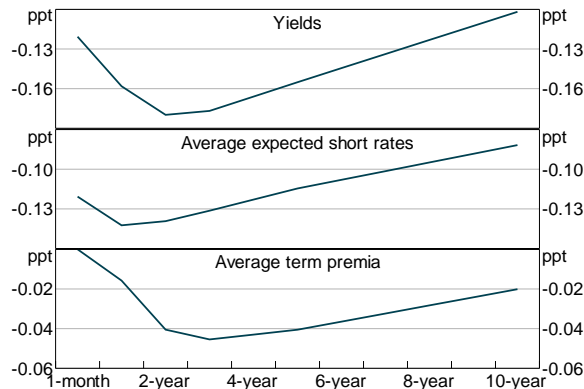Change before and after May 2016 Board



Figure 3 and Figure 4 summarise these changes over time at a few points on the yield curve. For monetary policy announcements, changes in expected policy rates tend to be the most important aspect of yield changes, even at longer horizons. But changes in term premia can be quite important as well. For example, premia spiked around policy announcements during the GFC in late 2008, offsetting some of the effects that lower rate expectations had in lowering longer-term yields. Focusing on other events, the figures also show that while the average effect of these events is smaller, during certain periods these events have had sizable effects on yields, indicating that they can potentially provide useful extra information on monetary policy shocks.

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2    We only use data up to 2016 to estimate the parameters to avoid any possibility of the proximity of the effective lower bound affecting the estimates. See Appendix A for further discussion.

**Figure 3: Decomposition of High-frequency Yield Curve Changes**
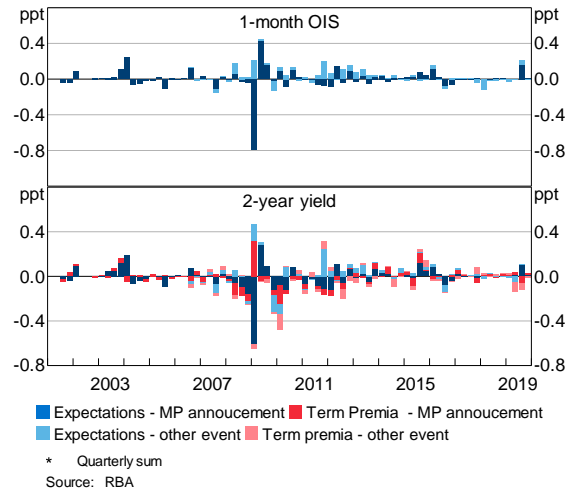


**Figure 4: Decomposition of High-frequency Yield Curve Changes**
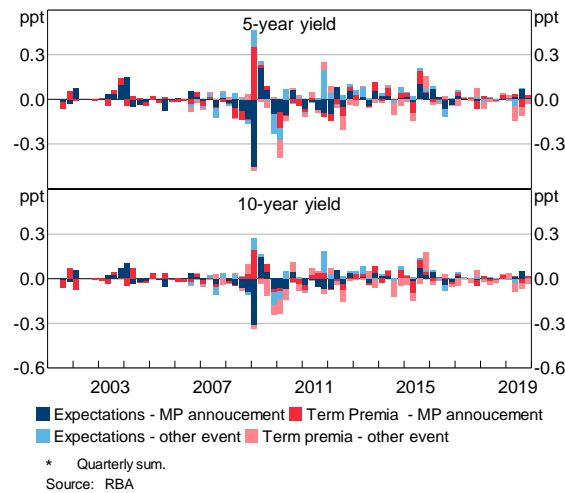


It is interesting to compare these results to an average day in the sample, as this can provide a sense of whether expected rates play a relatively larger role on monetary policy event days. To consider this, we run the ATSM over daily changes in yields across all days in the sample period (from 2001 to 2019). Perhaps unsurprisingly, on days with monetary policy announcements a far larger share of variation in yields reflects changes in expected interest rates compared with an average day (Table 2).

When we focus on non-policy announcements (e.g. speeches), changes in expected rates also play a larger role than premia in driving variation in yields, though typically not to the same extent as around monetary policy announcements. So while these other events primarily contain information about future interest rates, the composition of information released during these events is more skewed towards uncertainty or risk around the path of rates than in monetary policy announcements.

**Table 2: Share of Variation in Rates Due to Change in Expected Rates**

By yield maturity (per cent)

|  | 1-year | 3-year | 5-year | 10-year |
|---|---|---|---|---|
| Full sample[a] | 58 | 47 | 35 | 14 |
| Monetary Policy Announcement day[a] | 72 | 59 | 50 | 25 |
| Other Event day[a] | 64 | 51 | 49 | 30 |
| Monetary Policy Announcement window [b] | 95 | 79 | 75 | 58 |
| Other event announcement window[b] | 72 | 49 | 49 | 31 |

Note:     (a) Daily change
             (b) Change during window around announcements

## 3.3 Decomposing yield curve changes into changes in action, path, and premia shocks

While the above decomposition provides some useful extra information, it still doesn't fully differentiate between the different facets of monetary policy. For example, in the May 2016 announcement did the fall in the average expected policy rate over the next two years reflect the cut in the cash rate, or did it reflect forward guidance or signalling about the state of the economy and rates in the future? Equally, how much of the change in premia is directly related to changes in expected interest rates, which could, in turn, affect investors' view of economic conditions and therefore required term premia, and how much reflected reduced uncertainty about the future as a result of the central bank's communications?

To better understand these different facets of policy, KMS suggest adjusting the above decomposition to capture three distinct and more interpretable shocks:

- **'Action' shocks:** changes in expected policy rates flowing from changes in the current policy rate
- **'Path' shock:** changes in the expected path of policy rates unrelated to changes in the current policy rate (e.g. due to forward guidance or signaling).
- **'Premia' shock:** changes in term premia unrelated to changes in policy rate expectations.

The Action and Path shocks are constructed by taking the first two principal components of changes in expected rates across the curve (i.e. 'factors'), which summarise the changes, and transforming them so they have a cleaner interpretation. We rotate the factors such that one has no loading on the short-term interest rate (1-month forward rate) – the Path shock – while the other is allowed to load on the short rate – the Action shock. This is similar to the approach taken by Gurkaynak, Sack and Swanson (2005b), but they apply it to the raw yield curve rather than first removing term premia.[3]

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3   We use two factors following KMS, though there is evidence that one factor may be sufficient to encapsulate changes in expected rates. The first factor accounts for around 98 per cent of variation, while the second account for around 2 per cent (and others near zero). This finding is similar when using forward rates as well as expected average rates.

Focusing on policy announcement days, the factor loadings end up looking similar to a 'level' and 'slope' factor, which is a common finding when taking principal components of a yield curve (e.g. Hambur and Finlay 2018; Figure 5).[4] Action shocks lead to a fairly consistent increase in expected rates across the curve. Path shocks by construction have no effect on current rates, but larger effects on future interest rates, so lead to a steeper yield curve (all else equal).

**Figure 5: Factor Loadings**

Factors for average expected rates
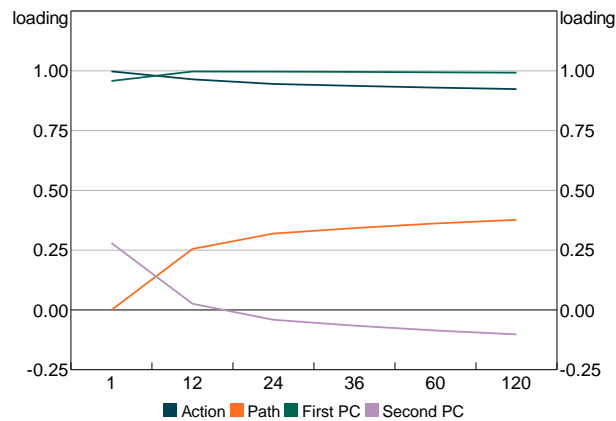


To construct the 'Premia' shock we compute the residual from a regression of the term premia changes on the above factors, which removes the influence of expected rate changes. We then take the first principal component of these residuals to summarise the changes across all maturities. KMS take the additional step of rotating the term premia so that it does no load on short-term premia, similar to the adjustment made to construct the Path factor. We experimented with this approach and it does not substantially change the results, but does lower the explanatory power of the Premia shocks.

Figure 6 and Figure 7 show the contribution of these different facets of monetary policy shocks to yields over time, focusing on monetary policy announcements. Much of the variation in yields across the curve reflects current policy actions (~65 per cent), and these shocks show a reasonable correlation with the measures proposed in Beckers (2020): around 0.5.[5] Changes in the expected path also plays an important role (~20 per cent), while changes in uncertainty/premia account for only a small share (~10 per cent).[6]

Similar to the above findings, the dominance of the action shock seems to be particularly evident on monetary policy announcement days. If we run the model over all days from 2001 to 2019 (and enforce the same factor loadings), the Path shock accounts for around 1.5 times as much variation
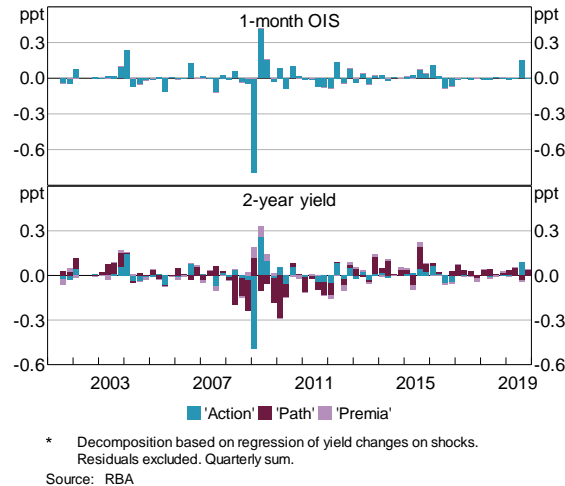
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4    Including the other events doesn't change the factor loadings substantially. However, if we focus only on other events the loadings on the action and path shocks have a stronger downward and upward slope, respectively (Figure B3).

5    While the shocks look potentially auto-correlated, there is no significant evidence of autocorrelation for the Action and Premia shocks. In the sample, the Path shocks do appear moderately positively correlated. While this is somewhat surprising, it is broadly consistent with evidence that participants have learnt about the Bank's reaction function over time, as discussed below. Once the component that is predictable based on other available economic information is removed, the autocorrelation is no longer evident.
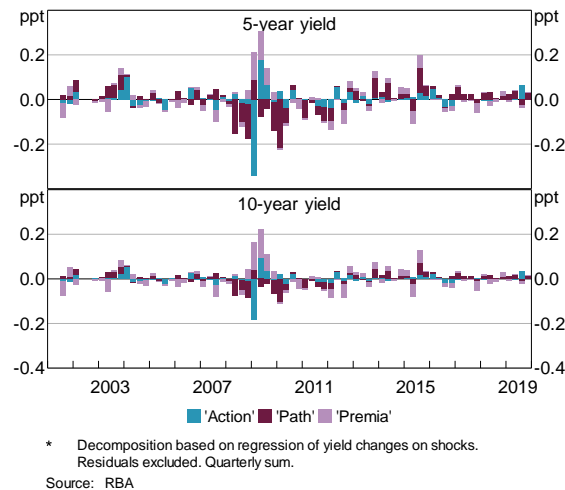
6    These shares are averages across the entire yield curve. 'Action' shocks tend to play a relatively more important role at the shorter end of the curve, while 'Path' and 'Premia' shocks play a more important role further out.

in yields as the Action shock across different maturities.[7] In contrast, on announcement days the two play a broadly similar role (and the Action shock is more important within the window). Similarly, focusing on other event days the Action shock accounts for only around 15 per cent of variation, compared with 60 per cent for the Path and 20 per cent for the Premia shock.[8] This suggests that monetary policy announcements are unique in containing mainly information related to interest rates in the immediate future (perhaps unsurprisingly).

**Figure 6: Decomposition of High-frequency Yield Curve Changes**



\* Decomposition based on regression of yield changes on shocks.
  Residuals excluded. Quarterly sum.
Source: RBA

**Figure 7: Decomposition of High-frequency Yield Curve Changes**



\* Decomposition based on regression of yield changes on shocks.
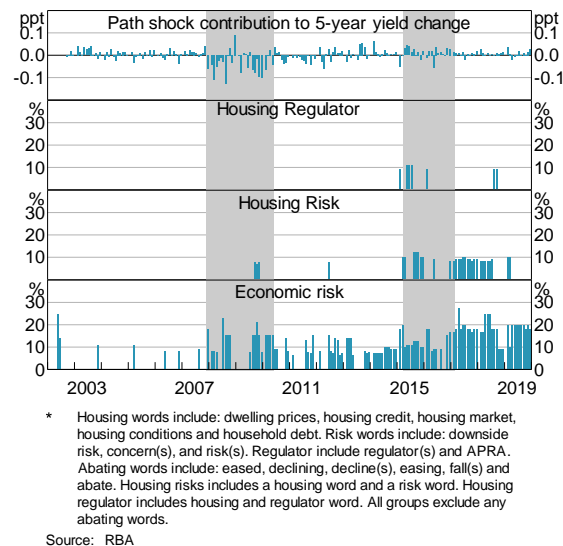  Residuals excluded. Quarterly sum.
Source: RBA

Even if Path and Premia shocks are relatively less important overall in policy announcement events, they have played crucial roles at different stages, particularly for medium-to-longer-term yields. For example, Path shocks consistently lowered medium-term yields during the early stages of the GFC in early and mid-2008. To understand this, we used simple text analysis to look for at the policy announcement. We find that the negative path shocks coincided with increased references to

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7    If we fail to enforce the same loading, the loadings change substantially. Moreover, the second raw factor accounts for a substantially larger share of variation in yields – around 15 per cent. This provides more evidence that announcement days contain much more varied information.

8    Despite the different loadings for the shocks, these shares are similar if we estimate the model only on other events.

softening credit and economic conditions, volatile overseas outcomes, and economic risks, as evident from the increase in the number of references to risk in the monetary policy announcements (Figure 8).[9]

**Figure 8: Usage of Terms in Monetary Policy Statement**
Paragraphs referencing, as a share of paragraph count



\*    Housing words include: dwelling prices, housing credit, housing market, housing conditions and household debt. Risk words include: downside risk, concern(s), and risk(s). Regulator include regulator(s) and APRA. Abating words include: eased, declining, decline(s), easing, fall(s) and abate. Housing risks includes a housing word and a risk word. Housing regulator includes housing and regulator word. All groups exclude any abating words.
Source:   RBA

Similarly, Path shocks seem to have consistently raised short- to medium-term yields during the mid-2010s. This was also evident for other events (see Figure B4 and Figure B5). One potential explanation could be that increased references to housing prices and risks caused markets to adjust their expectations for future policy rates higher. To consider this, we again used simple text analysis to look for references to risks in housing markets or to the regulator (with no offsetting word) in monetary policy announcements. As shown in Figure 8, references to these risks have tended to coincide with positive path shocks. While this finding is by no means causal and conclusive, it does provide some evidence that the shocks are able to parse some of the relevant information being communicated about the future path of interest rates.

Meanwhile Premia shocks appear to be related to monetary policy uncertainty. There were large Premia shocks around monetary policy announcements during the GFC, a period of heightened uncertainty. Moreover, there is a reasonable positive correlation between various proxies for monetary policy uncertainty and Premia shocks. For example, forecaster disagreement regarding the future cash rate as measured in the RBA Survey of Market Economists, a proxy for uncertainty, has a moderate correlation with the size of the Premia shocks in that quarter (Figure 9; top panel). This relationship is not present when looking at the Action or Path shocks, and does not simply reflect the GFC period. Similarly, there is a moderate correlation between the (conditional) volatility of the 3-month OIS and the Premia shock in a given month.[10]

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9    References to such risks remained high going forward, suggesting potential change in communication strategy.

10    More precisely, this is the conditional volatility of the residual from a forecasting model of the 3-month OIS, similar in spirit to Jurado, Ludvigson and Ng (2015).

**Figure 9: Premia Shocks and Disagreement in Surveyed Cash Rate Forecasts**
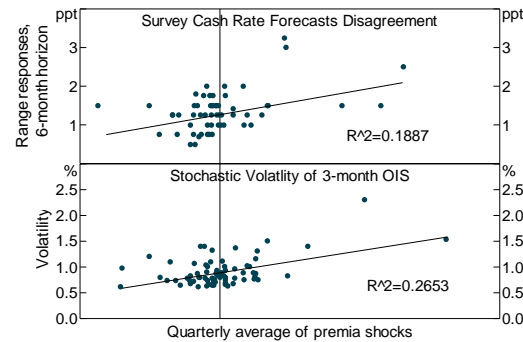


Finally, one natural question about these shocks is whether they are truly exogenous and unpredictable. Several papers have argued that high-frequency shocks can still be endogenous if the central bank has some additional economic information that it communicates, or if market participants misunderstand the central bank's responses to data (Nakamura and Steinsson 2018; Bauer and Swanson 2021, 2022). The former will naturally be captured in the Path shocks as this additional information about future outcomes should influence expected future interest rates. Separating this out, and being able to look at this aspect versus the effect of current actions is a key benefit of the KMS approach. The latter remains a cause for concern and so we explore it below.

To understand whether market participants systematically misinterpret the RBA's response to incoming data, we consider whether they could have 'predicted' the shocks using available data. Specifically, we regress each shock on various measures of economic and credit conditions which include the following: changes in the unemployment rate and (log) employment over the preceding 12 months, and 3-month changes in the (log) TWI, money market spread (3-month BBSW less OIS), the US commercial paper spread, the second principal component of the yield curve (strongly related to its slope), (log) commodity prices, (log) ASX 200, the US VIX and the US corporate bond spread (BAA). These variables are motivated by Bauer and Swanson (2021, 2022) and Beckers (2020). The regression is run separately while including and excluding the GFC period, to allow for the fact that the relationships may have changed during this period.[11]

We find that these factors explain around 20 per cent of the variation in Action shocks, 25 per cent of the variation in Path shocks and 15 per cent of the variation in Premia shocks when the GFC is included in the sample. If we exclude the GFC, the share for the Action shock declines substantially but remains the same for the other two components. This suggests that while the Action shocks are truly unpredictable, with the benefit of hindsight, market participants may have been able to predict the other shocks. It also suggests that the nature of what is being identified as a shock during the GFC could differ from the rest of the sample, potentially reflecting less efficient price discovery and incorporation of information during this volatile period.

How can we explain this predictability and the apparent systematic misunderstanding of the RBA's reaction function, at least with respect to the future stance of policy? One explanation is that markets

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11  We use final, rather than the original vintage of the data. However, given many of the variables are not revised (CPI and financial market) this is unlikely to be a major issue. Moreover, unless the RBA could predict the data revisions, both the RBA and market participants had the same information set, so we are simply introducing noise into our RHS variables. Nevertheless, we make sure the data release was available at the time of the policy meeting.

learn about the reaction function over time (Bauer and Swanson 2021, 2022). Relatedly, the reaction function could change over time, and agents may be slow to learn about those changes. This could explain the autocorrelation observed in the path shocks, which is removed once we orthogonalise the shocks with respect to available data. In either case, the results speak to the importance of effectively communicating the Bank's reaction function.

Interestingly, if we focus on the other events alone, the degree of predictability is far lower, in the region of 5-10 per cent. This suggests that these events contain relatively more 'exogenous' information.

In terms of using these shocks as instruments for monetary policy, the predictability of the path and premia shocks indicates that they are unlikely to be a valid instrument as they may be correlated with other structural shocks or expected future economic outcomes. That said, the direction of the bias will be less clear, and will be dependent on whether participants over or under-weight certain variables. Rather than exploring deeply the nature of the systematic error, we simply consider the macroeconomic effects of the shocks with and without the orthogonalisation step in the next section.

## 4.    The  effects of monetary policy shocks

The above section highlights that these new measures of monetary policy shocks contain relevant information about monetary policy and its communication. Given they seem to capture different facets of monetary policy, they may have different macroeconomic effects, and therefore this decomposition could potentially provide useful quantitative estimates of how monetary policy and its communication affect the macro-economy.

To consider this we use an instrumental-variable structural vector autoregression (IV-SVAR) approach. This approach was pioneered by Stock (2008), Stock and Watson ( 2012, 2018) and Mertens and Ravn (2013). The idea behind this approach is to use instruments (in our case policy surprises as discussed above) to identify (different facets of) monetary policy shocks from a reduced form VAR.

More precisely, we consider the following proxy SVAR model

$$Y_t = \sum_{j=1}^{p} B_j Y_{t-j} + u_t$$

$$( 1 )$$

where $Y_t$ is an $n \times 1$ vector of endogenous variables, $u_t$ is an $n \times 1$ vector of reduced-form innovations, $p$ is the number of lags, and $B_j's$ are $n \times n$ matrices of unknown coefficients. The reduced-form innovations are related to the structural shocks $\epsilon_t$ as follows:

$$u_t = A_0 \epsilon_t$$

$$( 2 )$$

where $A_0$ is an $n \times n$ non-singular matrix and the structural shocks $\epsilon_t$ are assumed to be serially and mutually uncorrelated and satisfy the following:

$$E(\epsilon_t) = 0 \quad and \quad E(\epsilon_t \epsilon_t') = D = diag(\sigma_1^2, \ldots, \sigma_n^2)$$

( 3 )

The variance-covariance matrix of the reduced-form innovations is given by

$$E(u_t u_t') = \Sigma = A_0 D A_0'$$

( 4 )

Assuming that the underlying reduced-form VAR is, $Y_t$ has a structural moving average (MA) representation

$$Y_t = \sum_{k=0}^{\infty} C_k(B) A_0 \, \epsilon_{t-k}$$

( 5 )

where $B = (B_1, B_2, \ldots, B_p)$, and $C_k(B)$ highlights the dependence of the MA coefficients on the AR coefficients in $B$, i.e.,

$$C_k(B) = \sum_{m=1}^{k} C_{k-m}(B) B_m, \quad k = 1, 2, \ldots$$

( 6 )

with $C_0(B) = I_n$ and $B_m = 0$ for $m > p$ (see, e.g., Olea et al 2021).

The structural impulse response function is the response of $Y_{i,t+k}$ to a one-unit change in $\epsilon_t^j$, which is given by

$$\frac{\partial Y_{i,t+k}}{\partial \epsilon_t^j} = e_i' C_k(B) A_0 e_j$$

( 7 )

where $e_i$ and $e_j$ denote the $ith$ and $jth$ columns of the identity matrix $I_n$, respectively.

Following Gertler and Karadi (2015), we identify the policy shock using an external instrument. Let $z_t$ denote an external instrument and $\epsilon_t^* = \epsilon_t \setminus \epsilon_t^{mp}$ be an $(n-1) \times 1$ vector of structural shocks other than the monetary policy shock. The key identification assumption in the external instrument approach is that $z_t$ is correlated with $\epsilon_t^{mp}$ but uncorrelated with $\epsilon_t^*$. Stock and Watson (2018) and Olea at al (2021) show that if this identifying assumption holds, then one can identify the structural shock of interest.

Our baseline VAR is estimated (using ordinary least squares) at a monthly frequency. The variables included in the IV-SVAR are: unemployment rate, (log) retail sales, (log) housing prices, (log) dwelling approvals, the mortgage spread (variable owner occupier rate less cash rate; adjusted for a break around the GFC), the (log) nominal TWI, and the first two principal components of the yield curve. The VAR is estimated over the sample from January 1994 to December 2019 to estimate the VAR parameters, while the high-frequency surprises that are used to identify the structural policy

shocks only begin in 2002. We examine the effect of each of the surprise components one-by-one, using them as instruments for the yield curve factors. Confidence bands are constructed using a wild bootstrap.[12]

Many papers incorporate specific interest rates, such as the cash rate, or other short-term interest rates. Given some of our shocks directly affect longer-term rates and not short-term rates, we also need to incorporate longer-term rates. Rather than choosing yields of certain maturities, we use the first two principal components of the yield curve in the VAR, similar to KMS. This allows us to flexibly account for the effect of the shocks, rather than taking a stand on the most relevant maturity, although it does make scaling and interpreting the shocks more challenging. We consider the effect of a shock that leads to a one standard deviation increase in one of the factors. We can then use the factor loadings to estimate the effect on relevant interest rates.

## 4.1 Monthly VAR

### 4.1.1 Action shocks

Figure 10 shows the impulse responses from an Action shock focusing on monetary policy announcements. The shock is scaled to lead to a one unit increase in the first PC of the yield curve, which equates to around a 200 basis point increase in the cash rate. The shock has a robust F-stat for instrument strength of around 10, which is the level often used to assess instrument strength (Staiger and Stock 1997; Table B1).

The responses are largely consistent with what would be expected from a standard contractionary monetary policy shock. Both short- and longer-term interest rates rise, the exchange rate appreciates instantaneously, and the shock leads to an eventual increase in unemployment, while house prices decline somewhat over time.

Nevertheless, there are some surprising dynamics as unemployment initially declines. Part of this appears to reflect the inclusion of the GFC period, with the extent of the decline tending to be much smaller if this period is removed (Figure B6). Similarly, the response of the TWI is also somewhat larger than would generally be expected but becomes smaller if the GFC period is removed.

Overall, the results are very similar to those obtained from simpler approaches, such as taking information directly from the yield curve without applying an ATSM. For example, using just the change in the 3-month or 24-month OIS rate around the meeting leads to very similar results, as does simply taking the first factor of the change in expected short-rates from the ATSM changes without rotating to extract the Action and Path shocks (Figure B9).[13] This provides some initial

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12 As in KMS we do not account for the fact that the shock is a generated regressor, given the difficulty in bootstrapping to include the ATSM step. We also implement the wild bootstrap despite as in Gertler and Karadi (2015). However, Jentsch and Lundsford (2019) show that the wild bootstrap is generally not asymptotically valid for inference about impulse response functions in IV-SVARs and propose a block bootstrap instead. To ensure that our resuls are not driven by the wild bootstrap procedure we conduct robustness checks using Bayesian Local projection and find similar results regarding significance (Figure B11).

13 The results are also broadly consistent if we orthogonalise the shocks with respect to recent economic outcomes, or use an ATSM with a bootstrap adjustments instead of surveys as in KMS. See Figure B6.

evidence that suggests that the identified Path and Premia shocks might have a fairly small systematic effect on economic outcomes.

Expanding the information set to include other events has relatively little effect on the results (Figure B10). This is unsurprising given the earlier findings that Action shocks were mainly relevant on policy announcement days.

**Figure 10: Response to Action Shock**
Scaled to unit increase in first PC of yield curve



* Error bands 90 per cent confidence intervals (bootstrapped).
Source: RBA
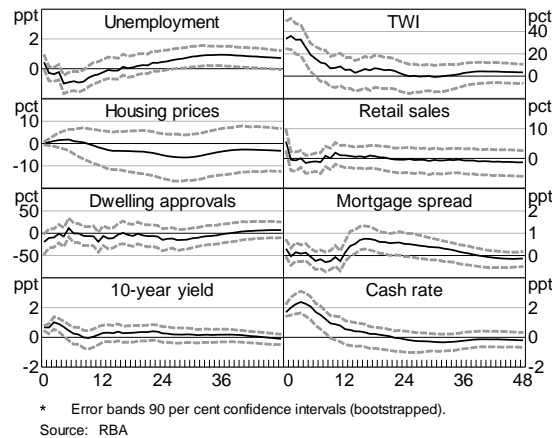
### 4.1.2 Path shocks

The Path shock appears to be a fairly weak instrument for monetary policy shocks, with a very low F-stat (Table B1). Accordingly, the effects are imprecisely estimated with large confidence bands and as such Figure 11 only reports the point estimates.[14] Moreover, the responses are not particularly robust to specification changes such as removing the GFC period or orthogonalising the shocks (Figure B7).

Expanding the information set to include the broader set of events does little to change the results, which remain poorly identified with a very low F-statistic (Table B1). This remains the case when we use only the non-monetary policy announcement events.

One explanation for the fact that Path shocks appear not to have significant macroeconomic effects is that policy and other announcements have little to no economic effects via signalling or information channels, unlike in the US (per KMS). This would be somewhat consistent with He (2021) who finds

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14 Taking the point estimates at face value we see some evidence that the shocks are picking up signalling about future economic outcomes, consistent with the results in KMS. The shocks are associated with an immediate increase in longer-term interest rates, but a future increase in the cash rate. Conditions initially improve, with house prices rising alongside dwelling approvals and retail sales, with these effects tending to wane over time. Nevertheless, given the weak instruments issue these results should be taken given much credence.

little evidence of signalling effects in RBA announcements apart from speeches when looking at equity prices using a simpler approach with high-frequency yields.

**Figure 11: Response to Path Shock**

Scaled to unit increase in second PC of yield curve



\* No responses are significant.
Source: RBA
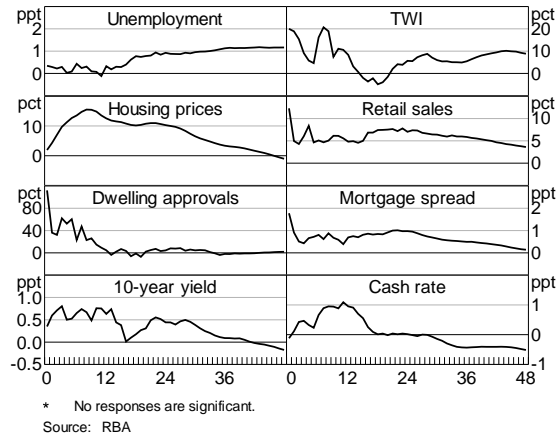
Another potential explanation is that Path shocks capture different aspects of the RBA's communication at different points in time. As discussed in Section 3, in the lead up to the GFC the declines in rates signalled downside risks to future economic conditions, consistent with standard signalling channels. But in the mid-2010s they reflected the RBA signalling that rates may remain elevated due to concerns over potential risks in the housing market, a pure monetary policy shock that would weigh on macroeconomic outcomes. These two types of shocks would have opposite effects on the macroeconomy and may net out when used in the SVAR.

### 4.1.3   Premia shocks

As in KMS, the responses to Premia shocks are difficult to interpret and do not conform to a standard view of the impact of uncertainty (Figure 12). Moreover, the impulse responses are highly sensitive to the inclusion of the GFC period, and are imprecisely estimated, consistent with Premia shocks being a weak instrument for changes in the yield curve, with a very low F-Stat (Figure B8; Table B1).

**Figure 12: Response to Premia Shock**

Scaled to unit increase in second PC of yield curve



\* No responses are significant.
Source: RBA
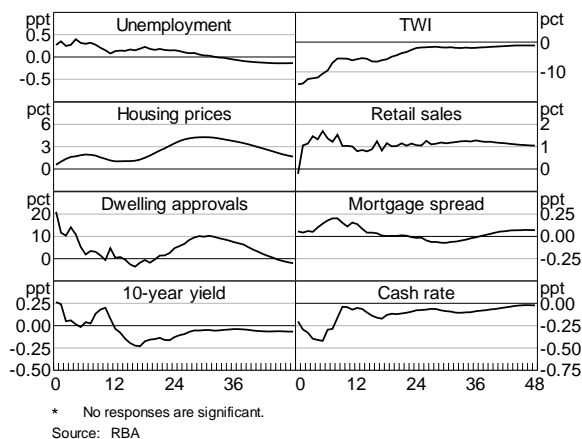
Again, expanding the information set does little to change the results. The premia shocks still represent weak instruments, with poorly identified responses.

## 4.2    Quarterly VAR

As the policy shocks are constructed at a monthly frequency, we use a monthly VAR for the baseline analysis. To consider whether these shocks are able to overturn the well-known price puzzle, we also estimate a quarterly VAR. The variables are largely the same, where we include the log trimmed-mean CPI in the model and replace retail sales with log GDP, and the nominal TWI with the real TWI. We sum the shocks in each quarter to get a quarterly shock series.

Figure 13 shows the results for the Action shock. Overall, the responses of most variables are similar to the monthly results. However, inflation rises following the shock, suggesting that the Action shock still contains some endogenous component. Orthogonalising the shocks does little to change this result, nor does removing the GFC period. This suggest that the high-frequency identification approach itself is unable to solve the price puzzle.

### Figure 13: Response to Action Shock Quarterly
Scaled to unit increase in first PC of yield curve



\*    Error bands 90 per cent confidence intervals (bootstrapped).
Source:  RBA
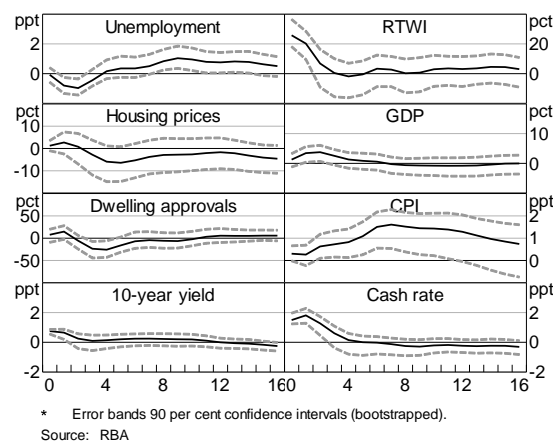
## 4.3    Robustness

We perform a number of checks to assess the robustness of the results for both the monthly and quarterly VAR. As we note above, we consider removing the GFC period. The main systematic difference is to the results for the action shock, with the surprising initial decline in unemployment being less significant this time.

As noted above, we also consider orthogonalise the shocks to remove any systematic relationship with variables that were known at the time, removing what Bauer and Swansson 2022 refer to as the 'Fed response to news' effect. Doing so had little implication for the action shocks but leads to much more muted responses for the Path shocks. This is consistent with the interpretation of these shocks as capturing RBA signals about future outcomes that are based on available news on recent outcomes, with markets systematically underappreciating this additional news.

In terms of the price puzzle, our results may reflect an information sufficiency issue in small-scale SVARs (e.g. see Gambetti, 2021). For example, Hartigan and Morley (2020) fnd this information deficinency to be relevant for Australia resolve the price puzzle using recursive identification in a factor-augmented VAR (FAVAR) with two factors extracted from a large macro dataset. Accordingly, we incorporate the macro-factors from Haritigan and Morley (2020) to increase the information set in our estimated VAR. However, the effects of the action shock remain largely unchanged with the price puzzle still remaining unresolved in our high-frequency identification setting.

As an alternative approach to the IV-SVAR we also consider a Bayesian local projections model, as in KMS. The results are generally quite similar to our baseline results, with the Action shock leading to an economic contraction, while the other shocks lead to poorly identified economic responses (Figure B11). This helps to address concerns around our choice of bootstrapping methods (see above)

The main other robustness check we consider is changing the ATSM. In particular, rather than incorporating surveys into the ATSM, we account for the small-sample bias using bootstrapping, similar to the statistical approach taken in KMS. Taking this approach leads to very similar estimated effects for the Action shocks (Figure B6). The main differences are evident in the path and premia shocks with the responses tending to be more muted (Figure B7 and Figure B8).

Our finding that the specification of the ATSM matters for the estimation results is not surprising. As discussed in Appendix A, the choice of small-sample adjustment can lead to very different estimated paths for future expected interest rates and term premia, with the survey model providing a more sensible account of history. This suggests that in adopting the KMS approach, it is important to think about the specification of the ATSM, as it can have substantial implications for what the model interprets as path and premia shocks. While this doesn't seem to be important in the Australian case, given only the Action shock has macroeconomic effects, it could be more important in other countries.

## 5.      Documenting shock measures during the COVID-19 pandemic

The above analysis shows that while the KMS approach does not seem to add much to our quantitative understanding of the macroeconomic effects of monetary policy shocks in Australia, it is still a potentially useful framework for understanding the multi-faceted nature of monetary policy decisions and their communication.

Such a framework could be particularly useful in trying to interpret the RBA's COVID-era policy. The cash rate was reduced to around the effective lower bound, and various unconventional policies were introduced, including a yield-curve target and a bond purchase program. Previous work has analysed these programs and their effects on markets in details, exploiting differential outcomes across different markets and instruments (Finlay et al 2022). However, the KMS approach provides another lens through which to examine these policies, decomposing them into effects on expected rates and term premia using a statistical model.

As such, we apply the KMS approach to a number of key dates around the announcement of the RBA's package of support policies, including the yield curve target and the bond purchase program. These are based on the dates examined in Finlay et al (2022). The full list is covered in Table 3.[15]

The analysis is similar to the work of Kaminska and Mumtaz (2022), who find that term premia play a larger role in monetary policy shocks in the UK post-QE period (from 2009-2019). However, our analysis differs in a number of ways. First, we focus on a shorter period and a smaller number of specific announcements, more akin to an event study approach. And relatedly, we only focus on the first step of the approach, decomposing rate changes into changes in expected rates and term premia. Given the cash rate was at the effective lower bound for most of the event dates, the further decomposition into 'Action', 'Path' and 'Premia' seems less relevant.

More importantly, our ATSM does not explicitly account for the effective lower bound on interest rates (or asset purchases). Previous work has shown that failing to account for the effective lower bound can lead the ATSM to expect rates to pick up more quickly than the market expects (e.g. Andreasen and Meldrum 2013). In turn this will bias down the premia, and therefore may cause us to overstate the role of term premia, compared to rate expectations. As such, the result should be thought of as somewhat of an upper bound on the role of premia.

**Table 3: Events for Unconventional Policy Study**

| Date | Event |
|---|---|
| 16 March | RBA statement that the Bank 'stands ready to purchase Australian government bonds in the secondary market to support the smooth functioning of that market' |
| 19 March | Reserve Bank announced a package of policy measures |
| 14 September 2020 | Newspaper article ('RBA and markets out of tune') |
| 22 September 2020 | Speech by Deputy Governor Debelle |
| 23 September 2020 | Market economist report calling for further policy easing |
| 6 October 2020 | October Board announcement |
| 7 October 2020 | Newspaper article ('Odds shortened on more easing') |
| 15 October 2020 | Speech by Governor Lowe |
| 26 October 2020 | Newspaper article ('RBA to buy bonds') |
| 3 November 2020 | November Board announcement of bond purchase program |
| 2 February 2021 | First extension of bond purchase program announced |
| 6 July 2021 | Announcement of tapering in bond purchases |

Note: Yield change measured as 'close-to-close'
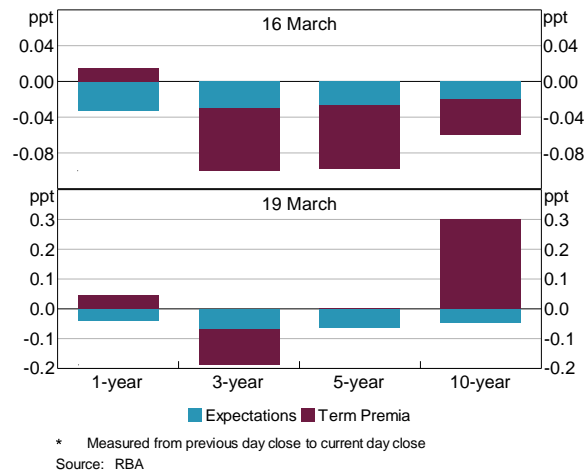Sources: Authors' calculations; RBA

Figure 14 shows the results focusing first on the March announcements of the first package. As discussed in Finlay et al (2022), this led to a large decline in yields at the short end of the curve but, on net, a moderate increase in longer-term yields. Our results imply that decline in expected future interest rates pushed down yields at the short end of the curve, consistent with the market interpreting the announcements as signalling that the cash rate would be kept low for a period, particularly the announcements on the 19th of March which included announcement of the yield curve target. The announcement of the yield curve target also coincided with a substantial decline

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15 Finlay et al (2022) mainly focus on open to close changes. For simplicity we focus on previous close to close changes.
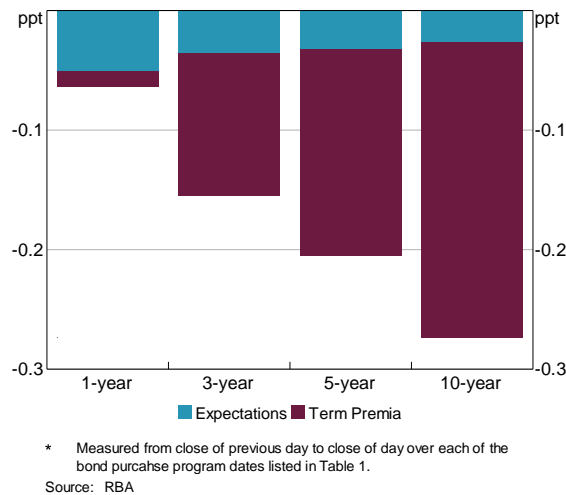
in the premia on yields for 3-year bonds not evident elsewhere on the curve, suggesting that part of the effects of the policy came through this channel. This finding is consistent with Lucca and Wright's (2022) findings for Australia, and more generally with D'Amico and King's (2013) findings of 'local supply effects' on targeted maturity bonds for US bond purchases.

Focusing on the long end of the curve, the documented rise in rates seems to have largely reflected increases in premia. As noted by Finlay et al (2022), it is hard to make a strong case that the announcements 'caused' premia on longer term yields to rise, but it does suggest that the announcement did little to lower the premia.

**Figure 14: Rate Expectations and Term Premia Changes**



\* Measured from previous day close to current day close

Source: RBA

**Figure 15: Expectation and Term Premia Changes**



\* Measured from close of previous day to close of day over each of the bond purcahse program dates listed in Table 1.

Source: RBA

Focusing on the later dates associated with the bond purchase program, we see that much of the effects seem to have come through lower premia, with only a smaller share of the decline reflecting lower expected future rates (Figure 15). This finding is similar to that of Finlay et al (2022) and suggests that the program largely worked through reducing premia. It is broadly consistent with other findings in the literature, though findings on the split between premia and signalling do vary across different unconventional monetary policy programs (e.g. Busetto et al 2022).

More generally, during the COVID period term premia appear to have played a much larger role in the transmission of monetary policy and monetary policy announcements. To see this, Table 4 compares the share of variation in rates accounted for by rate expectations for pre- and during

COVID monetary policy announcement dates. This is similar to the findings in Kaminska and Mumtaz (2022) for the UK. Taken together, the results suggest a much larger role for term premia in the transmission of COVID-era policy, consistent with Finlay et al (2022).

| **Table 4: Share of Variation in Rates Due to Expected Rate Changes** | | | | |
| --- | --- | --- | --- | --- |
| By yield maturity[a] | | | | |
| | 1-year | 3-year | 5-year | 10-year |
| Pre-COVID Monetary Policy Announcement | 72 | 59 | 50 | 25 |
| COVID Policy Announcement | 51 | 22 | 30 | 3 |

Note:    (a) Daily change
               (b) Removing large change in 10-year term premia on 19 March

## 6.     Conclusion

This paper explores a new approach to identifying the effects of monetary policy and its communication in Australia. Following Kaminska, Mumtaz and Sustek (2021), we combine high-frequency data on changes in yields around policy announcements with an Affine Term Structure Model to decompose unexpected changes in the yield curve into different facets of monetary policy: current policy action; signalling or forward guidance about future rates; and the impact of policy on uncertainty and term premia.

Overall, this new approach to monetary policy shock identification shows some promise. It produces an intuitive lens through which to examine and understand monetary policy and its communication and provides a number of insights. For example, Path (or signalling) shocks tended to affect expected rates during periods when the Bank has signalled concerns over future economic outcomes, or communicated that rates could remain higher than otherwise due to mounting risks in the housing market. Covid-era policy mainly affected yields by influencing term premia, unlike normal policy announcements. And some shocks to the path of rates are predictable based on past data, indicating that markets don't fully understand how the Bank reacts to information.

In a second step, we use these surprise changes in yields around policy announcements as instruments to identify the macroeconomics effects of different facets of policy and its communication through the lens of a proxy structural vector autoregression. The approach provides results that turn out to be similar to earlier findings around the effects of monetary policy on the economy, with shocks to current policy (Action shocks) producing similar effects to standard monetary policy shocks obtained using other alternative approaches. However, it adds relatively little new information compared to existing simpler approaches, as effects of Path and Premia shocks are imprecisely estimated and Action shocks fail to overturn the price puzzle. Still, given the observed importance of these other facets of policy in moving interest rates, further work in this space could be valuable.

## Appendix A: Affine Term Structure model

We use a simple nominal ATSM model to decompose yield changes.

In the model the one-period nominal interest rate ($r_t$) is given by

$$r_t = \rho_0 + \rho_1'X_t \tag{1}$$

where $\rho_0$ is a scalar and $\rho_1$ is a vector, so that $r_t$ is a linear function of the N pricing factors $X_t$. We assume that the data generating process (also called the 'real-world distribution' or 'P dynamics') of these pricing factors is a vector auto-regressive process with one lag

$$\Delta X_{t+1} = \mu + \theta X_t + \Sigma \epsilon_{t+1} \tag{2}$$

where $\mu$ is an N by 1 vector of intercepts, $\theta$ is an N by N matrix describing the evolution of $X_t$, and the N error terms $\epsilon_{t+1} \sim N(0, I_N)$.[16] Combining Equations (1) and (2) shows that the evolution of the short-term rate is controlled by the P dynamics.

Following Duffee (2002), we assume that the market price of risk is also a linear function of the factors and is given by

$$\lambda_t = \lambda_0 + \lambda_1'X_t \tag{3}$$

where $\lambda_t$ is an N by 1 vector that represents the price of risk associated with each of the factors at time $t$, $\lambda_0$ is an N by 1 vector and $\lambda_1$ is an N by N matrix. The specification implies that for each factor $i$, the compensation demanded by investors for bearing the risk associated with that factor is a constant $\lambda_{0,i}$ plus a linear combination of all the factors.

If we impose a no arbitrage condition and assume a particular functional form for how agents price risk (stochastic discount factor), Equations (1) to (3) imply a set of pricing equations for zero-coupon nominal bond yields. In particular,

$$n \times y_t^n = -A_n - B_n'X_t \tag{4}$$

where $y_t^n$ is the yield at time t for an n-period zero-coupon nominal bond (i.e. a bond that matures in $n$ periods), and $A_n$ and $B_n$ are functions of the underlying model parameters (see for example Hambur and Finlay 2018 for further details).

Of note, the bond pricing equations would be exactly the same if we take the true 'P-dynamics' and allowed risks to be priced, and if we assumed investors were risk neutral (so $\lambda_0 = \lambda_1 = 0$) but the pricing factors $X_t$ followed some other risk-adjusted (or risk-neutral) dynamics, often referred to as the 'Q dynamics'

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[16] The relatively restrictive error assumption used here, and throughout the paper, is unlikely to hold in the data. While we could allow for more complex error structures, doing so would significant increase the complexity of the model. Moreover, Bibkov and Mueller (2011) find that doing helps models match higher-order moments of the data, but not the first moments (i.e. yields).

$$\Delta X_{t+1} = \tilde{\mu} + \tilde{\theta} X_t + \Sigma \epsilon_{t+1}{}^Q \qquad (5)$$

for $\tilde{\mu} = \mu - \Sigma\lambda_0$, $\tilde{\theta} = \theta - \Sigma\lambda_1$ and $\epsilon_{t+1}{}^Q \sim N(0, I_N)$. In the literature $\mu$ and $\theta$ are often referred to as 'P parameters' as they determine the real-world or P dynamics, while $\tilde{\mu}$ and $\tilde{\theta}$, or equivalently, $\lambda_0$ and $\lambda_1$, are referred to as 'Q parameters'.

Given observational equivalence of these two situations it can be difficult to estimate the coefficients. More formally, the likelihood surfaces tended to be ill-behaved (i.e. have multiple local minima and flat areas). To address this we take the approach of Adrian Crump and Moench (2013) (ACM), who show that the parameters of an ATSM can be estimated using a simple 3-step linear regression process. This helps to separate out the P- and Q-dynamics, similar to the Joslin, Singleton and Zhu (2011) (JSZ) normalization.

A further complication in these models is a lack of information on the dynamics of short-term interest rates, given the short sample and high persistence of these rates. This makes it difficult to estimate the P-dynamics, and can bias down the estimated persistence of expected interest rate changes, therefore overstating the importance of changes in term premia (e.g Bauer, Rudebusch and Wu 2012). This reflects the well known bias in regressions of highly persistent variables (e.g. Nocholls and Pope 1993).

We address this approach by incorporating surveys of expected short-term rates, in the vein of Kim and Orphanides (2012) and Guimaraes (2016). This effectively gives us additional information about the dynamics of short-term rates by providing extra cross-sections.

In particular, we can think of the survey for the short rate in n periods being given by:

$$\mathbb{E}_t(r_{t+n}) = \pi_0 + \pi_1' \mathbb{E}_t(X_{t+n})$$

We take the surveys to be a noisy measure of the true expectation. As such, we shift to a maximum likelihood framework and include the likelihood of the survey data along with those of the pricing factors and the bond yields in the numerical optimisation.

KMS take a different approach, using statistical adjustments to overcome the persistence issue. We explore this approach using a bootstrap small-sample adjustment as in Malik and Meldrum (2016). However, doing so leads to a time series of expected interest rates that is less believable, compared to the survey model results (see below).

Consistent with ACM, our factors are the first K principal components from a panel of nominal interest rates. We use zero-coupon yields estimated using the methodology in Finlay and Chambers (X), with maturities of n= 2, 3, … and 120 months. We use 4 factors.
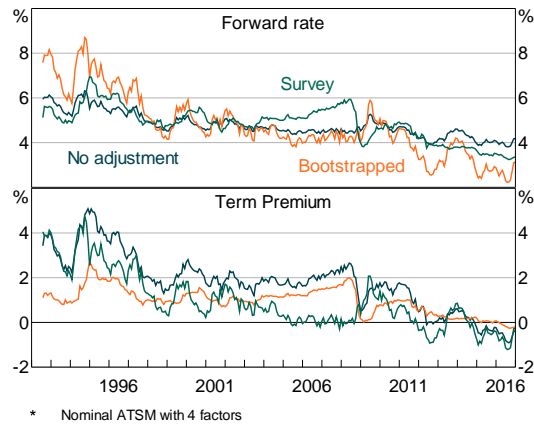
In calculating holding period returns – which are used in the ACM approach – we take the 1-month zero-coupon yield to be the short-term risk-free interest rate, and calculate returns for zero-coupon bonds with maturities of n= 6, 12, 18, 24, 36 … and 120 months. This gives us 12 cross-sectional units. The model is estimated at a monthly frequency.

We estimate the parameters of the model using data from mid-1992 to 2016., We end the sample in 2016 to avoid any potential issues introduced by rates nearing the effective lower bound. There may be some argument for excluding the early 1990s as inflation targeting was only introduced in this period, and so inflation dynamics could differ substantially. However, as argued by Guimareas (2016), inclusion of such transition period can help substantially with identification of model parameters. That said, as long as surveys are included, excluding this early period from the sample doesn't change the ATSM estimates substantially.
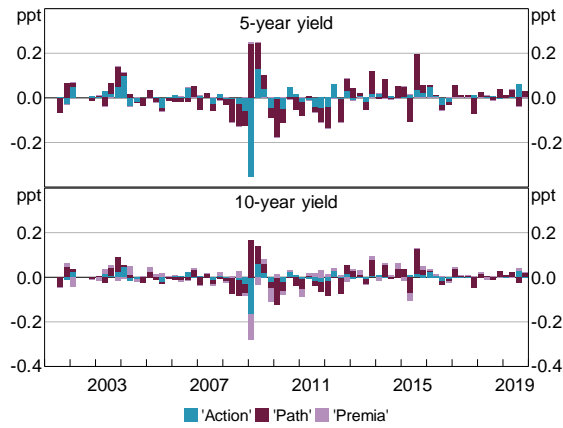
Figure A1 shows the results. Focusing on 10-year rates, we can see that the model with surveys shows a rise in expected rates through the mid-2000s, alongside strong economic outcomes and the early phase of the mining boom. Rates then fall around the Global Financial crisis. In contrast the Bootstrapped model shows long-term expected rates decline over the mid-2000s, and spike during the GFC. Similar counterintuitive dynamics are evident for term premia, with the estimated term premia dropping sharply during the GFC in the Bootstrapped model. Unsurprisingly, the expected rates are quite similar to those obtained in the joint term-structure model estimated in Hambur and Finlay (2018), while the term premia follow a similar path to those in Kim and Orphanides (2012) for the US.

As discussed in the paper, using the ATSM model leads to somewhat different estimated Path and Premia shocks, and differing estimated macroeconomic effects. This is evident in Figure A2, which shows that Premia shocks seem to account for a much smaller share of the variation in yields when using the Bootstrapped model. This is consistent with this model making expected rates substantially more flexible.

**Figure A1: Forward Short-term Rate and Term Premium**

5-year



\* Nominal ATSM with 4 factors

**Figure A2: Decomposition of High-frequency Yield Curve Changes**

Bootstrapped model



\* Decomposition based on regression of yield changes on shocks.
  Residuals excluded. Quarterly sum. Bootstrapped ATSM outputs.

Source: RBA

## Appendix B: Additional Results

| Table B1: Robust F-Statistics | | | | |
|---|---|---|---|---|
| | Baseline Sample | Orthoganlisied | No GFC | Bootstrapped |
| Action shock[a] | 9.84 | 6.62 | 7.68 | 8.89 |
| Path Shock[b] | 0.14 | 0.34 | 0.32 | 1.31 |
| Premia Shock[b] | 1.46 | 1.53 | 0.08 | 2.05 |
| 3-month OIS change[a] | 9.21 | n/a | n/a | n/a |
| 24-month yield change[a] | 8.32 | n/a | n/a | n/a |
| Action shock quarterly[a] | 11.72 | n/a | 3.96 | n/a |
| Path Shock quarterly [b] | 1.77 | n/a | 0.47 | n/a |
| Premia Shock quarterly [b] | 2.12 | n/a | 0.56 | n/a |
| Action shock all events[a] | 13.32 | n/a | n/a | 14.03 |
| Path Shock all events [b] | 0.90 | n/a | n/a | 1.01 |
| Premia Shock all events [b] | 1.82 | n/a | n/a | 7.01 |

Note:  (a) Instrumenting for first PC of yield curve
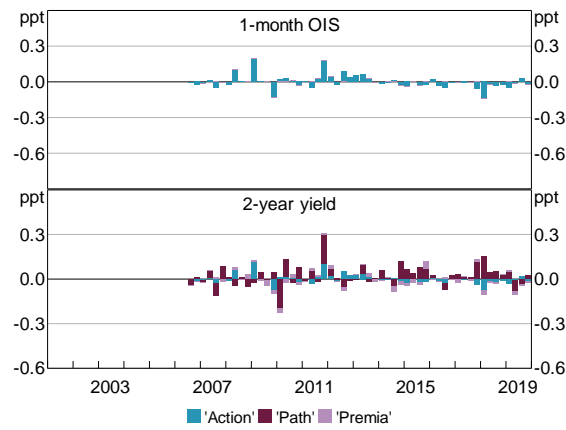       (b) Instrumenting for second PC of yield curve

### Figure B3: Factor Loadings
Factors for average expected rates, different event sets
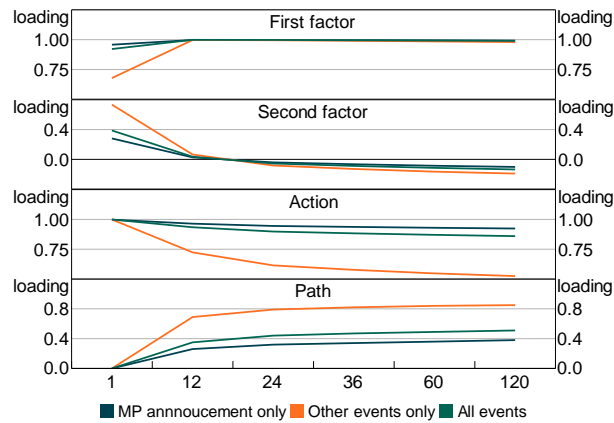


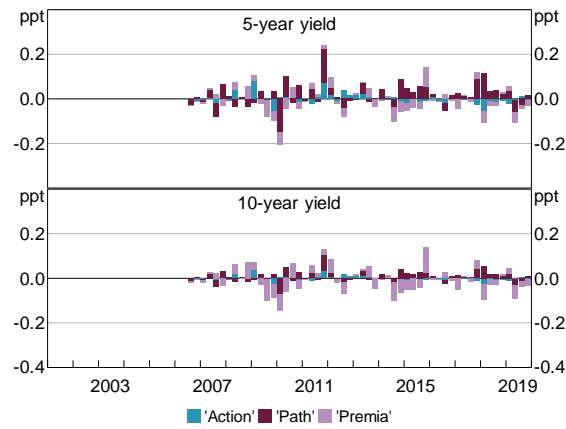Source: RBA

**Figure B4: Decomposition of High-frequency Yield Curve Changes**

Other events



* Decomposition based on regression of yield changes on shocks.
  Residuals excluded. Quarterly sum.
Source: RBA

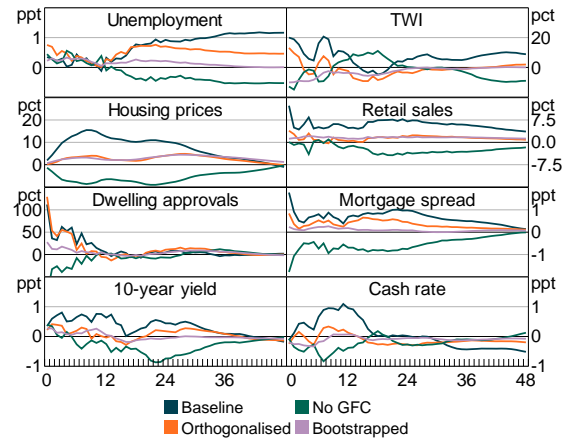**Figure B5: Decomposition of High-frequency Yield Curve Changes**

Other events



* Decomposition based on regression of yield changes on shocks.
  Residuals excluded. Quarterly sum.
Source: RBA

**Figure B6: Response to Action Shock**

Scaled to unit increase in first PC of yield curve
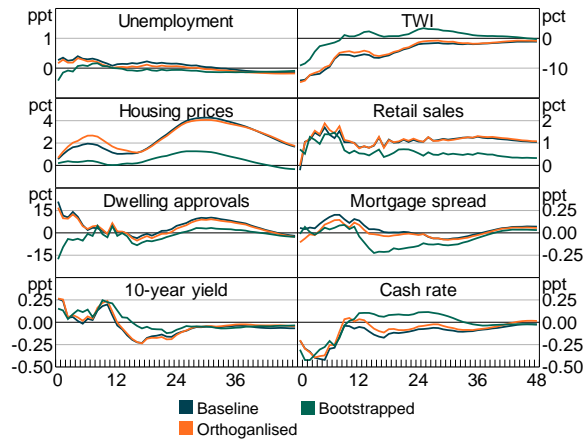


Source: RBA
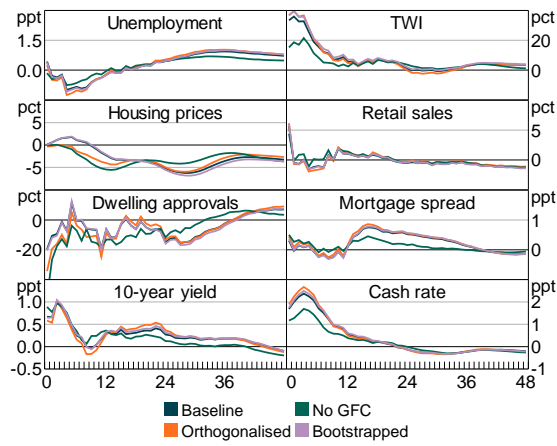
**Figure B7: Response to Path Shock**

Scaled to unit increase in second PC of yield curve



\*    Impulse for cash rate and 10-year yield are based on impulse response
     for yield curve factors in VAR. No responses are significant.

Source: RBA

**Figure B8: Response to Premia Shock**

Scaled to unit increase in second PC of yield curve



Baseline ■ Bootstrapped ■
Orthoganlised ■

*   Impulse for cash rate and 10-year yield are based on impulse response
    for yield curve factors in VAR. No responses are significant.

Source: RBA

**Figure B9: Response to Simpler Shocks**

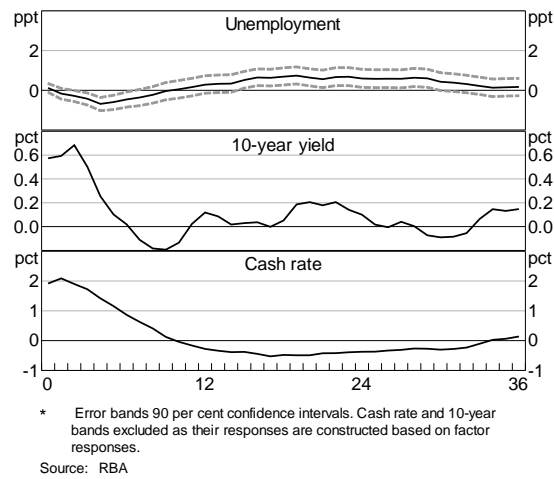Scaled to unit increase in first PC of yield curve



Action ■   3-month OIS change ■
First factor of exp. rate changes ■   24-month OIS change ■
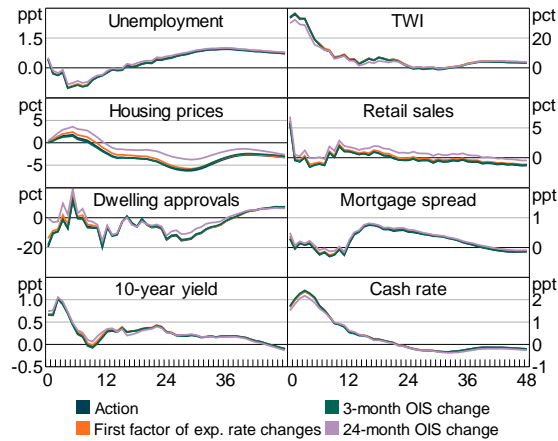
Source: RBA

**Figure B10: Response to 'Action' Shock – All events**

Scaled to unit increase in first PC of yield curve



\* Error bands 90 per cent confidence intervals (bootstrapped).
Source: RBA
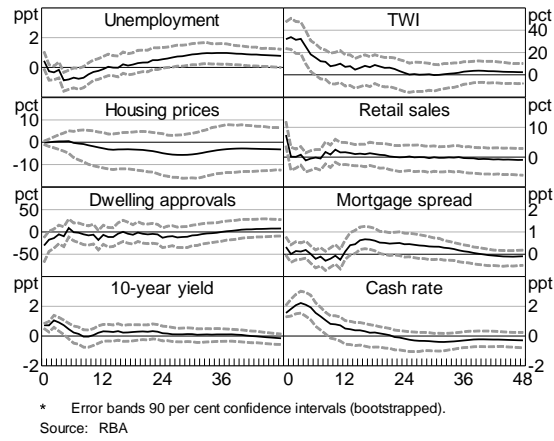
**Figure B11: Response to 'Action' Shock – Local Projections**

Scaled to unit increase in first PC of yield curve, selected variables



\* Error bands 90 per cent confidence intervals. Cash rate and 10-year bands excluded as their responses are constructed based on factor responses.
Source: RBA

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