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Optimal inflation measures for targeting under sectoral heterogeneity

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Declaration

I declare that this thesis is my own work and that, to the best of my knowledge, it contains no material that has been published or written by another person(s) except where due acknowledgement has been made. This thesis has not been submitted for award of any other degree or diploma at the University of New South Wales or at any other educational institution. I declare that the intellectual content of this thesis is the product of my own work except to the extent that assistance from others is acknowledged.

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Cameron Dark

November 2, 2015

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Abstract

This thesis investigates the extent of sectoral heterogeneity in Australian consumer prices and examines how an inflation targeting central bank can best address this issue when formulating policy. An approximate factor model is used to decompose sectoral inflation into its common and idiosyncratic components. Stylised facts on the dynamic behaviour of sectoral inflation and its components are established, which motivate the use of a multisector model with infrequent price-adjustments to summarise price-setting behaviour in Australian consumer prices.

A multisector New-Keynesian model is then used to examine how underlying inflation performs as the inflation target in the central bank's policy rule. The optimal measure inflation of underlying inflation reduces the welfare loss associated with sticky prices by 12 per cent. Under an optimal policy rule with underlying inflation, welfare is only marginally better than when the central bank follows an optimal policy rule with headline inflation. I conclude that formulation of good policy is of far greater importance than the particular inflation measure targeted.

1 Introduction

The existence of heterogeneity in the price-setting behaviour of firms has been well documented in the economics literature. Particular attention is applied to the frequency at which prices change, due to the crucial role this plays in explaining the real effects of monetary policy. This heterogeneity also creates a trade-off for the inflation targeting central bank when formulating policy. The numerical inflation target and its composition must be explicitly announced, and the central bank must assign a major role to the target in guiding policy actions.

Should the central bank target headline inflation, effectively ignoring the underlying sectoral heterogeneity, or should another inflation measure be constructed? If another measure of inflation is to be targeted, how significant is addressing this underlying sectoral heterogeneity, and what trade-offs need to be made in terms of the central bank's communicability and credibility with the public?

Monetary policy in Australia is conducted by the Reserve Bank of Australia (RBA). The RBA has been operating as an independent central bank since 1960 and formally adopted inflation targeting in 1993. The objectives of the RBA are as follows: (i) the stability of the currency of Australia; (ii) the maintenance of full employment in Australia; and (iii) the economic prosperity and welfare of the people of Australia. Since 1993 these objectives have been expressed in a target for consumer price inflation of 2 to 3 per cent. However, consumer price inflation is an aggregate measure across a representative basket of goods and services. This aggregate measure is often referred to as *headline inflation* and the frequency at which prices change for the contents of the basket are believed to differ remarkably. Many international studies have identified the frequency at which the prices of these goods and services change. However, the price quotations that form the basis of the consumer price index in Australia remain unavailable to researchers.

This thesis investigates the relationship between heterogeneity in consumer prices and the construction of an optimal measure of underlying inflation. I make two key contributions to the literature. The first is the decomposition of disaggregated consumer price inflation (hereafter sectoral inflation) for Australia into a common and idiosyncratic component. I use this decomposition to estimate volatility and persistence for each component, and motivate a model with heterogeneous sectors subject to infrequent price-adjustments.

The second is an application of the multisector New-Keynesian framework, exploring the use of underlying inflation by a central bank. I find that incorporating underlying inflation into the policy rule of the central bank is welfare-improving. I find evidence that certain analytical measures of underlying inflation used in practice may also be welfare-improving. I then consider how construction of the policy rule influences welfare, and find that the parametrisation of the policy rule is much more important than the measure of inflation that enters it.

The organisation of this thesis is as follows. Chapter 2 reviews the relevant literature. Chapter 3 sets out the empirical framework used to decompose sectoral inflation into a common and idiosyncratic component, and establishes stylised facts on the dynamic behaviour of these components. Chapter 4 introduces the multisector New-Keynesian framework and extends it to incorporate underlying inflation. Chapter 5 provides an overview of the two welfare approaches used to evaluate monetary policy. Chapter 6 explores the impact of incorporating underlying inflation in monetary policy and establishes an optimal measure of underlying inflation. Chapter 7 establishes optimal policy rules and compares their performance with policy rules incorporating underlying inflation. Chapter 8 concludes.

2 Literature Review

This chapter provides an overview of the relevant literature and is split into three sections. First, the literature on the heterogeneity of prices is examined. Second, the literature on monetary policy under heterogeneous sectors is explored. Finally, I conclude with an assessment of the literature relating to optimal inflation measures.

2.1 Heterogeneity in Price Stickiness

There exists a well-established but small literature which considers the presence of heterogeneity in the frequency of price changes for goods and services. While many early contributions focused on transactional data for a narrow subset of products, there has been a recent surge of analysis on the microdata used by national statistical agencies to construct price indices.

The first microdata founded study is attributed to Bils & Klenow (2004). In their analysis of consumer price changes in the United States, half of prices were found to last less than four months, and the frequency of prices changes was found to differ dramatically across categories of goods and services. This study resulted in a renewed wave of interest in sectoral price stickiness, with Belgian (Aucremanne & Dhyne 2004), French (Baudry, Le Bihan, Sevestre & Tarrieu 2004) and Italian (Veronese, Fabiani, Gattulli & Sabbatini 2005) studies into consumer prices following.

Aucremanne & Dhyne (2004) examined the degree of price rigidity in Belgian consumer prices, finding a substantial amount of heterogeneity in price rigidity across and within product categories. The size of price changes was found to be important, while within-category price-setting behaviour did not seem to be synchronised across price-setters operating in relatively homogenous sectors. Baudry et al. (2004) found strong heterogeneity across sectors in French consumer prices, both in the average duration of prices and in the pattern of price-setting. Furthermore, they found evidence of both time-dependent and state-dependent price-setting behaviour. Veronese et al. (2005) investigated the behaviour of Italian consumer prices, finding that the duration that prices remained unchanged was ten months on average. Price changes were more frequent in the energy sector, but less frequent for industrial goods and services. In contrast to the findings of Aucremanne & Dhyne (2004) considerable synchronisation across price-setters was noted in the service sector.

A microdata founded study does not yet exist for Australia. This is because the microdata used to construct the consumer price index remains unavailable to researchers. This is a significant limitation, however some attempts have been made to quantify the level of heterogeneity in price-setting behaviour for Australia. Park, Rayner & D'Arcy (2010) analyse the results of a Reserve Bank of Australia survey of Australian firms, finding that the reasons for changing prices differed substantially across firms belonging to different sectors. In addition, Park et al. (2010) found that approximately 30% of firms in the survey reviewed their prices in a state-dependent fashion, 45% in a time-dependent fashion, while the remaining 25% reviewed their prices for each transaction.

2.2 Interaction with Monetary Policy

Heterogeneity in price-setting behaviour presents itself in macroeconomic models as a multiple-sector variation on the regular price-setting mechanism. In the Taylor (1979) model of staggered price setting, differing contract lengths are the primary source of heterogeneity in price-setting behaviour. The primary contribution to understanding the role of this heterogeneity has occured through the generalised Taylor economy framework of Dixon & Kara (2005). Kara (2010) found that responding to economy wide inflation gave a welfare outcome that was nearly identical to an optimal policy rule. Further contributions within this framework include Dixon & Kara (2011), who found that monetary shocks will be more persistent when longer contracts are present, and Kara (2011) who concluded that implementing models which ignore the heterogeneity observed in microdata can lead to costly policy mistakes.

The effect of heterogeneity in the Calvo (1983) parameter was first investigated by Carvalho (2006), who found that for the U.S. economy, monetary policy shocks tend to have larger and more persistent real effects in heterogeneous economies, when compared to identical-firms economies with similar degrees of nominal and real rigidity. This was extended to heterogeneous pricing behaviour within sectors by Alvarez & Burriel (2010) who found that the assumption of within sector homogeneity was at odds with evidence found in consumer and producer prices microdata. Using a novel price-setting model that accounted for heterogeneity in individual price-setting behaviour Alvarez & Burriel (2010) found that this model closely matched consumer and producer price data and was crucial in understanding inflation and output dynamics. Cagliarini, Robinson & Tran (2011) investigated this heterogeneity of the Calvo parameter further, using estimates of price stickiness obtained from a New-Keynesian Phillips curve. From the pricing behaviour of Australian firms obtained through surveys, Cagliarini et al. (2011) found that conventional estimates will considerably overstate the degree of aggregate price stickiness. Furthermore, the presence of roundabout production leads to a false conclusion that prices are indexed to past inflation.

The impact of sectoral heterogeneity on monetary policy is further developed by Bouakez, Cardia & Ruge-Murcia (2009, 2014) who use a fully specified dynamic stochastic general equilibrium model with heterogeneous production sectors, convex costs of price adjustment (Rotemberg 1982), and roundabout production. Bouakez et al. (2009) found that for six broad sectors of the U.S. economy, realistic modelling of the input-output structure of the economy was important in understanding the transmission of monetary policy, and explained why some sectors with relatively more flexible prices responded strongly to monetary policy shocks. Bouakez et al. (2014) extend the model to thirty sectors that roughly correspond to the two-digit Standard Industrial Classification for the U.S. economy, finding that ignoring sectoral heterogeneity leads to understating the degree of monetary non-neutrality and overstating the contribution of sector-specific shocks to aggregate and sectoral fluctuations in output.

But while multi-sector variations on price-setting mechanisms and realistic production linkage structures do have some success in replicating inflation and output dynamics, where does the persistence observed in disaggregated prices originate from? Boivin, Giannoni & Mihov (2009) found that for the U.S. economy, the source of price stickiness in disaggregated prices is overwhelmingly from macroeconomic and monetary disturbances. Sector specific shocks exhibited a much more flexible influence on disaggregated prices, accounting for on average 85% of their month to month variation.

The practice of separating the macroeconomic and sectoral components of disaggregated prices was further developed by Maćkowiak, Moench & Wiederholt (2009), using a dynamic factor model, and Kaufmann & Lein (2013), using an approximate factor model. Maćkowiak et al. (2009) found that for the U.S. economy, the entirety of the response of sectoral prices to a sector-specific shock occurs in the same period as the shock, driving much of the period to period variation in disaggregated prices. Kaufmann & Lein (2013) found that for the Swiss economy, sectoral inflation was on average twice as volatile as aggregate inflation, with the source of variation overwhelming attributed to the sectoral component of disaggregated prices. Further findings included that the persistence observed in both aggregate and sectoral inflation was attributed to the macroeconomic component.

2.3 Optimal Inflation Measures

Aoki (2001) uses an optimising model with a flexible-price and sticky-price sector to analyse how inflation fluctuations are affected by relative price changes. Finding that it is optimal to target inflation in the sticky-price sector, Aoki (2001) also concludes that stabilising inflation in the sticky-price sector is sufficient to stabilise relative prices around their efficient level.

Benigno (2004) extends the framework to a two-region model with monopolistic competition and price stickiness. Using a welfare criterion, the optimal outcome is obtained by targeting a weighted average of regional inflation rates. Where both regions faced a uniform level of price stickiness, these weights were the relative share of the economy held by each region. However, when the price stickiness differed between regions, the optimal policy was where the higher weight was given to the region with the greater level of price stickiness.

Producer prices are added to the optimal inflation framework by Huang & Liu (2005). Finding that a welfare level close to the optimal level can be achieved using a simple hybrid rule where the central bank responds to both consumer and producer prices, Huang & Liu (2005) also noted that a significant welfare loss occurs if the central bank ignores producer prices. This view is refuted by Kara (2015), who shows that for the findings of Huang & Liu (2005) to hold, the stickiness in producer prices must be much higher than is empirically relevant. Using a realistic calibration for the stickiness of producer prices Kara (2015) finds that consume prices receive a substantial weight in the optimal inflation index.

3 Dynamic Behaviour of Sectoral Inflation

This section outlines the framework used to decompose sectoral inflation into a common and an idiosyncratic component. I use the framework of Boivin et al. (2009), Maćkowiak et al. (2009), and Kaufmann & Lein (2013) to establish stylised facts about the dynamic behaviour of each component, before drawing conclusions on the price-adjustment mechanism of sectoral inflation.

3.1 Empirical framework

Under a static factor structure, if $\mathbf{x}_t$ is an $N \times 1$ vector of time series then it may be decomposed into K common factors and some series-specific noise. The relationship between $\mathbf{x}_t$ and these components may be expressed as

$$\mathbf{x}_t = \mathbf{A}\mathbf{F}_t + \mathbf{e}_t, \tag{3.1}$$

where $\mathbf{A}$ is an $N \times K$ matrix of factor loadings, $\mathbf{F}_t$ is a $K \times 1$ vector of static factors and $\mathbf{e}_t$ is an $N \times 1$ vector of series-specific noise. Structural instability in the factor loadings can arise in the form of a single large structural break at time τ. Under this scenario, Chen, Dolado & Gonzalo (2014) suggest that the factor loadings before and after the structural break be separated

$$\mathbf{x}_t = \begin{cases} \mathbf{A}\mathbf{F}_t + \mathbf{e}_t & \text{for } t = 1, \ldots, \tau, \\ \mathbf{B}\mathbf{F}_t + \mathbf{e}_t & \text{for } t = \tau + 1, \ldots, T, \end{cases} \tag{3.2}$$

where $\mathbf{B}$ is the matrix of factor loadings after the structural break. The size of the breaks is captured by the matrix $\mathbf{C} = \mathbf{B} - \mathbf{A}$. The static factor structure with a single structural break can be rewritten as

$$\mathbf{x}_t = \mathbf{A}\mathbf{F}_t + \mathbf{C}\mathbf{G}_t + \mathbf{e}_t \tag{3.3}$$

where $\mathbf{G}_t = 0$ for $t = 1, \ldots, \tau$, and $\mathbf{G}_t = \mathbf{F}_t$ for $t = \tau + 1, \ldots, T$.

The static factor structure takes on an approximate form under the assumption that some cross-correlation is present in the error term. Principal components techniques may be used to extract the static factors, as the cross-correlation in the error terms will vanish as N approaches infinity (see Stock & Watson 2002).

3.1.1 Data

The data consists of a panel of quarterly frequency time series spanning 1989Q3 to 2014Q4. I include 146 macroeconomic and financial time series, which describe various aspects of the Australian economy and related markets. Broad categories include real output, the labour market, money and credit, foreign economies, and aggregate prices. Consumer prices are included for 72 of the 87 expenditure classes, comprising 77.1% of the consumer price index (CPI) by expenditure weight. Extraction of the common factors with principal components requires that each time series be covariance stationary. Where a time series is not stationary, it is transformed by taking the first-difference or log-difference, depending on which transformation is most appropriate for that particular time series. I also standardise each time series by demeaning and descaling by the mean and standard deviation.[1]

3.1.2 Estimation

I use principal components techniques to extract the static factors. The information criterion of Bai & Ng (2002) is used to identify the number of common factors, and I find that the 3 static factors explain 21.8% of the variation in the large panel of macroeconomic, financial and sectoral inflation time series. The relatively low explanatory power of the static factors is related to the variation in sectoral inflation arising from mostly idiosyncratic shocks (see Section 3.2).

Following extraction of the static factors, the factor loadings are estimated with ordinary least squares. Using the procedure of Chen et al. (2014) I test for structural breaks in the factor loadings, and find evidence of a structural break in 2001Q4. This break is likely to be related to the introduction of the Goods and Services Tax (GST) in 2000Q3 as the time series are not adjusted for the effects of tax changes.[2] The 72 standardised sectoral inflation rates are decomposed according to Equation 3.3, and standardised inflation in sector i is given as

$$\tilde{\pi}_{it} = \lambda_i \mathbf{\Gamma}_t + e_{it}, \tag{3.4}$$

where $\lambda_i \mathbf{\Gamma}_t = A_i \mathbf{F}_t + C_i \mathbf{G}_t$ is the common component and e_{it} is the idiosyncratic component. As the common and idiosyncratic components have been estimated in terms of standardised sectoral inflation, I descale each, multiplying the components by the corresponding standard deviation of sectoral inflation. I use these descaled terms in all subsequent analysis. I estimate volatility and persistence of sectoral inflation π_{it}, the common component $\lambda_i \mathbf{\Gamma}_t$ and the idiosyncratic component e_{it}.

[1] See Appendix A for a full list of variables and transformations.
[2] See Appendix B for an application of the Chen et al. (2014) procedure.

Volatility is measured by the sample standard deviation. Persistence is measured by fitting an autoregressive process with p lags of the form

$$y_{it} = \sum_{m=1}^{p} \rho_m \, y_{it-m} + \varepsilon_{it}, \tag{3.5}$$

where p is the optimal number of lags chosen by the finite sample adjusted Akaike information criterion and y_{it} is the corresponding time series (π_{it}, $\lambda_i \mathbf{\Gamma}_t$, e_{it}).

Following Fuhrer (2010), I measure the persistence of each process as

$$\rho(y_{it}) = \sum_{m=1}^{p} \rho_m, \tag{3.6}$$

so persistence is the sum of AR terms. I measure the variation in sectoral inflation π_{it} explained by the common component $\lambda_i \mathbf{\Gamma}_t$ with the R^2 from an OLS regression.

3.2 Statistical properties of sectoral inflation

Table 3.1 shows the standard deviation, persistence and R^2, for all groups inflation and the 11 expenditure groups. These expenditure groups form the highest level of disaggregation in the consumer price index, and the statistics presented are calculated from the statistics of the underlying expenditure classes, as a weighted mean using expenditure share weights. The average and median statistics are drawn from the 72 expenditure classes included in the factor model.

The standard deviation of all groups inflation is 0.57 percentage points, which is significantly lower than the standard deviation of sectoral inflation in each expenditure group at 0.96 to 2.52 percentage points. Similarly, the persistence of aggregate inflation (0.37) is higher than the persistence of sectoral inflation in each expenditure group, with the exception of housing (0.60), and insurance and financial services (0.44). The lower volatility and higher persistence found in all groups inflation is broadly explained by the aggregation process, and this finding is consistent with many other studies (See Altissimo, Mojon & Zaffaroni (2009)).

For sectoral inflation, the average volatility of the idiosyncratic components (1.65) is higher than the average volatility of the common components (0.27), and this holds across all expenditure groups. Similarly, for most expenditure groups the sectoral idiosyncratic components are not very persistent, while the sectoral common components are. The housing expenditure group shows particularly high persistence in the idiosyncratic component.

	sd(π_{it})	sd($\lambda_i \mathbf{\Gamma}_t$)	sd(e_{it})	$\rho(\pi_{it})$	$\rho(\lambda_i \mathbf{\Gamma}_t)$	$\rho(e_{it})$	R^2
All groups	0.57	0.24	0.45	0.37	0.50	0.27	0.43
Food, non-alcoholic beverages	2.52	0.28	2.40	0.04	0.48	0.03	0.22
Alcohol and tobacco	1.27	0.36	1.15	0.38	0.49	0.35	0.23
Clothing and footwear	1.50	0.50	1.29	-0.20	0.50	-0.28	0.31
Housing	0.96	0.26	0.85	0.60	0.48	0.60	0.21
Furnishings, household equip.	1.48	0.30	1.38	0.15	0.48	0.14	0.16
Health	2.21	0.25	2.18	-0.02	0.50	-0.09	0.05
Transport	2.31	0.36	2.21	0.19	0.45	-0.02	0.09
Communication	1.15	0.40	0.98	0.16	0.50	0.09	0.31
Recreation and culture	2.12	0.20	2.09	-0.07	0.45	-0.02	0.04
Education	-	-	-	-	-	-	-
Insurance, financial services	1.52	0.25	1.41	0.44	0.47	0.38	0.18
Average	1.74	0.27	1.65	0.13	0.47	0.07	0.14
Median	1.37	0.20	1.35	0.17	0.50	0.11	0.07

Notes: I report the standard deviation and persistence of inflation (π_{it}), the common component ($\lambda_i \mathbf{\Gamma}_t$) and the idiosyncratic component (e_{it}). The standard deviation is measured in percentage points and the R^2 gives the share of variation in inflation explained by the common component. Education is not published prior to 2000Q2. Sectoral figures are reported as weighted means.

Table 3.1: Descriptive statistics

Idiosyncratic factors wash out in aggregation, causing all groups inflation to be less volatile and more persistent than sectoral inflation. This results in all groups inflation to be mainly explained by macroeconomic shocks, and here three common factors explain 43% of the variation in *all groups* inflation. In contrast the common components explain on average only 14% of the variation in sectoral inflation. Idiosyncratic shocks are more important than macroeconomic shocks for explaining variations in sectoral inflation.

Figure 3.1 shows the distribution of volatility across expenditure classes. The distribution of volatility is much tighter for the common component than it is for the idiosyncratic component. All the expenditure classes have a common component with standard deviation of less than one percentage point, whilst the standard deviation of the idiosyncratic component is mostly distributed between zero and three percentage points. The outliers are automotive fuel (5.08), child care (5.98) and fruit (9.56).

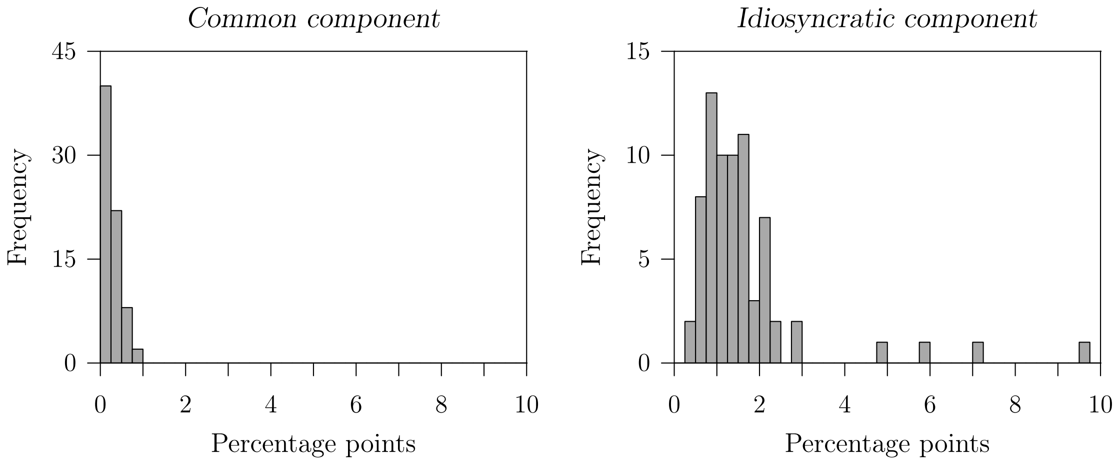

Figure 3.1: Histogram of standard deviations

To analyse persistence in the common and idiosyncratic components of sectoral inflation, I use the autoregressive processes from Equation 3.5 to derive univariate impulse response functions to a standardised shock to the common and idiosyncratic components. The responses of each expenditure class and the average responses are shown in Figure 3.2. For most expenditure classes, an idiosyncratic shock is incorporated into sectoral inflation quite quickly, while the macroeconomic shock has a persistent effect on sectoral inflation lasting more than four quarters.

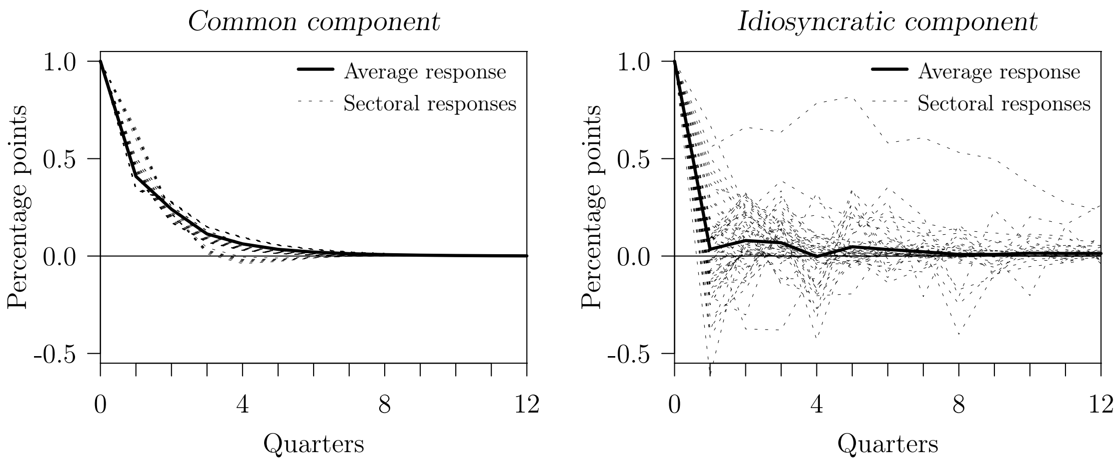

Figure 3.2: Impulse responses: Standardised shock

The sectoral responses are distributed much tighter around the average response for the macroeconomic shock than the idiosyncratic shock. Additional information on the persistence of sectoral inflation can be found in the speed of response to a macroeconomic or idiosyncratic shock.

Following Maćkowiak et al. (2009) I define the speed of response in sector i as

$$\mathrm{speed}_i = \frac{\sum_{q=0}^{2} |\mathrm{resp}_{i,q}|}{\sum_{q=5}^{7} |\mathrm{resp}_{i,q}|}, \tag{3.7}$$

where $\mathrm{resp}_{i,q}$ is the impulse response to a standardised shock after q quarters for sector i. The speed of response takes a value close to 1 when the component has very high persistence, and a value close to zero when the component has very low persistence. The tightness in distribution of the speed of response mirrors that of the impulse responses, and the correlation of the speed of responses of macroeconomic and idiosyncratic shocks is positive (Table 3.2).

	$\mathrm{sd}(\pi_{it})$	$\mathrm{sd}(\lambda_i \mathbf{\Gamma}_t)$	$\mathrm{sd}(e_{it})$	$\frac{\mathrm{sd}(e_{it})}{\mathrm{sd}(\lambda_i \mathbf{\Gamma}_t)}$	$\mathrm{speed}_i^{\mathrm{macro}}$	$\mathrm{speed}_i^{\mathrm{idio}}$
$\mathrm{sd}(\pi_{it})$	1.00					
$\mathrm{sd}(\lambda_i \mathbf{\Gamma}_t)$	0.32	1.00				
$\mathrm{sd}(e_{it})$	0.99	0.26	1.00			
$\frac{\mathrm{sd}(e_{it})}{\mathrm{sd}(\lambda_i \mathbf{\Gamma}_t)}$	0.46	-0.45	0.49	1.00		
$\mathrm{speed}_i^{\mathrm{macro}}$	-0.10	-0.09	-0.10	0.38	1.00	
$\mathrm{speed}_i^{\mathrm{idio}}$	0.09	0.01	0.10	-0.01	0.08	1.00

Table 3.2: Correlations of descriptive statistics

Stylised facts are established for sectoral inflation, for which we observe:

1. a slower response to macroeconomic shocks than to idiosyncratic shocks,
2. positive correlation between the speed of responses to macroeconomic and idiosyncratic shocks,
3. cross-sectional variation of the sectoral speeds of responses to macroeconomic shocks is tighter than to sector-specific shocks.

3.3 Informing a model of price-adjustment

The slower response to macroeconomic shocks than idiosyncratic shocks observed in Australian sectoral inflation motivates two popular models of price-adjustment. First, the multisector model with infrequent price adjustments of Carvalho (2006) and second, the rational-inattention model of Maćkowiak et al. (2009).

The multisector model with infrequent price adjustments argues that the frequency at which prices change is associated with nominal rigidities within the economy in the form of sticky prices. These nominal rigidities often take the form of Taylor (1979) pricing, where prices are adjusted according to the length of contracts, or Calvo (1983) pricing, where firms have a particular probability of being able to reset their price in each period. In contrast, the rational-inattention model argues that if idiosyncratic shocks are large relative to macroeconomic shocks, then it is rational for firms to direct their attention to the former. Idiosyncratic shocks cause firms to adjust their prices frequently, and macroeconomic shocks are incorporated into prices slowly.

Should the rational-inattention model of price-setting be present in the Australian sectoral inflation, we would expect that if the idiosyncratic component is on average more volatile than the common component, then the distribution of speed of responses to idiosyncratic shocks will be tighter than to macroeconomic shocks. The statement on volatility holds for Australian sectoral inflation, however the speed of response to macroeconomic shocks has the tighter distribution. This is consistent with the multisector model with infrequent price adjustments. Moreover, the Carvalho (2006) model suggests that relatively flexible sectors will response quickly to macroeconomic shocks. This requires that there be a positive correlation between the speed of responses to macroeconomic and idiosyncratic shocks, which I find holds for Australian sectoral inflation (Table 3.2).

There are limitations when applying the frameworks of Boivin et al. (2009), Maćkowiak et al. (2009), and Kaufmann & Lein (2013) to the Australian economy. First, many of the conclusions that lead to a model of price-setting rely on knowing the frequency of price changes for each sectors. These are often taken from microdata founded studies of the price quotations that form the basis of national consumer price indices (See Bils & Klenow (2004) as a well-cited study of the U.S. economy, and Kaufmann (2009) for the Swiss economy).

The analysis of Australian sectoral inflation has been limited by the unavailability of price quotation microdata. This prevents four additional stylised facts from being presented. In the multisector model with infrequent price adjustments the sectoral frequencies of price adjustments are expected to have a positive correlation with, (i) the size of response to a macroeconomic shock, (ii) the speed of response to a macroeconomic shock, (iii) the standard deviation of the common component, and (iv) the standard deviation of the idiosyncratic component. To move forward towards a model of price-setting, I draw on the results of a survey conducted by the Reserve Bank of Australia on the price-setting behaviour of firms (Park et al. 2010). The long average duration of prices, and the focus of firms when forming a pricing strategy supports the multisector model with infrequent price adjustments. The frequent price-adjustment behaviour supported by the rational-inattention model is not observed by Park et al. (2010).

Industry	Average duration$^{(a)}$	Dominant pricing strategy (%)		
		Cost-focus	Demand-focus	Other
Agriculture	4	18	82	-
Construction	$1\frac{1}{3}$	71	27	2
Manufacturing	2	47	46	6
Mining	4	18	71	11
Utilities	4	18	27	55
Wholesale and retail	1	44	50	7
Transport and storage	4	57	30	13
Business services	4	55	44	1
Household services	4	35	30	35
Tourism	4	20	80	-

Source: Park, Rayner and D'Arcy (2010)
$^{(a)}$ in quarters

Table 3.3: Average duration of prices and dominant pricing strategy

The stylised facts from the approximate factor model and the survey of price-setting behaviour both point toward a multisector model with infrequent price adjustments appropriately summarising the heterogeneous price-setting behaviour in Australian sectoral inflation.

4 A Multisector New-Keynesian Model

The model utilised in this thesis is an extension of the multisector New-Keynesian model of Cagliarini et al. (2011). The Cagliarini et al. (2011) model draws on Carvalho (2006) and Nakamura & Steinsson (2010), incorporating heterogeneity in the average duration of prices across sectors, within a roundabout production framework where technology parameters differ across sectors.

In extending the model I consider a measure of underlying inflation that takes the form of a weighted sum of sectoral inflation rates. The monetary authority responds to this underlying measure according to its policy rule, while economy-wide inflation is determined endogenously within the model. The specifications imposed for underlying inflation draw on those measures commonly used in practice by central banks, along with others that are functions of the structural parameters.

4.1 Overview

4.1.1 Agents

The economy consists of a unit interval of identical households, N final-goods producers, a continuum of intermediate-goods producers and a monetary authority.[1]

Households

Households are identical, obtaining utility from consumption c_t and real money holdings H_t/P_t^c, and disutility from supplying labour l_t^s, according to

$$U_t = a_t \ln c_t + \ln \frac{H_t}{P_t^c} - \frac{1}{1+\frac{1}{\eta}}(l_t^s)^{1+\frac{1}{\eta}}, \tag{4.1}$$

where a_t is the household preference for consumption and η is the Frisch elasticity of labour supply. Households maximise intertemporal utility

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[a_t \ln c_t + \ln \frac{H_t}{P_t^c} - \frac{1}{1+\frac{1}{\eta}}(l_t^s)^{1+\frac{1}{\eta}} \right], \tag{4.2}$$

subject to

$$T_t + V_t + H_{t-1} + B_{t-1} + W_t l_t^s \;\geq\; P_t^c c_t + \frac{B_t}{I_t} + H_t, \tag{4.3}$$

where β is the household discount factor, T_t is monetary transfers, V_t is dividends, H_{t-1} is nominal money holdings carried forward from the period prior, $W_t l_t^s$ is the

[1] See Appendix C for the first-order and market-clearing conditions required to solve the model.

value of labour income, $P_t^c c_t$ is the value of consumption, B_t/I_t is the present value of bonds held and H_t is nominal money holdings in the current period.

Final-goods firms

There are N perfectly competitive final-goods producing firms, one representing each sector of the economy. Each final-goods producing firm takes their total production $c^s_{j,t}$, prices for their output $P_{j,t}$ and intermediate inputs $P_t(k)$ as given, selling final goods to households that are produced using inputs from intermediate-goods producers within their own sector.

Final-goods producing firms minimise cost

$$\int_{\psi_{j-1}}^{\psi_j} P_t(k)\, c_t^d(k)\, dk, \tag{4.4}$$

subject to

$$c^s_{j,t} \leq \left[\left(\frac{1}{\gamma_j}\right)^{\frac{1}{\varepsilon}} \int_{\psi_{j-1}}^{\psi_j} c_t^d(k)^{\frac{\varepsilon-1}{\varepsilon}} dk \right]^{\frac{\varepsilon}{\varepsilon-1}}, \tag{4.5}$$

where $\gamma_j = \psi_j - \psi_{j-1}$ is the share of sector j and span of the continuum of intermediate goods producers in sector j. The prices and demand for intermediate inputs by the final-goods producing firm are $P_t(k)$ and $c_t^d(k)$ where $k \in (\psi_{j-1}, \psi_j]$. The elasticity of substitution is given by ε.

Intermediate-goods firms

There is a continuum of monpolistically competitive intermediate-goods producers indexed on the unit interval $(0, 1]$. Each sector holds a share of the unit interval given by $\gamma_j = \psi_j - \psi_{j-1}$. Intermediate-goods producing firms can change their price according to a sector-specific Calvo probability θ_j and set prices according to

$$P_t(k) = \frac{\varepsilon}{\varepsilon - 1} \frac{\mathbb{E}_t \sum_{n=0}^{\infty} \Lambda_{t+n}\, \theta_j^n\, \Omega_{j,t+n}\, (P^m_{t+n})^{\varepsilon}\, y_{t+n}}{\mathbb{E}_t \sum_{n=0}^{\infty} \Lambda_{t+n}\, \theta_j^n\, (P^m_{t+n})^{\varepsilon}\, y_{t+n}}, \tag{4.6}$$

where Λ_t is the Lagrange multiplier from solving the household utility maximisation problem, $\Omega_{j,t}$ is the marginal cost faced by intermediate-goods producing firms in sector j, while P^m_t and y_t are the price and output of the aggregate intermediate good. Once prices are determined, intermediate-goods producing firms meet demand for their good from final-goods producing firms within their own sector and other intermediate-goods producers.

Taking wages W_t and the price of the aggregate intermediate good P_t^m as given, intermediate-goods producing firms minimise cost

$$W_t l_{i,t}^d + P_t^m m_{i,t}^d, \tag{4.7}$$

subject to

$$y_t(i) \leq \left(z_{j,t} z_t l_{i,t}^d\right)^{\alpha_j} \left(m_{i,t}^d\right)^{1-\alpha_j}, \tag{4.8}$$

where $y_t(i)$, l_t^d and m_t^d are the output, demand for labour and demand for intermediate inputs for firm i, $z_{j,t}$ and α_j are the sector-specific productivity and the factor share of labour in sector j, and z_t is the state of aggregate productivity. As the factor shares of labour are sector-dependent, the steady-state labour cost shares, marginal costs and prices faced by firms will also be sector-dependent.

Monetary authority

The monetary authority follows a policy rule, setting the nominal interest rate I_t according to its prior period value, the growth in final-goods consumption g_t and the rate of underlying inflation π_t^U in the economy

$$I_t = I_{t-1}^{\rho_i} \left(\frac{1}{\beta} e^{-(1-\phi_g)\mu_z} \left(\pi_t^U\right)^{\phi_\pi} g_t^{\phi_g}\right)^{1-\rho_i} e^{\varepsilon_{i,t}}, \tag{4.9}$$

where ρ_i, ϕ_π, ϕ_g are policy rule parameters, μ_z is the average growth rate of aggregate technology and $\varepsilon_{i,t}$ is the monetary policy shock.

4.1.2 External shocks

There are four driving forces within the model, a consumption preference shock $\varepsilon_{a,t}$, an aggregate technology shock for intermediate-goods producers $\varepsilon_{z,t}$, sector-specific technology shocks for intermediate-goods producers $\varepsilon_{z,j,t}$ and a monetary policy shock $\varepsilon_{i,t}$. The preference and technology shock processes evolve as follows

$$a_t = a_{t-1}^{\rho_a} e^{\varepsilon_{a,t}}, \tag{4.10}$$

$$z_t = z_{t-1} e^{\mu_z + \varepsilon_{z,t}}, \tag{4.11}$$

$$z_{j,t} = z_{j,t-1}^{\rho_{z,j}} e^{\varepsilon_{z,j,t}}, \tag{4.12}$$

while the monetary policy shock is incorporated into the policy rule (4.9).

4.1.3 Market clearing

The N markets for N final goods, market for intermediate goods, a labour market, a bond market and a money market, all clear according to

$$
\begin{aligned}
c_{j,t}^d &= c_{j,t}^s \quad \text{for } j = 1, \ldots, N, && (4.13)\\
y_t(k) &= c_t^d(k) + \int_0^1 m_t^d(k)\, di \qquad \text{for } k \in (0,1]\,, && (4.14)\\
l_t^s &= \int_0^1 l_{i,t}^d\, di, && (4.15)\\
B_t &= 0, && (4.16)\\
H_t &= H_{t-1} + T_t. && (4.17)
\end{aligned}
$$

Aggregation across firms and sectors yields

$$
\begin{aligned}
y_t &= c_t + m_t^d, && (4.18)\\
m_t^d &= \sum_{j=1}^{N} m_{j,t}^d, && (4.19)\\
l_t^d &= \sum_{j=1}^{N} l_{j,t}^d. && (4.20)
\end{aligned}
$$

4.2 Underlying inflation

Ideally, a measure of underlying inflation should abstract from price changes that are not influenced by monetary factors. Measures used in practice can be categorised as either an exclusion-based measure or statistical measure (Roberts 2005).

I consider measures of underlying inflation that take the form

$$\pi_t^U = \sum_{j=1}^{N} \phi_{\pi_j} \pi_{j,t}, \tag{4.21}$$

where the weights assigned to sectoral inflation are subject to the constraints

$$\phi_{\pi_j} \geq 0 \quad \forall\ j \qquad \text{and} \qquad \sum_{j=1}^{N} \phi_{\pi_j} = 1,$$

with underlying inflation equal to headline inflation when $\phi_{\pi_j} = \gamma_j$ for all j.

4.2.1 Exclusion-based measures of underlying inflation

Exclusion-based measures exclude price changes in sectors that are believed most likely to influence headline inflation for reasons not related to monetary factors. In practice, items are often excluded based on their volatility, as the price changes associated with these items are often transitory. As the structural parameters are known for the sectors of the model economy, I construct exclusion measures using the Calvo probability as an indicator of price-setting behaviour in each sector.

Exclusion 1

The first exclusion measure excludes the least sticky sector, wholesale and retail trade ($\theta_j = 0.10$). The weight assigned to this sector is set to zero and the remaining sectors are reweighted so that $\sum_{j=1}^{N} \phi_{\pi_j} = 1$.

Exclusion 2

The second exclusion measure excludes the two least sticky sectors, wholesale and retail trade ($\theta_j = 0.10$) and construction ($\theta_j = 0.25$). The weights assigned to these sectors are set to zero and the remaining sectors are reweighted so that $\sum_{j=1}^{N} \phi_{\pi_j} = 1$.

4.2.2 Statistical measures of underlying inflation

Statistical measures include the commonly used trimmed mean, and the less common weighted median. The trimmed mean is defined as the average rate of inflation after removing a percentage of observations from either end of the distribution of price changes. A trim percentage of 15% is often seen in practice, removing 15% of both the smallest and largest price changes. The weighted median is the limiting case of the trimmed mean, where 50% of observations are trimmed (Roberts 2005).

It is not clear how one would compute the rational expectations solution in the case of trimmed mean inflation. This results in different weights being assigned to sectoral inflation at different times. These time-varying parameters then evolve as a function of the model state, making the rational expectations solution non-linear, hence the usual linear methods cannot be used. I leave the inclusion of trimmed mean inflation into the multisector framework to future research.

4.2.3 Other measures of underlying inflation

As the data generating process is known, I construct two additional measures of underlying inflation, one from the share and Calvo probability of each sector, and another through optimising the weights in order to maximise a welfare criterion.

Calvo-share

In the first of the other measures I weight each sector according to the normalised product of its Calvo probability θ_j and share γ_j. This specification seeks to retain the economic importance of each sector through its share, as emphasised in Diewert (1995), while incorporating the response to monetary factors through its stickiness.

Optimal

In the second of the other measures I construct the weights for sectoral inflation by numerically maximising the objective function of the monetary authority. I consider two objectives for the monetary authority. First, following Woodford (2003) I use a utility-based objective function derived from the household period utility function, and second, I use an objective function that is consistent with the mandate of the monetary authority. Further detail is provided in Chapter 5.

4.3 Calibration of parameters

The heterogeneity in intermediate-goods producing firms price-setting behaviour is a key distinction from the standard New-Kenyesian framework. The choice of sectors for which the model is calibrated must reflect the availability of information on price-setting behaviour. In the previous chapter, I discussed the current state of microdata availability for the price quotations that form the basis of the consumer price index in Australia. This information is currently unavailable to researchers, preventing the analysis of price-setting behaviour for the elementary goods that form the basis of expenditure classes in the consumer price index.

To arrive at a calibration that remains realistic but is also attainable, I follow the approach of Cagliarini et al. (2011), and draw on their calibration for ten broad sectors of the Australian economy. I use the results from a survey of firms conducted by the Reserve Bank of Australia on price-setting behaviour from June 2000 to April 2006 (Park et al. 2010). The average duration of prices (in quarters) and the corresponding Calvo probability θ_j are detailed in Table 4.1.

The size of each sector γ_j is drawn from the share of gross revenue from the input-output tables of the Australian national accounts. The steady-state shares of sectors' labour $\frac{l_j}{l}$ and intermediate inputs $\frac{m_j}{m}$ are drawn from their share of hours worked and estimates of multifactor productivity. The technology parameters for each sector are drawn from experimental estimates of multifactor productivity, and include: (i) persistence of the technology shock process ρ_j, (ii) standard deviation of the technology shock process σ_{z_j}, and (iii) labour income share α_j. These calibrated parameters are detailed in Table 4.2.

Sector	Average duration (quarters)	Calvo probability (θ_j)
Agriculture	4	0.75
Construction	$1\frac{1}{3}$	0.25
Manufacturing	2	0.50
Mining	4	0.75
Utilities	4	0.75
Wholesale and retail trade	1	0.10[(a)]
Transport and storage	4	0.75
Business services	4	0.75
Household services	4	0.75
Tourism	4	0.75

[a] Calibrated at 0.10 as the sector is empirically close to a flexible price sector.

Table 4.1: Calvo probabilities by sector

Market sector multifactor productivity is used to calibrate the standard deviation of the aggregate technology shock σ_z. Average growth in aggregate technology μ_z is calibrated to from the growth in GDP per-capita over the period 1993Q1 to 2007Q4 and set to 1.0061, which equals 2.46% on an annualised basis. The household discount factor β is set to 0.99, which implies an steady-state annualised interest rate of 3.52%. The Frisch elasticity of labour supply η is set to one-half following Carvalho (2006), and the elasticity of substitution ε is set to four, representing a one-third mark-up following Nakamura & Steinsson (2010).

Sector	Shares			Technology		
	γ_j	l_j/l	m_j/m	ρ_j	σ_{z_j}	α_j
Agriculture	0.06	0.05	0.06	0.83	3.91	0.29
Construction	0.15	0.10	0.17	0.88	1.46	0.24
Manufacturing	0.29	0.25	0.30	0.86	0.60	0.29
Mining	0.05	0.03	0.05	0.80	1.71	0.24
Utilities	0.03	0.02	0.03	0.93	0.53	0.24
Wholesale and retail trade	0.19	0.26	0.17	0.88	0.50	0.39
Transport and storage	0.08	0.07	0.09	0.87	0.61	0.29
Business services	0.07	0.12	0.06	0.91	0.61	0.44
Household services	0.05	0.06	0.05	0.79	0.69	0.35
Tourism	0.02	0.03	0.02	0.91	0.80	0.39

Notes: Share values are for the period 1995-2003 and do not sum to one because of rounding errors. The sectoral share parameters imply a steady-state share of value added in gross output ($\frac{C}{Y}$) of 0.48.

Table 4.2: Calibration of sectoral shares and technology parameters

The monetary policy rule parameters ρ_i, ϕ_π and ϕ_g, persistence of the preference shock ρ_a and standard deviations of the remaining aggregate shocks σ_a and σ_i are estimated. Cagliarini et al. (2011) use the Kalman filter to estimate these parameters from growth in GDP per capita, the overnight cash rate and headline inflation in consumer prices (excluding taxes and volatile items) over the period 1993Q1 to 2007Q4. Values for the behavioural parameters are detailed in Table 4.3.

	Description	Parameter value	Standard error
β	Household discount factor	0.99	
ε	Elasticity of substitution	4.00	
η	Frisch elasticity of labour supply	0.50	
σ_z	Standard deviation of aggregate technology shock	0.44	
ρ_i	Persistence of the nominal interest rate	0.71	0.04
ϕ_π	Policy rule response to inflation	1.16	0.13
ϕ_g	Policy rule response to growth in value added	0.21	0.11
ρ_a	Persistence of preference shock	0.89	0.07
σ_i	Standard deviation of monetary policy shock	0.12	0.02
σ_a	Standard deviation of preference shock	0.40	0.11

Table 4.3: Calibration and estimation of behavioural parameters

As there is growth in aggregate technology I detrend some variables in order to make them stationary. The log-linearised rational expectations model is then solved using the development release of Dynare 4.5 in MATLAB 2014b.[2]

[2] The development release was used as constrained minimisation is not available in Dynare 4.4.

5 Welfare Approaches to Optimality

Stickiness in prices is the nominal rigidity introduced to the model economy through the price-setting behaviour of intermediate-goods producing firms. This nominal rigidity allows the monetary authority to influence the real economy, however it also causes inefficiency as the economy is prevented from reaching equilibrium in the short-run.

I evaluate the relative performance of different compositions for underlying inflation with two approaches. First, I use a social welfare approach, where the monetary authority maximises a utility-based objective function, and second, I use a simple mandate approach, where the monetary authority maximises a objective function chosen to achieve the monetary authority's mandate.[1] This chapter outlines the relative merits and empirical foundations of each approach.

5.1 Social welfare approach

The social welfare loss is calculated using the method outlined in Woodford (2003) where the period loss function is an approximation of the discounted sum of utility for the representative household. I generalise Woodford's (2003) two-sector model with Calvo pricing, and following a second order approximation around the efficient steady-state, the social welfare loss function is of the form

$$L_t^{SW} = \sum_{j=1}^{N} \lambda_j \hat{\pi}_{jt}^2 + \lambda_c \hat{c}_t^2, \tag{5.1}$$

where $\hat{\pi}_{jt}$ is the log-deviation from trend for inflation in sector j and $\hat{c}_t$ is the log-deviation from trend for value added output.[2] The weights are given by

$$\lambda_j = \frac{\gamma_j \kappa}{\kappa_j}, \qquad \text{and} \qquad \lambda_c = \frac{\kappa}{\varepsilon},$$

where for sector j, γ_j is the share of the economy and κ_j is the slope of the sectoral New-Keynesian Phillips Curve (NKPC)

$$\kappa_j = \frac{(1-\theta_j)(1-\beta\theta_j)}{\theta_j}. \tag{5.2}$$

θ_j is the Calvo probability faced by firms in sector j, while β and ε are the household discount factor and elasticity of substitution. κ is the weighted harmonic mean of the sector-specific κ_j terms

[1] Minimising the loss is equivalent to maximising the monetary authority objective.
[2] 'Value added' or 'final' output. See Equation 4.18 ($y_t = c_t + m_t^d$).

$$\kappa = \left[\sum_{j=1}^{N} \gamma_j \kappa_j^{-1} \right]^{-1} . \tag{5.3}$$

The welfare loss depends on the rate of inflation in each sector and value-added output. The relative weight on variations in inflation in sector j is greater the relative size of the sector, and greater the relative degree of price stickiness faced by the sector. The relative weight on variations in value added output is lesser the relative degree of overall price stickiness faced by the economy.

Table 5.1 summarises the parameters for the social welfare approach as calibrated in Chapter 4. The social welfare approach emphasises the importance of allowing flexible price sectors, which already operate efficiently, to adjust to shocks without intervention from the monetary authority. This is particularly visible in the sectoral weights of the loss function. For the calibrated model, the wholesale and retail trade sector holds a large relative share of the economy, yet is weighted an order of magnitude less than the smallest sector, tourism.

Sector	Share (γ_j)	Calvo (θ_j)	Weight (λ_j)
Agriculture	0.06	0.75	0.14
Construction	0.15	0.25	0.01
Manufacturing	0.28	0.50	0.11
Mining	0.05	0.75	0.11
Utilities	0.03	0.75	0.07
Wholesale and retail	0.20	0.10	0.01
Transport and storage	0.08	0.75	0.20
Business services	0.08	0.75	0.20
Household services	0.05	0.75	0.13
Tourism	0.01	0.75	0.03

Notes: The weight for value added is $\lambda_c = 0.05$.
Values do not sum to 1 in the table because of rounding errors.

Table 5.1: Social welfare function parameters

Figure 5.1 shows how the loss function weights, given a general level of price stickiness within the economy, are impacted by the size of a sector and the level of price stickiness it faces. For this particular calibration of the multisector model, the social loss function assigns very little importance to a sector, given its size, until its prices become at least moderately sticky. For a sector to be assigned a loss function weight equivalent to its size, the average duration of prices within that sector should fall between three and four quarters.

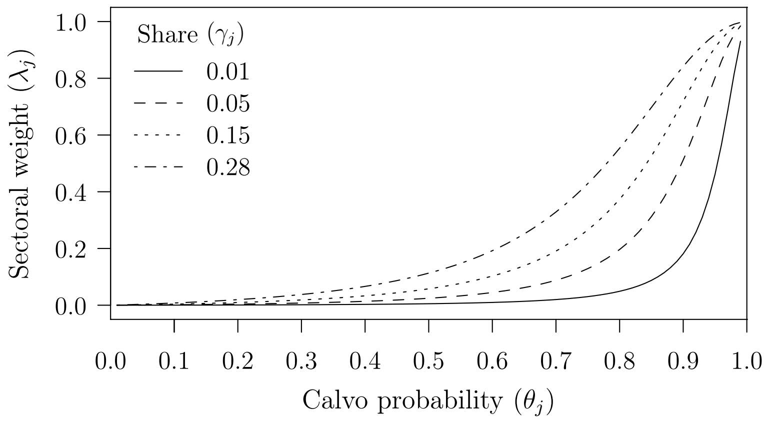

Figure 5.1: Loss function weights: Sectoral inflation

The importance of particularly large, sticky sectors is further emphasised by the behaviour of the loss-function weight when $\gamma_j = 0.28$, where the weight assigned for a Calvo probability of 0.75 is approximately twice as large as the share of the sector. The weight assigned to value added λ_c is much less sensitive to individual variations in sectoral price stickiness.

Figure 5.2 shows how this weight is impacted if we assume that the Calvo probability is uniform across sectors. The weight as calibrated ($\lambda_c = 0.05$) implies that the general level of price stickiness in the economy is equivalent to all sectors facing a uniform Calvo probability of 0.65.

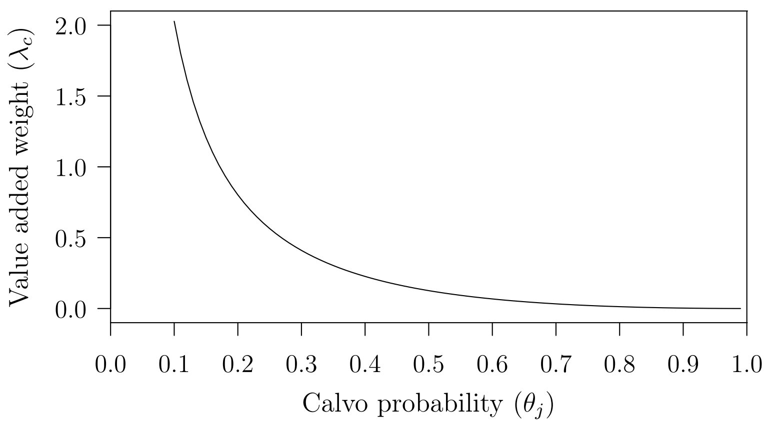

Figure 5.2: Loss function weights: Value added output

5.2 Simple mandate approach

In the simple mandate approach, the monetary authority seeks to maximise an objective function drawn from its operating mandate, which is often set out in legislation or regulation from the executive government. Using the simple mandate approach has two particular advantages over the social welfare approach in practice. First, the loss-function weights are not derived from the structural parameters of the economy, which are unobserved, and second, it allows the monetary authority to operate in a fashion that is far more communicable to the public.

5.2.1 Headline inflation and value-added output

In forming the simple mandate, I assume that the monetary authority is concerned with stabilising headline inflation and value added output around their steady states. The simple mandate loss function is defined as

$$L_t^{SMi} = \lambda_\pi \hat{\pi}_t^2 + \lambda_c \hat{c}_t^2 \qquad \text{for } i = 1, 2, \tag{5.4}$$

where $\hat{\pi}_{jt}$ is the log-deviation from trend for headline inflation and $\hat{c}_t$ is the log-deviation from trend for value added output. The weights are assigned according to their relative importance in the simple mandate, for which I consider two cases. First, the mandate of the monetary authority places equal importance on the stabilisation of headline inflation ($\lambda_\pi = 1$) and value added output ($\lambda_c = 1$) around their respective steady-states. I refer to this as simple mandate 1 and the loss function is

$$L_t^{SM1} = \hat{\pi}_t^2 + \hat{c}_t^2. \tag{5.5}$$

Second, the mandate of the monetary authority places twice as much importance on stabilising headline inflation ($\lambda_\pi = 2/3$) over value added output ($\lambda_c = 1/3$) around their respective steady-states. I refer to this as simple mandate 2 and the loss function is

$$L_t^{SM2} = \frac{2}{3}\,\hat{\pi}_t^2 + \frac{1}{3}\,\hat{c}_t^2. \tag{5.6}$$

For the social welfare and simple mandate approaches, a higher relative value of the loss function indicates a welfare gain. This comparison is valid within each specification of the loss function, but not across different loss functions. In the chapters that follow, I use these approaches to evaluate the performance of different measures of underlying inflation in the monetary policy rule; and, alternative specifications of the monetary policy rule.

6 Performance of Underlying Inflation

In this chapter I compare the performance of headline inflation with four alternative measures of underlying inflation, within the welfare framework outlined in the previous chapter. The weights for the optimal measure of underlying inflation are calculated, then the relative welfare loss of the four alternative measures are compared. Finally, I consider how targeting the optimal measure of underlying inflation impacts on the transmission of monetary policy.

6.1 Optimal measures of underlying inflation

The social welfare (SW) and simple mandate (SM1, SM2) approaches both calculate welfare as a weighted sum of the variances of value added output $\hat{c}_t$ and sectoral inflation $\hat{\pi}_t$. The welfare loss will therefore be minimised when the variances are minimised. I calculate the optimal measure of underlying inflation by numerically minimising the welfare loss by choosing sectoral inflation weights ϕ_{π_j} subject to

$$\phi_{\pi_j} \geq 0, \qquad \text{and} \qquad \sum_{j=1}^{N} \phi_{\pi_j} = 1. \tag{6.1}$$

The objective function for each approach is highly non-linear in the underlying parameterisation and there is a risk of the numerical minimiser becoming stuck within the valley of a local minimum. I address this by generating 500 random sets of starting parameters for the sectoral weights, subject to the constraints in Equation 6.1. The set of sectoral weights that minimises the welfare loss is consistent across many of these sets of starting parameters. I also conduct optimisation of the sectoral weights using a pattern search approach. The results are consistent with those from the constrained minimisation procedure.

I report the optimised sectoral weights ϕ_j^{SW}, ϕ_j^{SM1}, ϕ_j^{SM2}, sectoral share weights γ_j, steady-state shares of labour and intermediate inputs l_j/l, m_j/m, sectoral Calvo probabilities θ_j and standard deviation of the sectoral technology shocks σ_{z_j} in Table 6.1. For the social welfare measure of underlying inflation a surprising result is that five of the ten sectors have a weight of zero. Three of these sectors are those with the smallest Calvo probabilities, wholesale and retail trade, construction, and manufacturing. The construction of the social welfare loss function heavily penalises sectors that have a Calvo probability lower than the equivalent uniform Calvo probability. In the previous section I found that this equivalent Calvo probability was 0.65, so the sectoral weights in these three sectors are not unexpected.

Sector	ϕ_j^{SW}	ϕ_j^{SM1}	ϕ_j^{SM2}	γ_j	l_j/l	m_j/m	θ_j	σ_{z_j}
Agriculture	0.00	0.00	0.00	0.06	0.05	0.06	0.75	3.91
Construction	0.00	0.08	0.03	0.15	0.10	0.17	0.25	1.46
Manufacturing	0.00	0.42	0.21	0.28	0.25	0.30	0.50	0.60
Mining	0.07	0.00	0.00	0.05	0.03	0.05	0.75	1.71
Utilities	0.30	0.00	0.00	0.03	0.02	0.03	0.75	0.53
Wholesale and retail	0.00	0.02	0.00	0.20	0.26	0.17	0.10	0.50
Transport and storage	0.23	0.00	0.10	0.08	0.07	0.09	0.75	0.61
Business services	0.00	0.05	0.08	0.08	0.12	0.06	0.75	0.61
Household services	0.35	0.34	0.49	0.05	0.06	0.05	0.75	0.69
Tourism	0.04	0.09	0.09	0.01	0.03	0.02	0.75	0.80

Table 6.1: Underlying inflation sectoral weights

6.1.1 Response to sectoral technology shocks

The two other sectors with a zero weight are agriculture and business services. The agriculture sector has a sectoral technology shock process with a high standard deviation (3.91), and relatively uniform shares of gross revenue (0.06), labour inputs (0.05) and intermediate inputs (0.06). As roundabout production is a feature of this economy, Intermediate-goods producing firms use the output of other intermediate-goods producing firms as an input. This transmits technology shocks that originate in one sector into the others, according to their share of steady-state intermediate inputs. The response of sectoral inflation and sectoral value added output to three sectoral technology shocks with differing standard deviations is shown in Figure 6.1.

Here I compare the response of sectoral inflation and sectoral value output added to technology shocks originating in the agriculture ($\sigma_{z_j} = 3.91$), mining ($\sigma_{z_j} = 1.71$) and household services ($\sigma_{z_j} = 0.69$) sectors. These three sectors are approximately equal in size and their use of labour and intermediate inputs. I omit the within-sector responses to allow comparisons across different shocks using the same scale. The impulse response functions for each shock show a slight difference in profile, but a remarkable difference in magnitude.

A positive sectoral technology shock temporarily decreases the marginal cost faced by intermediate-goods producing firms in that sector, and as prices are sticky, these firms can only reset their prices according to their Calvo probability. The intermediate-goods producing firms in the three sectors highlighted in Figure 6.1 have very sticky prices ($\theta_j = 0.75$), which is equivalent to a 25% chance of being able to reset their prices within a given period. The firms that are unable to decrease their prices respond by increasing their production. The market for intermediate goods clears, so the increase in intermediate-goods production in one sector will increase production by intermediate-goods producing firms in other sectors.

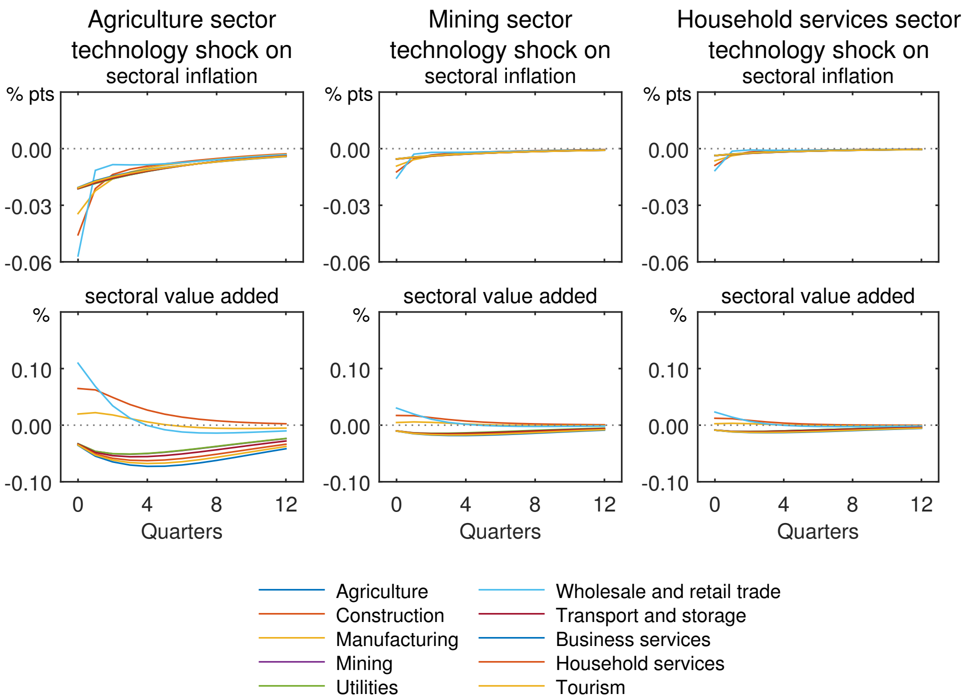

Figure 6.1: Impulse responses: Sectoral technology shocks

Baseline: Monetary authority responds to headline inflation

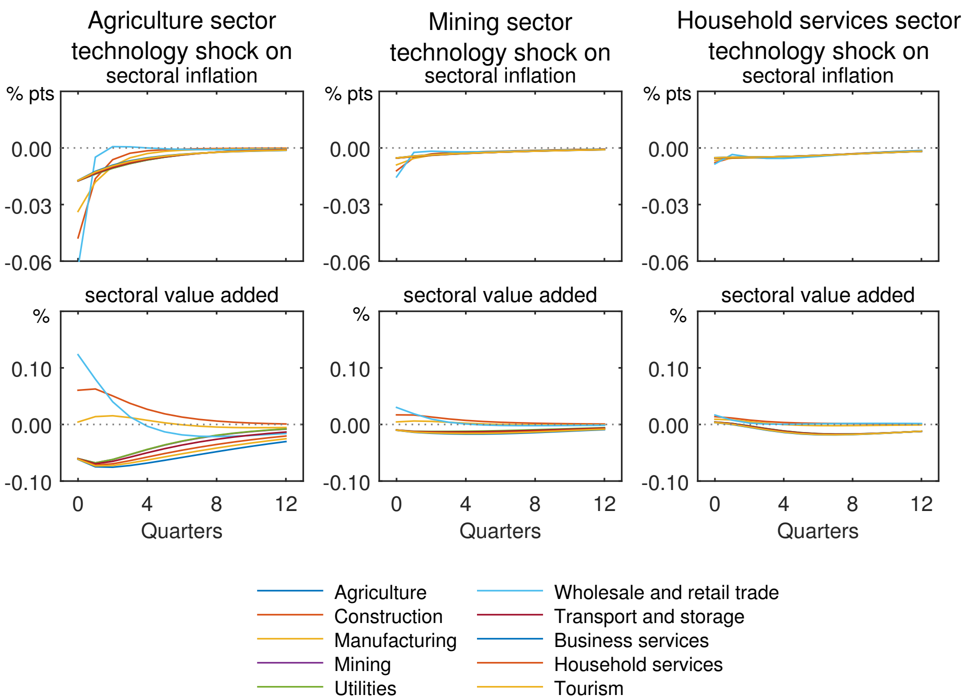

Figure 6.2: Impulse responses: Sectoral technology shocks

Optimal: Monetary authority responds to underlying inflation

Consequently, the production of final goods also increases and the economy experiences positive growth in value added output. The monetary authority responds to the negative inflation in sectoral prices and positive growth in value added output. The response to growth dominates the response to inflation so the nominal interest rate increases. Figure 6.2 shows the response of sectoral inflation and sectoral value added output to the same set of sectoral technology shocks, however the monetary authority now responds to the social welfare optimal measure of underlying inflation. In response to the agriculture shock, sectoral inflation and value added output in the particularly sticky sectors returns to steady-state faster. Value added in the wholesale and retail trade sector ($\theta_j = 0.10$) overshoots the steady-state. The response of sectoral inflation and value added output to a shock in the mining sector shows very minor improvement, while the response to a shock in the household services sector worsens.

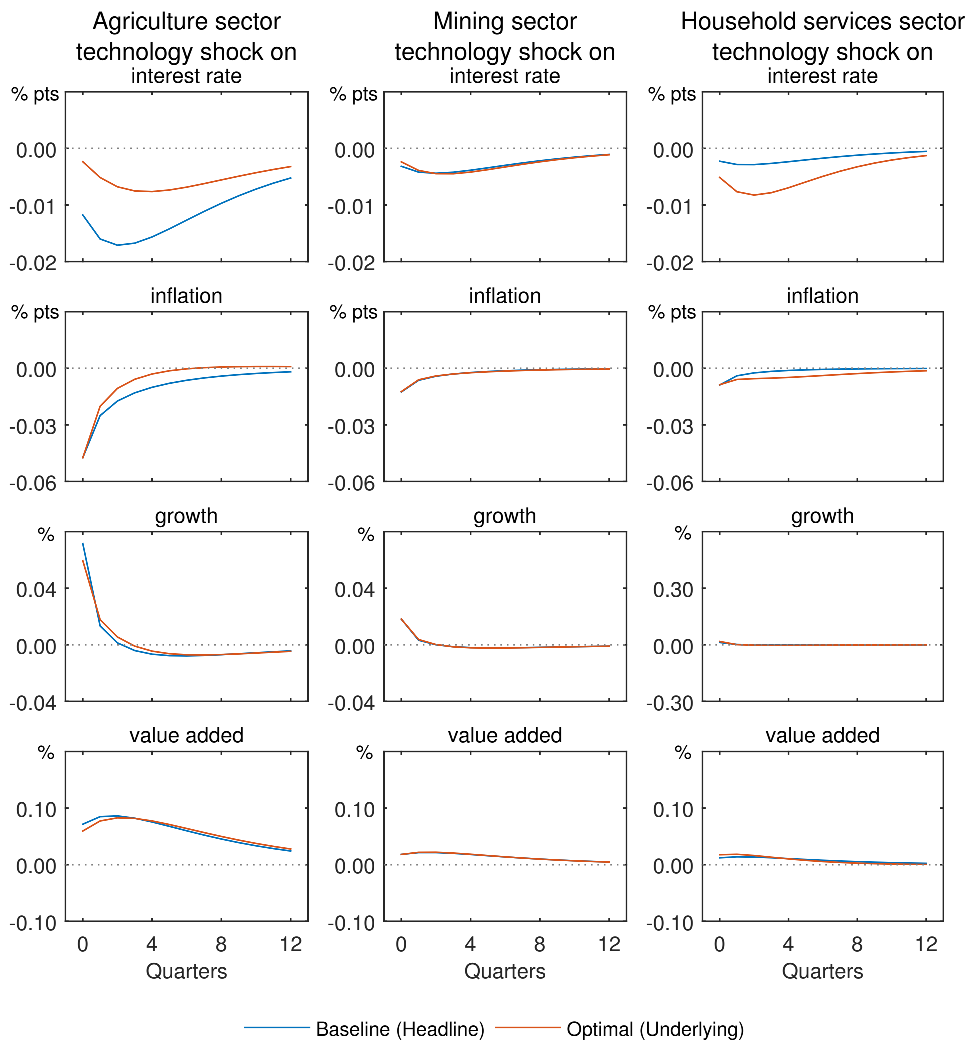

Figure 6.3: Impulse responses: Sectoral technology shocks

The optimal measure of underlying inflation maximises social welfare. It is optimal only in an *aggregate* context so the net welfare improvement can be comprised of an improved response to some shocks, and a worsened response to others. Figure 6.3 shows the response of the nominal interest rate, inflation, growth and value added output to the same set of sectoral technology shocks.

At the outset, note that the observations made around the aggregate response improving or worsening holds. Responding to the optimal measure of underlying inflation: (i) improves the response to a technology shock in the agriculture sector; (ii) has little to no net effect on the response to a technology shock in the mining sector; and (iii) worsens the response to a technology shock in the household services sector. The magnitude of response in each shock is particularly small. Inflation deviates by less than 0.05 percentage points from its steady-state, while growth and value added output deviate by less than 0.1 per cent from their respective steady-states. Moreover, the magnitude of the monetary policy response provides a useful reference for which to frame the result. The largest initial response is to a technology shock in the agriculture sector, where the one-hundredth of a percentage point negative deviation from steady-state is equivalent to four and a half basis points, annualised. Such fine adjustments to the policy rate are not made in practice.

6.1.2 Response to aggregate shocks

The aggregate shocks are less prone to influence from the composition of underlying inflation. Figure 6.4 shows the sectoral responses when responding to headline inflation, while Figure 6.5 shows the sectoral responses when responding to the social welfare optimal measure of underlying inflation. When conducting a visual inspection of the path back to steady-state, the differences are of such a minuscule nature at the sectoral level that it is difficult to determine if there is any improvement from responding to underlying inflation. Figure 6.6 shows an improvement on the aggregate variables: the nominal interest rate, inflation, growth in value added output, and value added output. While the aggregate improvement from responding to the social welfare optimal measure of underlying inflation is still small, we can now assess it visually.

Preference shock

A positive shock to household preferences increases demand for final goods. Final-goods producing firms increase their demand for intermediate goods, which the intermediate-goods producing firms meet by adjusting their prices or output, according to the Calvo probability faced by the firm. The monetary authority responds to the increase in prices and growth in value added output by increasing

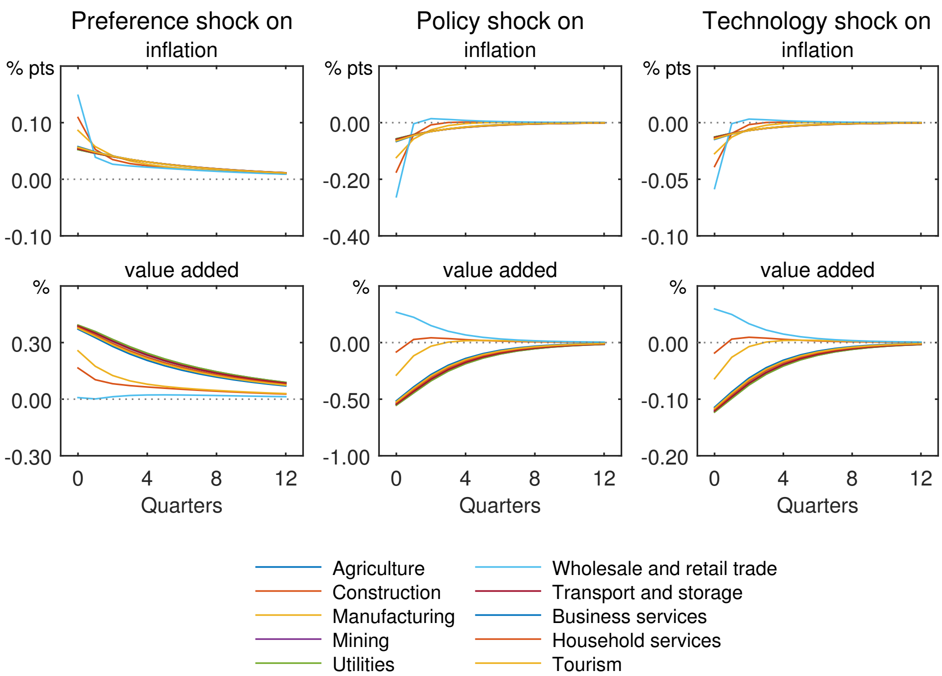

Figure 6.4: Impulse responses: Aggregate shocks

Baseline: Monetary authority responds to headline inflation

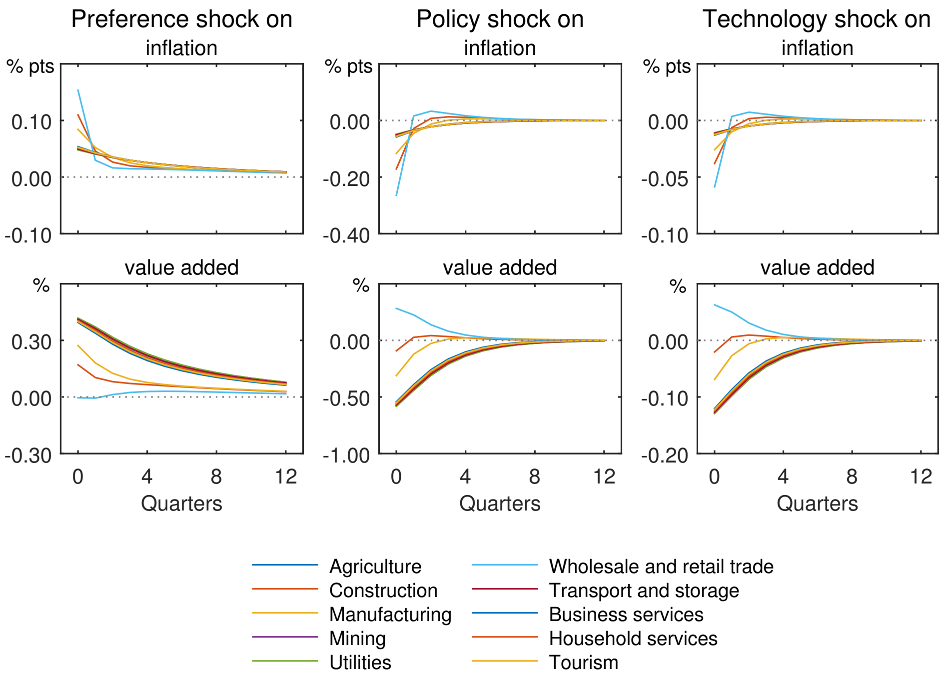

Figure 6.5: Impulse responses: Aggregate shocks

Optimal: Monetary authority responds to underlying inflation

the nominal interest rate. Inflation returns to its steady state at a quicker pace, while the response of growth in value added output and value added output are relatively unchanged. More notable is that by responding to underlying inflation, the intervention by the monetary authority returns inflation to its steady state quicker, but is smaller. The difference in the size of the response is reasonably small, approximately 6 basis points on an annualised basis.

Monetary policy shock

A positive shock to the nominal interest rate decreases the relative price level in each sector, which decreases the marginal costs faced by intermediate-goods producing firms. Intermediate-goods producing firms reset their prices in line with their Calvo probability, and those that cannot reset their price adjust their output. The monetary policy shock decreases inflation, growth in value added output, and value added output. When responding to underlying inflation the monetary authority can increase the nominal interest rate by an additional 12 basis points (annualised).

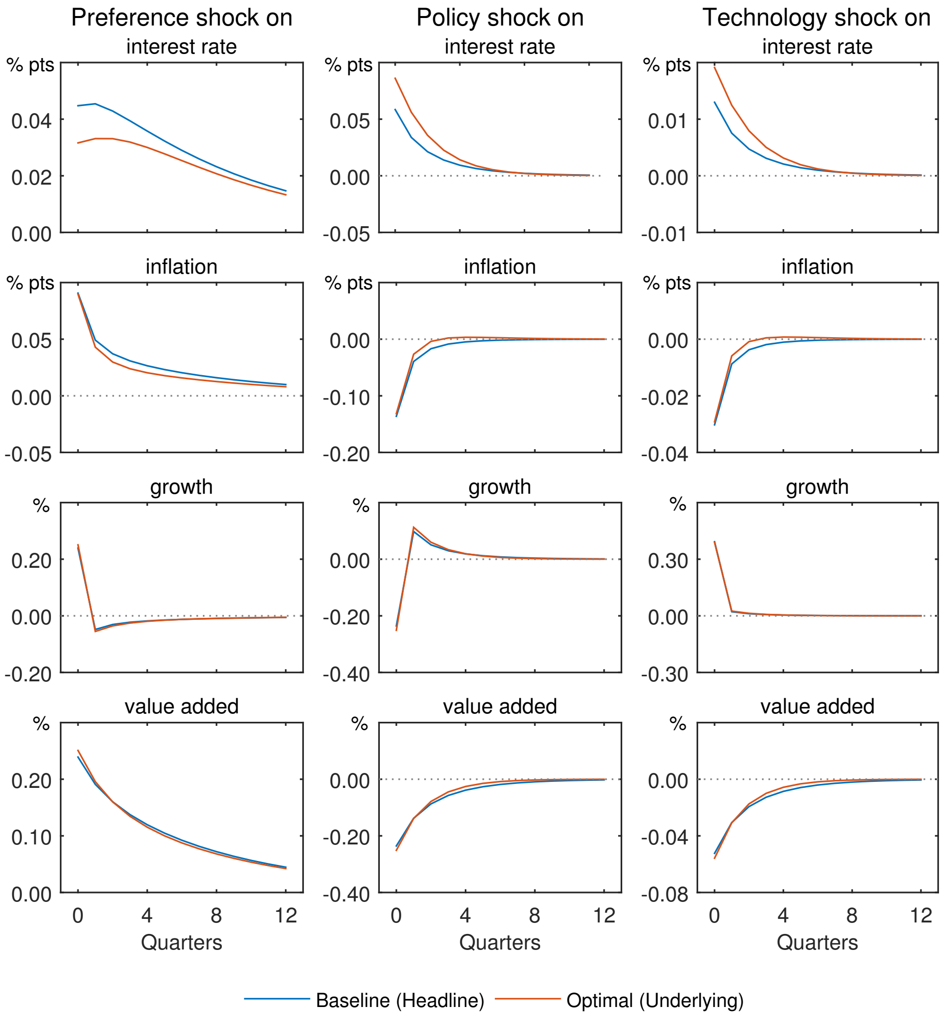

Figure 6.6: Impulse responses: Aggregate shocks

Inflation will then return to its steady state at a quicker pace. The larger shock when responding to underlying inflation has a minor positive effect on growth in value added output, and value added output.

Technology shock

A positive shock to aggregate technology increases growth in value added output and decreases inflation. This rather unintuitive response needs to be framed in terms of *detrended* variables. The positive shock is permanent, which increases the steady-state level of value added output. Intermediate-goods producing firms respond to the shock according to their Calvo probability, and because prices are sticky, actual value added does not immediately increase. This causes value added output to fall below its new steady-state value. When responding to underlying inflation the monetary authority can increase the nominal interest rate by an additional 2 basis points on an annualised basis, and inflation will return to its steady state at a quicker pace. The larger shock when responding to underlying inflation has a minor positive effect on growth in value added output, and value added output.

6.2 Measuring the welfare loss

In the previous section, I established that responding to the social welfare optimal measure of underlying inflation allows for a quicker return to steady-state following an aggregate shock. The impulse response functions are useful in the optimal case, as the welfare loss is minimised and the sources of improvement can be identified graphically. Evaluating the two exclusion measures and the Calvo-share measure of underlying inflation, and comparing their relative performance requires that we return to the loss functions defined in Chapter 5.

Recall that there are three specifications for the loss function: (i) social welfare, derived from the sectoral Calvo probabilities and sectoral shares; (ii) simple mandate 1, where equal weight is assigned to stablising aggregate inflation and value added output; and (iii) simple mandate 2, where the stabilisation of aggregation inflation is given twice the weight of value added output. The losses calculated by the different specifications are not directly comparable across loss functions. For any given model the theoretical variances that enter the loss function are scaled differently. To make cross-function comparisons, I measure the *relative welfare loss* compared to a baseline where the monetary authority responds to headline inflation. I report the relative welfare loss for each measure of underlying inflation, for each loss function specification in Table 6.2. The welfare loss associated with responding to headline inflation is normalised to equal 100. A relative welfare loss of less than 100 indicates a welfare gain with the difference approximating the percentage improvement in

Underlying inflation measure	Welfare loss		
	L_t^{SW}	L_t^{SM1}	L_t^{SM2}
Headline	100.0	100.0	100.0
Exclusion 1	97.4	99.9	99.7
Exclusion 2	93.9	100.1	99.4
Calvo-share	94.8	100.1	99.5
Optimal			
Social welfare	87.3	100.2	98.9
Simple mandate 1	94.5	99.3	98.9
Simple mandate 2	90.0	99.5	98.6

Notes: I report normalised losses where the welfare loss of headline inflation is equal to 100.00. Values less than 100.00 represent an improvement in welfare.

Table 6.2: Welfare loss by underlying measure of inflation

welfare. All alternative measures of underlying reduce the social welfare relative loss. Excluding the least sticky sector, wholesale and retail trade, reduces the social welfare loss by 2.6 per cent. Excluding the two least sticky sectors, wholesale and retail trade, and construction, reduces the social welfare loss by 6.1 per cent. Weighting each sector by the product of its share and Calvo probability reduces the social welfare loss by 5.2 per cent. Choosing sectoral weights to minimise the social welfare loss results in a reduction of 12.7 per cent.

The relative welfare loss from the simple mandates are less definitive in their improvement. Excluding the wholesale and retail trade sector reduces the simple mandate relative losses by 0.1 and 0.3 per cent. Excluding wholesale and retail trade, and construction, increases the relative welfare loss for simple mandate 1 by 0.1 per cent. For simple mandate 2, this measure reduces the relative welfare loss by 0.6 per cent. Weighting each sector by the product of its share and Calvo probability increases the relative welfare loss for simple mandate 1 by 0.1 per cent. For simple mandate 2, this measure reduces the relative welfare loss by 0.5 per cent.

The large differences between the social welfare and simple mandate approaches are the product of two issues. First, the social welfare loss function imposes large penalties on the variances of the most sticky sectors. As the less sticky sectors will fluctuate regardless of the policy stance of the monetary authority, excluding them from the policy response will reduce the variability in the sectors that are targeted. Second, when aggregating sectoral inflation into headline inflation, much of the variability is washed out. Boivin et al. (2009) finds that this is due to the cancelling out of the idiosyncratic components of sectoral inflation during aggregation; I found that this held for Australian consumer price inflation in Chapter 3.

Underlying inflation measure	Variance				
	$\hat{\pi}_t$	$\hat{\pi}^U_t$	$\hat{i}_t$	$\hat{c}_t$	$\hat{g}_t$
Headline	0.058	0.058	0.029	0.542	0.320
Exclusion 1	0.056	0.046	0.030	0.543	0.325
Exclusion 2	0.054	0.035	0.028	0.546	0.325
Calvo-share	0.054	0.038	0.028	0.545	0.324
Optimal					
Social welfare	0.050	0.019	0.026	0.551	0.327
Simple mandate 1	0.055	0.039	0.027	0.541	0.322
Simple mandate 2	0.052	0.026	0.026	0.545	0.324

Table 6.3: Variance by underlying measure of inflation

Examination of the theoretical variances is perhaps a better method of identifying the relative improvement. The theoretical variances from the rational expectations solution are calculated for each measure of underlying inflation, and reported for headline inflation $\hat{\pi}_t$, underlying inflation $\hat{\pi}^U_t$, the nominal interest rate $\hat{i}_t$, value added output $\hat{c}_t$ and growth in value added output $\hat{g}_t$ in Table 6.3.

Through its policy rule, the monetary authority responds to a measure of inflation and to growth in value added output. By responding to a measure of underlying inflation, the monetary authority can reduce the variability in headline inflation. This often reduces the variability in the nominal interest rate, but increases the variability in value added output and growth in value added output. This trade-off appears why such little relative improvement in welfare is observed when following a simple mandate.

6.3 Selecting a measure of underlying inflation

In the Cagliarini et al. (2011) model, the monetary authority takes the form of an inflation targeting central bank. Inflation targeting requires the announcement of a numerical inflation target, and its composition, along with a high degree of transparency and accountability from the monetary authority (Svensson 2008). So for a monetary authority faced with six different measures of underlying inflation, all which appear as welfare-improving, which is the 'best' to target?

Two issues of varying importance arise from this question: (i) how does the monetary authority construct their chosen measure of underlying inflation; and (ii) is the measure of underlying inflation communicable?

Measures of underlying inflation rely on sectoral weights that are constructed from characteristics of the sector. Here we know the true data-generating process, and can therefore construct underlying inflation using the structural characteristics of each sector. In practice this is not the case, and while central banks have access to a vast amount of information on the economy and financial markets, there are notable gaps. The lack of detailed price-adjustment information prevents use of the price stickiness faced by a sector. While we have used survey responses across ten broad sectors here, the reality of consumer price inflation is that the disaggregated expenditure classes are highly heterogeneous. With the requirement to be transparent and accountable comes the issue of communicability. In practice, the verbal and written communications of central banks are widely circulated and highly scrutinised. For an inflation targeting central bank to remain credible, the measure of underlying inflation chosen must be disclosed. Measures of underlying inflation that are derived from mathematical methods, either statistical or optimisation-based, suffer heavily in this respect. Most agents within the economy have little to no formal training in economics or mathematics, so the communicability of these measures is reduced.

However, the social welfare optimal measure of underlying inflation provided a key insight which may address the issues outlined above. The optimal measure heavily penalised those sectors where the sectoral technology shock has a high standard deviation. The empirical findings from Chapter 3 established that the standard deviation of sectoral inflation is mostly driven by the idiosyncratic component. It should then be possible to use sectoral volatility in forming sectoral inflation weights for a measure of underlying inflation. Placing less emphasis on the sectors that have relatively volatile prices, which fluctuate independently of monetary factors, is a far more communicable concept. To test this hypothesis I construct a measure of underlying using a neo-Edgeworthian approach (Diewert 1995).

The neo-Edgeworthian measure is

$$\hat{\pi}_t^U = \frac{\sum_{j=1}^{N} \frac{\hat{\pi}_{j,t}}{\sigma_{z_j}}}{\sum_{j=1}^{N} \frac{1}{\sigma_{z_j}}} \tag{6.2}$$

and its performance is reported in Table 6.4 and Table 6.5. The neo-Edgeworthian measure of underlying inflation reduces the relative social welfare loss by 7 per cent, and the relative simple mandate welfare loss by 0.2 and 0.9 per cent. The improvement is comparable to the unoptimised measures of underlying inflation. However, the new-Edgeworthian approach is not without its detractors. It is certainly arguable that excluding (or re-weighting) sectoral inflation using volatility is no more communicable than a statistical procedure such as the trimmed mean. Heath, Roberts & Bulman (2004) also found that for Australian consumer price inflation, the neo-Edgeworthian index: (i) was difficult to calculate, as the weights of sectoral inflation change from time to time; and (ii) exhibited significant bias.

Underlying inflation measure	Welfare loss		
	L_t^{SW}	L_t^{SM1}	L_t^{SM2}
Headline	100.0	100.0	100.0
Exclusion 1	97.4	99.9	99.7
Exclusion 2	93.9	100.1	99.4
Calvo-share	94.8	100.1	99.5
Optimal			
Social welfare	87.3	100.2	98.9
Simple mandate 1	94.5	99.3	98.9
Simple mandate 2	90.0	99.5	98.6
neo-Edgeworthian	93.0	99.8	99.1

Notes: I report normalised losses where the welfare loss of headline inflation is equal to 100.00. Values less than 100.00 indicate a welfare gain.

Table 6.4: Welfare loss by underlying measure of inflation (NE)

The volatility of sectoral inflation is important in formulating policy responses. This result is derived from a structural model, supported by the empirical results of Chapter 3. Given the importance of volatility in sectoral inflation, the construction and use of volatility themed analytical inflation series' by national statistical agencies and central banks is comforting.

However, as we have seen volatility in a very sticky sector should not be treated the same as volatility in a relatively flexible sector. Moreover, the unavailability of detailed price-adjustment information for the consumer price index remains an important issue that separates Australia from many other developed economies where item level price stickiness can be incorporated into policy.

Underlying inflation measure	Variance				
	$\hat{\pi}_t$	$\hat{\pi}_t^U$	$\hat{i}_t$	$\hat{c}_t$	$\hat{g}_t$
Headline	0.058	0.058	0.029	0.542	0.320
Exclusion 1	0.056	0.046	0.030	0.543	0.325
Exclusion 2	0.054	0.035	0.028	0.546	0.325
Calvo-share	0.054	0.038	0.028	0.545	0.324
Optimal					
Social welfare	0.050	0.019	0.026	0.551	0.327
Simple mandate 1	0.055	0.039	0.027	0.541	0.322
Simple mandate 2	0.052	0.026	0.026	0.545	0.324
neo-Edgeworthian	0.054	0.036	0.025	0.545	0.322

Table 6.5: Variance by underlying measure of inflation (NE)

7 Alternative Monetary Policy Rules

In this chapter, I investigate if the reduction in welfare loss from responding to a measure of underlying inflation can instead be obtained with an alternative monetary policy rule. I begin by introducing the family of monetary policy rules under investigation, then minimise the social welfare loss by adjusting the response of the monetary authority to aggregate inflation and growth in value added output. Finally, I examine how the optimal policy rule impacts the transmission of shocks.

7.1 The optimal monetary policy rule

I consider three specifications for the monetary policy rule, in the form of a generalised Taylor rule that contains a lagged interest rate term

$$\hat{i}_t = \rho_i \hat{i}_{t-1} + \phi_\pi \hat{\pi}_t^U + \phi_g \hat{g}_t + \hat{\varepsilon}_{i,t} \tag{7.1}$$

where the nominal interest rate $\hat{i}_t$ is determined by its previous period value, underlying inflation $\hat{\pi}_t$, growth in value added output $\hat{g}_t$, and the policy shock $\hat{\varepsilon}_{i,t}$;

$$\hat{i}_t = \rho_i \hat{i}_{t-1} + \phi_\pi \hat{\pi}_t + \phi_g \hat{g}_t + \hat{\varepsilon}_{i,t} \tag{7.2}$$

where the nominal interest rate $\hat{i}_t$ is determined by its previous period value, aggregate inflation $\hat{\pi}_t$, growth in value added output $\hat{g}_t$, and the policy shock $\hat{\varepsilon}_{i,t}$; and

$$\hat{i}_t = \hat{i}_{t-1} + \phi_\pi \hat{\pi}_t + \phi_g \hat{g}_t + \hat{\varepsilon}_{i,t} \tag{7.3}$$

with the key difference that the *change* in nominal interest rate responds to aggregate inflation and growth in value added output. Each specification has particularly desirable properties under certain parameterisations. Rotemberg & Woodford (1999) find that allowing ρ_i to take a value greater than one results in an explosive monetary policy rule, while also producing a set of stable equilibria. I focus on this explosive yet stable result in my analysis.

7.1.1 Return to the welfare approach to optimality

The social welfare approach from Chapter 5 is used to choose the set of monetary policy rule parameters that minimises the welfare loss.

(i) Rule A is the baseline policy rule estimated in Chapter 4,

(ii) Rule B chooses ρ_i, ϕ_π and ϕ_g,

(iii) Rule C restricts $\rho_i = 1$ and chooses ϕ_π and ϕ_g, and

(iv) Rule D chooses ρ_i, ϕ_π and ϕ_g as well as the sectoral inflation weights ϕ_{π_j}.

Because the social welfare loss function is highly non-linear, I start each minimisation procedure from many different sets of starting parameters. The relative welfare loses are reported in Table 7.1, sectoral weights ϕ_{π_j} are reported in Table 7.2, and selected variance measures are reported in Table 7.3. The improvement in relative social welfare loss is fairly remarkable. When choosing sectoral inflation weight only, the largest improvement in relative social welfare loss was 12.7 per cent. When optimising the parameters of the monetary policy rule (Rule B), the relative welfare loss improves by 47.3 per cent from the baseline. When restricting the autoregressive coefficient ρ_i to be equal to one (Rule C), the reduction in relative welfare loss is marginally worse than Rule B. Simultaneously choosing the monetary policy rule parameters ρ_i, ϕ_π, and ϕ_g, and sectoral inflation weights ϕ_{π_j} yields the greatest reduction in relative welfare loss, a 50.8 per cent improvement (Rule D).

Rules C and D are examples of explosive yet stable monetary policy rules. Rotemberg & Woodford (1999) explain that the potential for explosive interest rates is actually the mechanism which keeps the price level on track. Increases in inflation are matched by subsequent decreases in inflation that work to ensure the interest rate does not explode. Within this explosive-policy stable-equilibria framework, higher values of ϕ_π work well when seeking to stabilise inflation. The optimised sectoral inflation weights in Rule D better reflect my a priori expectations given the loss function weights. Sectors with very similar characteristics have similar weights, the highly volatile sectors receive a low weight, as do the sectors that face a relatively low Calvo probability. This better distribution of sectoral weights is likely to resolve the net welfare improvement issue identified in Chapter 6, where the response to a sectoral shock could worsen under the 'optimal' weights.

Policy rule	Welfare loss	Policy rule parameters		
		ρ_i	ϕ_π	ϕ_g
Headline inflation				
Rule A	100.0	0.71	1.16	0.20
Rule B	52.7	0.49	6.84	1.14
Rule C	52.8	1.00	7.91	1.28
Optimal inflation				
Rule D	49.2	19.09	142.90	5.76

Notes: I report normalised losses where the welfare loss of headline inflation is equal to 100.00. Values less than 100.00 represent an improvement in welfare.

Table 7.1: Welfare loss for alternative monetary policy rules

Sector	ϕ_j^{SW}	γ_j	l_j/l	m_j/m	θ_j	σ_{z_j}
Agriculture	0.01	0.06	0.05	0.06	0.75	3.91
Construction	0.00	0.15	0.10	0.17	0.25	1.46
Manufacturing	0.02	0.28	0.25	0.30	0.50	0.60
Mining	0.03	0.05	0.03	0.05	0.75	1.71
Utilities	0.26	0.03	0.02	0.03	0.75	0.53
Wholesale and retail	0.00	0.20	0.26	0.17	0.10	0.50
Transport and storage	0.22	0.08	0.07	0.09	0.75	0.61
Business services	0.17	0.08	0.12	0.06	0.75	0.61
Household services	0.20	0.05	0.06	0.05	0.75	0.69
Tourism	0.09	0.01	0.03	0.02	0.75	0.80

Table 7.2: Underlying inflation sectoral weights

The source of welfare improvement is well-observed through the theoretical variances reported in Table 7.3. Rather remarkable is the reduction in variance across all key variances from optimising the monetary policy rule. Rule B retains the decaying period-to-period behaviour of Rule A, but takes a particularly strong stance on fluctuations in inflation and growth in value added output. Under Rule B the response to inflation and growth in value added output by the monetary authority is approximately six times greater than under Rule A. The variance of headline inflation has decreased by an order of magnitude. The variance of the nominal interest rate has decreased by half. Value added and growth in value added output both show reduced variances, although the improvement is not as remarkable.

The reduction in variance of the nominal interest rate for Rule B is equivalent to a 27 basis point reduction in its standard deviation. Rule D improves on this further, by trading a high variance of headline inflation for a low variance of the nominal interest rate, value added output and growth in value added output. Under Rule D the standard deviation of the nominal interest rate is 37 basis points lower than under Rule A.

Policy rule	Variance				
	$\hat{\pi}_t$	$\hat{\pi}_t^U$	$\hat{i}_t$	$\hat{c}_t$	$\hat{g}_t$
Headline inflation					
Rule A	0.0580	0.0580	0.0292	0.5416	0.3200
Rule B	0.0051	0.0051	0.0135	0.4951	0.2101
Rule C	0.0051	0.0051	0.0113	0.4948	0.2118
Optimal inflation					
Rule D	0.0091	0.0005	0.0085	0.4408	0.1960

Notes: Rule A is the baseline model where parameters are calibrated from Chapter 4, and the monetary authority responds to headline inflation.

Table 7.3: Variance for alternative monetary policy rules

7.1.2 Response to aggregate shocks

Figure 7.1 shows the response of the nominal interest rate, inflation, growth in value added output, and value added output under each rule to a preference, policy and technology shock. Here we see the inflation stabilisation effect operating through large values of ϕ_π.

Preference shock

A positive shock to household preferences increases demand for final goods. Final-goods producing firms increase their demand for intermediate goods, which the intermediate-goods producing firms meet by adjusting their prices or output, according to the Calvo probability faced by the firm. Under the alternative policy rules, the response of the monetary authority is of a similar magnitude to the baseline

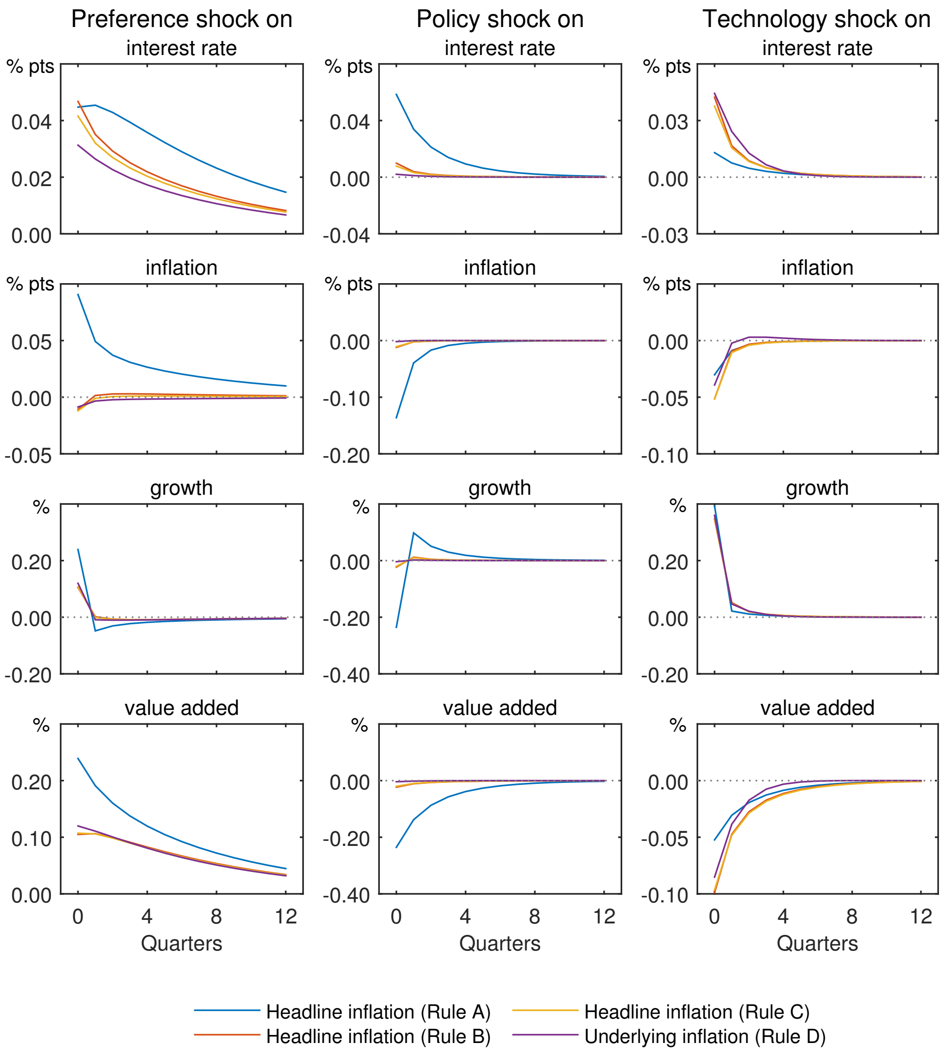

Figure 7.1: Impulse responses: Aggregate shocks

Optimal: Monetary authority responds to underlying inflation

rule. The response of inflation is the same for the stable and explosive alternative policy rules, which shows that the response is driven by the large values of ϕ_π. Inflation and growth in value added output both return to their steady-states rapidly. Value added returns to its steady state faster than under the baseline policy rule, however it is a gradual rather than rapid return.

This behaviour reflects price-setting decisions of firms seeking to keep the nominal interest rate from entering an explosive path. Instead of adjusting prices according to their Calvo probability as occurs in the baseline case, the intermediate-goods producing firms are particularly sensitive to the expected response of the monetary authority, information which within a rational expectations framework is available to agents.

Monetary policy shock

A positive shock to the nominal interest rate decreases the relative price level in each sector, which decreases the marginal costs faced by intermediate-goods producing firms. Intermediate-goods producing firms reset their prices in line with their Calvo probability, and those that cannot reset their price adjust their output. In the baseline case, the monetary policy shock decreases both inflation and value added output.

The same relative responses are observed for the alternative monetary policy rules, however the magnitude of shock and the subsequent responses are significantly smaller. This again reflects price-setting decisions of firms seeking to keep the nominal interest rate from entering an explosive path. Under the alternative policy framework, the monetary authority is able to influence the behaviour of agents by making much smaller adjustments than in the baseline case. This acts to stabilise inflation around its steady-state with much greater vigour than before.

Technology shock

A positive shock to aggregate technology increases growth in value added output and decreases inflation. This rather unintuitive response needs to be framed in terms of *detrended* variables. The positive shock is permanent, which increases the steady-state level of value added output. Intermediate-goods producing firms respond to the shock according to their Calvo probability, and because prices are sticky, actual value added output does not immediately increase. This causes value added output to fall below its new steady-state value.

Here the alternative monetary policy rules depart from their previous performance. Instead of returning to the steady-state at a quicker pace, we observe the opposite.

Larger values of ϕ_g drive an intervention by the monetary authority that is larger than the baseline case. This then results in lower levels of inflation as intermediate-goods producers adjust to the higher interest rate, and further reduces value added output. Despite the alternative policy rules being constructed as 'optimal' this response is markedly worse.

7.2 The credible and communicable policy rule

A common theme throughout the modern monetary economics literature is the need for a monetary authority that is credible and can anchor expectations through its verbal and written communications. Given the policy stance formulated through the optimal monetary policy rules, what challenges exist in their communicability?

The functional form of a generalised Taylor rule that involve a lagged interest rate is not particularly challenging in its communicability. That the monetary authority sets the interest rate by observing the previous period interest rate, and the economic conditions that impact on inflation and value added output, is both intuitive and approachable for non-economists. However, once we consider the parameter values that form the particulars of the monetary policy stance this does not hold.

Rule D has parameter values of 19.09, 142.90 and 5.76 for ρ_i, ϕ_π and ϕ_g. The monetary authority sets the interest rate by taking 19 times the interest rate in the last period, 142 times inflation in the current period, and 5 times the growth in value added output in the current period. While these parameter value were calculated within a rational expectations framework where the price level must react properly or the real interest rate will deviate on an explosive path. I acknowledge the theoretical appeal of this framework for monetary economists, however Rule D holds very little intuitive appeal for the layman. So while Rule D falters in this respect, Rule C with its *change in interest rate* interpretation shines.

8 Conclusion

8.1 Discussion of results

This thesis investigated the extent of sectoral heterogeneity in Australian consumer prices and examined how an inflation targeting central bank can best address this issue when formulating policy.

An approximate factor model was used to decompose sectoral inflation into a common and idiosyncratic component. I estimated the volatility and persistence of each component, and established stylised facts explaining their dynamic behaviour. These stylised facts were used to motivate a model of price-adjustment, and I found that a multisector model with infrequent price-adjustments was able to summarise the heterogeneous price-setting behaviour in Australian sectoral inflation.

I then used a multisector New-Keynesian to examine the welfare effect of incorporating a measure of underlying inflation into the policy rule of the central bank. I found that by excluding sectors with minimally sticky prices or very high volatility from the policy rule was welfare-improving. I also found that alternative specifications of the policy rule, that respond to headline inflation, demonstrated a welfare-improvement close to a policy rule that responds to underlying inflation.

8.2 Future research

This thesis has identified two future research paths.

The first applies the approximate factor model framework to simulations arising from the multisector New-Keynesian model. As the data generating process is known, this extension may allow further stylised facts to be established on the frequency of price changes. Ideally, these stylised facts would be applied to disaggregated consumer price inflation, bridging the literature gap on the frequency of price changes.

The second is more ambitious and relates to the inclusion of the trimmed mean as a measure of underlying inflation. As described in Chapter 4, it is not clear how one would compute the rational expectations solution in this case as it results in different weights being assigned to sectoral inflation at different times. As the time-varying parameters evolve as a function of the model state, the rational expectations solution becomes non-linear. Given the popularity of trimmed mean inflation within central banking circles, this extension could provide further justification for its use in policy formulation.

8.3 Concluding remarks

Overall, the findings of my thesis support the existence of heterogeneity in sectoral inflation, and the incorporation of a measure of underlying inflation into the policy rule of the central bank. However, the policy conclusions arise from a highly stylised model of the Australian economy, and should be framed as such. It was also comforting to find that the measures of underlying inflation found in practice were welfare-improving within the multisector framework.

In closing, the results of the multisector model indicate that a focus for policy makers should be on identifying the factors which drive heterogeneity in prices. Not enough work is being done to address the growing literature gap on Australian prices. While every microdata-founded international study has concluded that heterogeneity in prices exists, there is no uniformity with regards to its exact form. Sectoral heterogeneity in prices is important, and therefore should continue to be a central consideration in future monetary policy research.

A Data Sources

Table A.1 lists the short name of each series, a brief description, the transformation applied and the data source. Each series begins in 1989Q3 and ends in 2014Q4. After individual series transformations the balanced panel begins in 1989Q4.

Transformation key

Code	Description	Expression
0	None	$X_{it} = Y_{it}$
2	First difference	$X_{it} = \triangle Y_{it}$
5	First difference of logarithm	$X_{it} = \triangle \ln Y_{it}$

Data source key

Code	Source	
ABS	Australian Bureau of Statistics	(abs.gov.au)
FRED	Federal Reserve Bank of St. Louis	(research.stlouisfed.org)
MK-DR	Kulish & Rees (2015)	
RBA	Reserve Bank of Australia	(rba.gov.au)
Yahoo	Yahoo! Finance	(finance.yahoo.com)

Real Output

Name	Description	Trans.	Source
RGDP	Gross Domestic Product - Total	5	ABS
RGDP.A	Gross Value Added - Agriculture, forestry and fishing	5	ABS
RGDP.B	Gross Value Added - Mining	5	ABS
RGDP.C	Gross Value Added - Manufacturing	5	ABS
RGDP.D	Gross Value Added - Electricity, gas, water and waste services	5	ABS
RGDP.E	Gross Value Added - Construction	5	ABS
RGDP.F	Gross Value Added - Wholesale trade	5	ABS
RGDP.G	Gross Value Added - Retail trade	5	ABS
RGDP.H	Gross Value Added - Accommodation and food services	5	ABS
RGDP.I	Gross Value Added - Transport, postal and warehousing	5	ABS
RGDP.J	Gross Value Added - Information media and telecommunications	5	ABS
RGDP.K	Gross Value Added - Financial and insurance services	5	ABS
RGDP.L	Gross Value Added - Rental, hiring and real estate services	5	ABS
RGDP.M	Gross Value Added - Professional, scientific and technical services	5	ABS
RGDP.N	Gross Value Added - Administrative and support services	5	ABS
RGDP.O	Gross Value Added - Public administration and safety	5	ABS
RGDP.P	Gross Value Added - Education and training	5	ABS
RGDP.Q	Gross Value Added - Health care and social assistance	5	ABS
RGDP.R	Gross Value Added - Arts and recreation services	5	ABS
RGDP.S	Gross Value Added - Other services	5	ABS

Labour Market

Name	Description	Trans.	Source
EMP.TOT	Employment (SA)	5	ABS
LAB.FOR	Labour Force (SA)	5	ABS
UNEMP	Unemployment rate (SA)	2	ABS
EMP.A	Employment - Agriculture, Forestry and Fishing (SA)	5	ABS
EMP.B	Employment - Mining (SA)	5	ABS
EMP.C	Employment - Manufacturing (SA)	5	ABS
EMP.D	Employment - Electricity, Gas, Water and Waste Services (SA)	5	ABS
EMP.E	Employment - Construction (SA)	5	ABS
EMP.F	Employment - Wholesale Trade (SA)	5	ABS
EMP.G	Employment - Retail Trade (SA)	5	ABS
EMP.H	Employment - Accommodation and Food Services (SA)	5	ABS
EMP.I	Employment - Transport, Postal and Warehousing (SA)	5	ABS
EMP.J	Employment - Information Media and Telecommunications (SA)	5	ABS
EMP.K	Employment - Financial and Insurance Services (SA)	5	ABS
EMP.L	Employment - Rental, Hiring and Real Estate Services (SA)	5	ABS
EMP.M	Employment - Professional, Scientific and Technical Services (SA)	5	ABS
EMP.N	Employment - Administrative and Support Services (SA)	5	ABS
EMP.O	Employment - Public Administration and Safety (SA)	5	ABS
EMP.P	Employment - Education and Training (SA)	5	ABS
EMP.Q	Employment - Health Care and Social Assistance (SA)	5	ABS
EMP.R	Employment - Arts and Recreation Services (SA)	5	ABS
EMP.S	Employment - Other Services (SA)	5	ABS
ULC	Unit labour cost (SA)	5	ABS
ULC.NF	Unit labour cost - Non-farm (SA)	5	ABS

Housing

Name	Description	Trans.	Source
DHPS	Number of dwellings - Houses - Private Sector (SA)	5	ABS
DXPS	Number of dwellings - Excluding houses - Private Sector (SA)	5	ABS
DTGS	Number of dwellings - Public Sector (SA)	5	ABS
DTTS	Number of dwellings - Total (SA)	5	ABS
DHPS.NSW	Number of dwellings - New South Wales - Houses - Private Sector (SA)	5	ABS
DHPS.VIC	Number of dwellings - Victoria - Houses - Private Sector (SA)	5	ABS
DHPS.QLD	Number of dwellings - Queensland - Houses - Private Sector (SA)	5	ABS

DHPS.SA	Number of dwellings - South Australia - Houses - Private Sector (SA)	5	ABS
DHPS.WA	Number of dwellings - Western Australia - Houses - Private Sector (SA)	5	ABS

Households

Name	Description	Trans.	Source
HHE.FOOD	Household expenditure - Food (CVM, SA)	5	ABS
HHE.CAT	Household expenditure - Cigarettes and tobacco (CVM, SA)	5	ABS
HHE.ALC	Household expenditure - Alcoholic beverages (CVM, SA)	5	ABS
HHE.CLO	Household expenditure - Clothing and footwear (CVM, SA)	5	ABS
HHE.RENT	Household expenditure - Rent and other dwelling services (CVM, SA)	5	ABS
HHE.ENG	Household expenditure - Electricity, gas and other fuel (CVM, SA)	5	ABS
HHE.EQP	Household expenditure - Furnishings, household equipment (CVM, SA)	5	ABS
HHE.HEA	Household expenditure - Health (CVM, SA)	5	ABS
HHE.PHV	Household expenditure - Purchase of vehicles (CVM, SA)	5	ABS
HHE.OPV	Household expenditure - Operation of vehicles (CVM, SA)	5	ABS
HHE.TRN	Household expenditure - Transport services (CVM, SA)	5	ABS
HHE.COM	Household expenditure - Communications (CVM, SA)	5	ABS
HHE.REC	Household expenditure - Recreation and culture (CVM, SA)	5	ABS
HHE.EDU	Household expenditure - Education services (CVM, SA)	5	ABS
HHE.HCR	Household expenditure - Hotels, cafes and restaurants (CVM, SA)	5	ABS
HHE.IFS	Household expenditure - Insurance, other financial services (CVM, SA)	5	ABS
HHE.OTH	Household expenditure - Other goods and services (CVM, SA)	5	ABS
HHE.FCE	Household final consumption expenditure (SA)	5	ABS

Government

Name	Description	Trans.	Source
GOV.FCE.DEF	Government - National final consumption expenditure - Defence (SA)	5	ABS
GOV.FCE.NDF	Government - National final consumption expenditure - Non-defence (SA)	5	ABS
GOV.FCE.TOT	Government - National final consumption expenditure (SA)	5	ABS
GOV.FCE.STL	Government - State and local final consumption expenditure (SA)	5	ABS
GOV.FCE	Government - Total final consumption expenditure (SA)	5	ABS

Inventories

Name	Description	Trans.	Source
INV.MIN	Changes in Inventories - Private - Mining (CVM, SA)	0	ABS
INV.MAN	Changes in Inventories - Private ; Manufacturing (CVM, SA)	0	ABS
INV.WT	Changes in Inventories - Private ; Wholesale trade (CVM, SA)	0	ABS
INV.RT	Changes in Inventories - Private ; Retail trade (CVM, SA)	0	ABS
INV.NF.OTH	Changes in Inventories - Private - Non-farm - Other non-farm (CVM, SA)	0	ABS
INV.NF	Changes in Inventories - Private - Non-farm (CVM, SA)	0	ABS
INV.FM	Changes in Inventories - Farm (CVM, SA)	0	ABS
INV.PA	Changes in Inventories - Public authorities (CVM, SA)	0	ABS

Investment

Name	Description	Trans.	Source
AE.BLD	Actual Expenditure - Buildings and Structures (CVM, SA)	5	ABS
AE.EQP	Actual Expenditure - Equipment, Plant and Machinery (CVM, SA)	5	ABS
AE.MIN	Actual Expenditure - Mining (CVM, SA)	5	ABS
AE.MAN	Actual Expenditure - Manufacturing (CVM, SA)	5	ABS
AE.OSI	Actual Expenditure - Other Selected Industries (CVM, SA)	5	ABS
FCF.ALL	All sectors gross fixed capital formation (SA)	5	ABS
FCF.GOV	General government gross fixed capital formation (SA)	5	ABS
FCF.PUB	Public corporations gross fixed capital formation (SA)	5	ABS
FCF.PRV	Private gross fixed capital formation (SA)	5	ABS

Stock Prices

Name	Description	Trans.	Source
ALL.ORD	All Ordinaries Index - Adjusted Close	5	Yahoo

Exchange Rates

Name	Description	Trans.	Source
RTWI	Real trade-weighted index	5	RBA
RMWI	Real import-weighted index	5	RBA
RXWI	Real export-weighted index	5	RBA
R7WI	Real G7 GDP-weighted index	5	RBA
FXR.CNY	Chinese renminbi per Australian dollar	5	RBA
FXR.HKD	Hong Kong dollar per Australian dollar	5	RBA
FXR.IDR	Indonesian rupiah per Australian dollar	5	RBA
FXR.JPY	Japanese yen per Australian dollar	5	RBA
FXR.MYR	Malaysian ringgit per Australian dollar	5	RBA
FXR.TWD	New Taiwan dollar per Australian dollar	5	RBA
FXR.NZD	New Zealand dollar per Australian dollar	5	RBA
FXR.SGD	Singapore dollar per Australian dollar	5	RBA
FXR.KRW	South Korean won per Australian dollar	5	RBA
FXR.GBP	United Kingdom pound sterling per Australian dollar	5	RBA
FXR.USD	United States dollar per Australian dollar	5	RBA

Foreign Sector

Name	Description	Trans.	Source
RGDP.CAN	Real gross domestic product - Canada	5	FRED
RGDP.FRA	Real gross domestic product - France	5	FRED
RGDP.GBR	Real gross domestic product - United Kingdom	5	FRED
RGDP.USA	Real gross domestic product - United States	5	FRED
CPI.CAN	Consumer price index - Canada	5	FRED
CPI.FRA	Consumer price index - France	5	FRED
CPI.GER	Consumer price index - Germany	5	FRED
CPI.ITA	Consumer price index - Italy	5	FRED
CPI.JAP	Consumer price index - Japan	5	FRED
CPI.GBR	Consumer price index - United Kingdom	5	FRED
CPI.USA	Consumer price index - United States	5	FRED
FOR.RATE	Average policy rate of USA, Japan and Eurozone (Germany pre-1999)	5	MK-DR

Interest Rates

Name	Description	Trans.	Source
IR.CASH	Interest rate - Interbank overnight	5	RBA
IR.90D	Interest rate - Bank accepted bills - 90 days	5	RBA
BOND.5Y	Yield - Australian Government bonds - 5 years	5	RBA
BOND.10Y	Yield - Australian Government bonds - 10 years	5	RBA

Money and Credit

Name	Description	Trans.	Source
CR.TH	Credit - Housing - 12-month ended growth (SA)	2	RBA
CR.OP	Credit - Other personal - 12-month ended growth (SA)	2	RBA
CR.BS	Credit - Business - 12-month ended growth (SA)	2	RBA
CR.TO	Credit - Total - 12-month ended growth (SA)	2	RBA
AG.M3	M3 - 12-month ended growth (SA)	2	RBA
AG.BM	Broad money - 12-month ended growth (SA)	2	RBA

Prices

Name	Description	Trans.	Source
CPI.ALL	Consumer price index - Australia (SA)	5	ABS
INFL.EXP	Business inflation expectations - 3-months ahead	2	RBA
INFL.BE	Break-even 10-year inflation rate	2	RBA

COM.SDR	Index of commodity prices - SDR	5	RBA
COM.RU.SDR	Commodity price index - Rural component - SDR	5	RBA
COM.NR.SDR	Commodity price index - Non-rural - SDR	5	RBA
COM.BM.SDR	Commodity price index - Non-rural - Base metals - SDR	5	RBA
COM.BK.SDR	Commodity price index - Non-rural âĂŞ Bulk commodities - SDR	5	RBA

Sectoral Prices

Name	Description	Trans.	Source
CPI.EC.01	Consumer price index - Bread (SA)	5	ABS
CPI.EC.02	Consumer price index - Cakes and biscuits (SA)	5	ABS
CPI.EC.03	Consumer price index - Breakfast cereals (SA)	5	ABS
CPI.EC.04	Consumer price index - Other cereal products (SA)	5	ABS
CPI.EC.05	Consumer price index - Beef and veal (SA)	5	ABS
CPI.EC.06	Consumer price index - Pork (SA)	5	ABS
CPI.EC.07	Consumer price index - Lamb and goat (SA)	5	ABS
CPI.EC.08	Consumer price index - Poultry (SA)	5	ABS
CPI.EC.09	Consumer price index - Other meats (SA)	5	ABS
CPI.EC.10	Consumer price index - Fish and other seafood (SA)	5	ABS
CPI.EC.11	Consumer price index - Milk (SA)	5	ABS
CPI.EC.12	Consumer price index - Cheese (SA)	5	ABS
CPI.EC.13	Consumer price index - Ice cream and other dairy products (SA)	5	ABS
CPI.EC.14	Consumer price index - Fruit (SA)	5	ABS
CPI.EC.15	Consumer price index - Vegetables (SA)	5	ABS
CPI.EC.16	Consumer price index - Eggs (SA)	5	ABS
CPI.EC.17	Consumer price index - Jams, honey and spreads (SA)	5	ABS
CPI.EC.18	Consumer price index - Food additives and condiments (SA)	5	ABS
CPI.EC.19	Consumer price index - Oils and fats (SA)	5	ABS
CPI.EC.20	Consumer price index - Snacks and confectionery (SA)	5	ABS
CPI.EC.21	Consumer price index - Other food products n.e.c. (SA)	5	ABS
CPI.EC.22	Consumer price index - Coffee, tea and cocoa (SA)	5	ABS
CPI.EC.23	Consumer price index - Waters, soft drinks and juices (SA)	5	ABS
CPI.EC.24	Consumer price index - Restaurant meals (SA)	5	ABS
CPI.EC.25	Consumer price index - Take away and fast foods (SA)	5	ABS
CPI.EC.26	Consumer price index - Spirits (SA)	5	ABS
CPI.EC.27	Consumer price index - Wine (SA)	5	ABS
CPI.EC.28	Consumer price index - Beer (SA)	5	ABS
CPI.EC.29	Consumer price index - Tobacco (SA)	5	ABS
CPI.EC.30	Consumer price index - Garments for men (SA)	5	ABS
CPI.EC.31	Consumer price index - Garments for women (SA)	5	ABS
CPI.EC.32	Consumer price index - Garments for infants and children (SA)	5	ABS
CPI.EC.33	Consumer price index - Footwear for men (SA)	5	ABS
CPI.EC.34	Consumer price index - Footwear for women (SA)	5	ABS
CPI.EC.35	Consumer price index - Footwear for infants and children (SA)	5	ABS
CPI.EC.37	Consumer price index - Cleaning, repair, hire of clothing & footwear (SA)	5	ABS
CPI.EC.38	Consumer price index - Rents (SA)	5	ABS
CPI.EC.40	Consumer price index - Maintenance and repair of the dwelling (SA)	5	ABS
CPI.EC.43	Consumer price index - Electricity (SA)	5	ABS
CPI.EC.44	Consumer price index - Gas and other household fuels (SA)	5	ABS
CPI.EC.45	Consumer price index - Furniture (SA)	5	ABS
CPI.EC.46	Consumer price index - Carpets and other floor coverings (SA)	5	ABS
CPI.EC.47	Consumer price index - Household textiles (SA)	5	ABS
CPI.EC.48	Consumer price index - Major household appliances (SA)	5	ABS
CPI.EC.49	Consumer price index - Small electric household appliances (SA)	5	ABS
CPI.EC.50	Consumer price index - Glassware, tableware and household utensils (SA)	5	ABS
CPI.EC.51	Consumer price index - Tools and equipment for house and garden (SA)	5	ABS
CPI.EC.52	Consumer price index - Cleaning and maintenance products (SA)	5	ABS
CPI.EC.53	Consumer price index - Personal care products (SA)	5	ABS
CPI.EC.54	Consumer price index - Other non-durable household products (SA)	5	ABS
CPI.EC.55	Consumer price index - Child care (SA)	5	ABS

CPI.EC.56	Consumer price index - Hairdressing and personal grooming services (SA)	5	ABS
CPI.EC.57	Consumer price index - Other household services (SA)	5	ABS
CPI.EC.58	Consumer price index - Pharmaceutical products (SA)	5	ABS
CPI.EC.59	Consumer price index - Therapeutic appliances and equipment (SA)	5	ABS
CPI.EC.60	Consumer price index - Medical and hospital services (SA)	5	ABS
CPI.EC.61	Consumer price index - Dental services (SA)	5	ABS
CPI.EC.62	Consumer price index - Motor vehicles (SA)	5	ABS
CPI.EC.63	Consumer price index - Spare parts and accessories for motor vehicles (SA)	5	ABS
CPI.EC.64	Consumer price index - Automotive fuel (SA)	5	ABS
CPI.EC.65	Consumer price index - Maintenance and repair of motor vehicles (SA)	5	ABS
CPI.EC.66	Consumer price index - Other services in respect of motor vehicles (SA)	5	ABS
CPI.EC.67	Consumer price index - Urban transport fares (SA)	5	ABS
CPI.EC.68	Consumer price index - Postal services (SA)	5	ABS
CPI.EC.69	Consumer price index - Telecommunication equipment and services (SA)	5	ABS
CPI.EC.70	Consumer price index - Audio, visual and computing equipment (SA)	5	ABS
CPI.EC.71	Consumer price index - Audio, visual, computing media and services (SA)	5	ABS
CPI.EC.74	Consumer price index - Domestic holiday travel, accommodation (SA)	5	ABS
CPI.EC.75	Consumer price index - International holiday travel, accommodation (SA)	5	ABS
CPI.EC.78	Consumer price index - Pets and related products (SA)	5	ABS
CPI.EC.79	Consumer price index - Veterinary and other services for pets (SA)	5	ABS
CPI.EC.85	Consumer price index - Insurance (SA)	5	ABS

Table A.1: Data sources and transformations

B Test for Structural Breaks

I test for structural breaks in the factor loadings using the procedure outlined in Chen et al. (2014). Let $\mathbf{F}_t$ be a $N \times 3$ matrix of static factors

$$\mathbf{F}_t = \begin{bmatrix} F_{1,t} & F_{2,t} & F_{3,t}. \end{bmatrix}$$

I estimate the following regression using ordinary least squares

$$F_{1,t} = c_1 F_{2,t} + c_2 F_{3,t}. + \varepsilon_t$$

and jointly test for breakpoints in $\begin{bmatrix} c_1 & c_2 \end{bmatrix}$ using regular breakpoint test methods. I use the Bai-Perron multiple breakpoint test and the Quandt-Andrews unknown break point test. Results are reported for the Bai-Perron test in Table B.1, and the F-statistic for the Quandt-Andrews test in Figure B.1.

Breaks	Critical value	Break in loadings		
		F-statistic	Scaled F-statistic	Date(s)
0 or 1	11.47	14.85*	29.70*	2001Q4
1 or 2	12.95	21.54*	43.09*	2001Q4, 1994Q4
2 or 3	14.03	2.14	4.28	-

Notes: Bai-Perron tests of $L+1$ vs. L sequentially determined breaks.
* indicates the test is significant at the 0.05 level.

Table B.1: Test for multiple structural breaks

Here we see that although the Bai-Perron test finds two sequential breakpoints, that the breakpoint at 2001Q4 is the 'big' one, for which the Chen et al. (2014) procedure designed to find and correct.

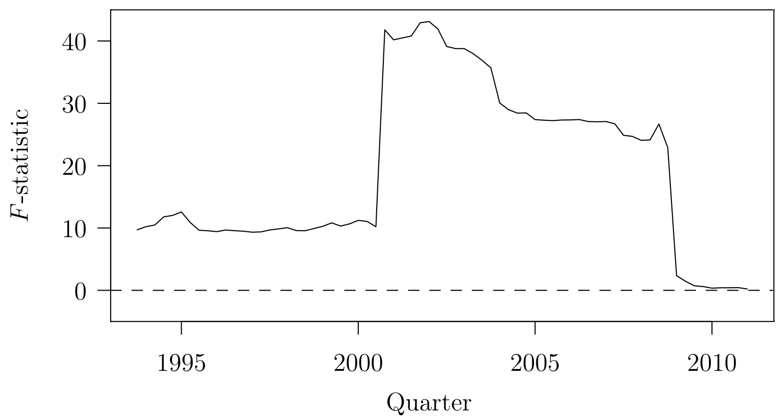

Figure B.1: Quandt-Andrews F-statistic

C Model

In this section I provide the transformations, non-linear equations, and log-linearised equations that comprise the multisector New-Kenyesian model. A full derivation of the model can be found in the online appendix of Cagliarini et al. (2011).

C.1 Transformations

As there is growth in aggregate technology z_t, some variables are detrended in order to make them stationary.

$$\tilde{c}_t = \frac{c_t}{z_t} \qquad \tilde{w}_t = \frac{W_t}{z_t P_t} \qquad \tilde{y}_{j,t} = \frac{y_{j,t}}{z_t} \qquad \tilde{y}_t = \frac{y_t}{z_t} \qquad \tilde{h}_t = \frac{H_t}{z_t P_t}$$

$$\tilde{m}^d_{j,t} = \frac{m^d_{j,t}}{z_t} \qquad \tilde{m}^d_t = \frac{m^d_t}{z_t} \qquad \tilde{\Lambda}_t = \beta^{-1} z_t \Lambda_t \qquad r_t = \frac{P_{j,t}}{P_t} \qquad r^+_t = \frac{P^+_{j,t}}{P_t}$$

$$\tilde{\pi}_t = \frac{P_t}{P_{t-1}} \qquad \tilde{\pi}_{j,t} = \frac{P_{j,t}}{P_{j,t-1}} \qquad \tilde{\omega}_t = \frac{\Omega_{j,t}}{P_{j,t}}$$

C.2 Non-linear equations

The non-linear equations are the first-order conditions and market-clearing conditions required to solve the model at the sectoral level.

First-order conditions

$$l_t^{\frac{1}{\eta}} = \frac{\tilde{w}_t a_t}{\tilde{c}_t} \tag{C.1}$$

$$\frac{a_t}{\tilde{c}_t} = \beta \mathbb{E}_t \left(\frac{a_{t+1}}{\tilde{c}_{t+1}} \frac{1}{\pi_{t+1}} I_t e^{\mu_z + \varepsilon_{z,t+1}} \right) \tag{C.2}$$

$$\frac{\tilde{c}_t}{a_t \tilde{h}_t} = 1 - \frac{1}{I_t} \tag{C.3}$$

$$\tilde{\Lambda}_t = \frac{a_t}{\tilde{c}_t} \tag{C.4}$$

$$\tilde{h}_t = \Theta_t \tilde{h}_{t-1} \frac{1}{\pi_t} e^{-\mu_z - \varepsilon_{z,t}} \tag{C.5}$$

$$g_t = \frac{\tilde{c}_t}{\tilde{c}_{t-1}} e^{-\mu_z - \varepsilon_{z,t}} \tag{C.6}$$

$$I_t = I_{t-1}^{\rho_i} \left(\frac{1}{\beta} e^{-(1-\phi_g)\mu_z} \pi_t^{\phi_\pi} g_t^{\phi_g} \right) e^{\varepsilon_{i,t}} \tag{C.7}$$

For $k \in (\psi_{j-1}, \psi_j]$ and $j = 1, \ldots, N$:

$$\omega_{j,t} = \frac{1}{\alpha_j^{\alpha_j}(1-\alpha_j)^{1-\alpha_j}} \frac{1}{(z_{j,t})^{\alpha_j}} \frac{\tilde{w}_t^{\alpha_j}}{r_{j,t}} \tag{C.8}$$

$$l_{j,t}^d = \frac{\alpha_j \omega_{j,t}}{\tilde{w}_t} \tilde{y}_{j,t} \tag{C.9}$$

$$\tilde{y}_{j,t} = \gamma_j \left(r_{j,t}^+\right)^{-\varepsilon} \tilde{y}_t \tag{C.10}$$

$$m_{j,t}^d = (1-\alpha_j)\,\omega_{j,t} r_{j,t} \tilde{y}_{j,t} \tag{C.11}$$

$$1 = \theta_j \pi_{j,t}^{\varepsilon-1} + (1-\theta_j)\,(r_{j,t}(k))^{1-\varepsilon} \tag{C.12}$$

$$r_{j,t}(k) = \frac{\varepsilon}{\varepsilon-1} \frac{\mathbb{E}_t \sum_{n=0}^{\infty} (\beta\theta_j)^n \frac{\tilde{\Lambda}_{t+n}}{\pi_{t,t+n}} \omega_{j,t+n} \pi_{j,t,t+n}^{1+\varepsilon} \tilde{\tilde{y}}_{j,t+n}}{\mathbb{E}_t \sum_{n=0}^{\infty} (\beta\theta_j)^n \frac{\tilde{\Lambda}_{t+n}}{\pi_{t,t+n}} \pi_{j,t,t+n}^{\varepsilon} \tilde{\tilde{y}}_{j,t+n}} \tag{C.13}$$

$$r_{j,t} = r_{j,t-1} \frac{\pi_{j,t}}{\pi_t} \tag{C.14}$$

$$\left(r_{j,t}^+\right)^{-\varepsilon} = \theta_j \left(r_{j,t-1}^+ \frac{1}{\pi_{j,t}}\right)^{-\varepsilon} + (1-\theta_j)\,(r_{j,t}(k))^{-\varepsilon} \tag{C.15}$$

where

$$\pi_{j,t,t+n} = \frac{P_{j,t+n}}{P_{j,t}}, \tag{C.16}$$

$$\pi_{t,t+n} = \frac{P_{t+n}}{P_t}, \tag{C.17}$$

$$\tilde{\tilde{y}}_{j,t+n} = c_{j,t}^s + \int_0^1 m_{i,t}^{j,d}\, di, \quad \text{and} \tag{C.18}$$

$$r_{j,t}(k) = \frac{P_t(k)}{P_{j,t}}. \tag{C.19}$$

Market clearing and aggregation

$$l_t = \sum_{j=1}^{N} l_{j,t}^d \tag{C.20}$$

$$\tilde{y}_t = \tilde{c}_t + \tilde{m}_t^d \tag{C.21}$$

$$\tilde{m}_t^d = \sum_{j=1}^{N} \tilde{m}_{j,t}^d \tag{C.22}$$

$$1 = \sum_{j=1}^{N} \gamma_j r_{j,t}^{1-\varepsilon} \tag{C.23}$$

Stochastic processes

$$
\begin{aligned}
a_t &= a_{t-1}^{\rho_a} e^{\varepsilon_{a,t}} && \text{(C.24)} \\
z_{j,t} &= z_{j,t-1}^{\rho_j} e^{\varepsilon_{z,j,t}} && \text{(C.25)}
\end{aligned}
$$

C.3 Log-linearised equations

The log-deviation from steady-state for variable x_t is $\hat{x}_t = \ln\left(\frac{x_t}{x}\right)$.

First-order conditions

$$
\begin{aligned}
\frac{1}{\eta}\hat{l}_t &= \hat{a}_t - \hat{c}_t + \hat{w}_t && \text{(C.26)} \\
\hat{c}_t - \hat{a}_t - \hat{h}_t &= \left(\frac{1}{i-1}\right)\hat{i}_t && \text{(C.27)} \\
(1-\rho_a)\,\hat{a}_t - \hat{c}_t &= \hat{i}_t - \mathbb{E}_t\left(\hat{c}_{t+1} + \hat{\pi}_{t+1}\right) && \text{(C.28)} \\
\hat{h}_t &= \hat{\xi}_t + \hat{h}_{t-1} - \hat{\pi}_t - \varepsilon_{z,t} && \text{(C.29)} \\
\hat{g}_t &= \hat{c}_t - \hat{c}_{t-1} + \varepsilon_{z,t} && \text{(C.30)} \\
\hat{i}_t &= \rho_i \hat{i}_{t-1} + (1-\rho_i)\left(\phi_\pi \hat{\pi}_t + \phi_g \hat{g}_t\right) + \varepsilon_{i,t} && \text{(C.31)}
\end{aligned}
$$

For $j = 1, \ldots, N$:

$$
\begin{aligned}
\hat{\omega}_{j,t} &= -\alpha_j \hat{z}_{j,t} + \alpha_j \hat{w}_t - \hat{r}_{j,t} && \text{(C.32)} \\
\hat{l}_{j,t} &= \hat{\omega}_{j,t} - \hat{w}_t + \hat{r}_{j,t} - \varepsilon \hat{r}_{j,t}^{+} + \hat{y}_{j,t} && \text{(C.33)} \\
\hat{y}_{j,t} &= -\varepsilon \hat{r}_{j,t} + \hat{y}_t && \text{(C.34)} \\
\hat{m}_{j,t} &= \hat{\omega}_{j,t} + \hat{r}_{j,t} - \varepsilon \hat{r}_{j,t}^{+} + \hat{y}_{j,t} && \text{(C.35)} \\
\hat{\pi}_{j,t} &= \frac{(1-\beta\theta_j)(1-\theta_j)}{\theta_j}\hat{\omega}_{j,t} + \beta \mathbb{E}_t \hat{\pi}_{j,t+1} && \text{(C.36)} \\
\hat{r}_{j,t} &= \hat{r}_{j,t-1} + \hat{\pi}_{j,t} - \hat{\pi}_t && \text{(C.37)} \\
\hat{r}_{j,t}^{+} &= \theta_j \hat{r}_{j,t-1}^{+} && \text{(C.38)}
\end{aligned}
$$

Market clearing and aggregation

$$\hat{l}_t = \sum_{j=1}^{N} \left(\frac{l_j}{l}\right) \hat{l}_{j,t} \tag{C.39}$$

$$\hat{y}_t = \left(\frac{c}{y}\right) \hat{c}_t + \left(\frac{m}{y}\right) \hat{m}_t \tag{C.40}$$

$$\hat{m}_t = \sum_{j=1}^{N} \left(\frac{m_j}{m}\right) \hat{m}_{j,t} \tag{C.41}$$

$$0 = \sum_{j=1}^{N} \gamma_j r^{1-\varepsilon} \hat{r}_{j,t} \tag{C.42}$$

Stochastic processes

$$\hat{a}_t = \rho_a \hat{a}_{t-1} + \varepsilon_{a,t} \tag{C.43}$$

$$\hat{z}_{j,t} = \rho_{z,j} \hat{z}_{j,t-1} + \varepsilon_{z,j,t} \tag{C.44}$$

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