A SMALL MODEL OF THE AUSTRALIAN MACROECONOMY

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The first version of this model was put together by David Gruen and Geoff Shuetrim in late 1995 and presented in June 1996 at a Reserve Bank of Australia one-day conference on monetary policy. A modified version was subsequently used by Gordon de Brouwer, James O'Regan, Philip Lowe and Luci Ellis in papers prepared for the 1997 Reserve Bank of Australia Conference Volume. Thanks are due to these people and to John Romalis, Alex Heath, Gordon Menzies, Troy Swann and Matthew Boge for contributions to the model's development over several years and to Adrian Pagan for helpful comments. Any errors are ours alone. The views expressed herein are those of the authors and do not necessarily reflect those of the Reserve Bank of Australia.

Abstract

This paper presents a small model of the Australian macroeconomy. The model is empirically based, aggregate in nature and consists of five estimated equations – for non-farm output, the real exchange rate, import prices, unit labour costs and consumer prices. The stylised facts underlying each equation are discussed and estimation results are presented.

The model's primary use is to examine macroeconomic developments over the short to medium term, although it also has a well-defined steady state in the longer run with appropriate theoretical properties. Dynamic responses of the model to monetary policy changes and selected shocks are illustrated in the paper.

JEL Classification Numbers: E10, E17, E31, E37, E52

Keywords: Australian economy, macroeconomic model, monetary policy

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1. Introduction

This paper presents a small model of the Australian macroeconomy. The model provides a convenient way of summarising the main macroeconomic interrelationships in the Australian economy. It can be used as a simple framework with which to analyse developments in the economy and the effects of shocks, and to generate forecasts of the economy's likely future evolution.

The model is predominantly empirically based and designed to be consistent with the behaviour of the main macroeconomic aggregates in the Australian economy over the past fifteen years. It is primarily of interest for examining macroeconomic developments – including the effects of monetary policy on the economy – over the short to medium run; that is, for perhaps one to three years. Despite this main focus, however, the model also has a well-defined steady state to which it converges in the longer run, with properties that accord, in crucial respects, with our theoretical expectations.

The model consists of five estimated equations. Two of these equations explain real variables, non-farm output and the real exchange rate, while the remaining three explain nominal 'price' variables, import prices, unit labour costs, and consumer prices. The equations are specified to encompass both short-run dynamics and longer-run steady-state relationships. Restrictions are imposed on some of the coefficients in the three equations explaining price variables to generate appropriate steady-state behaviour.

The paper is structured as follows. Section 2 provides a broad overview of the model. Section 3 presents estimation results for the five equations in the model. Section 4 characterises the steady-state properties of the model and describes the calculation of potential output. Section 5 presents several illustrative simulations of the model, and Section 6 concludes.

2. Overview

We begin the overview by discussing some of the model's characteristics, before turning to a few stylised facts about the Australian macroeconomy over the past fifteen years that provide motivation for the specification of some of the model equations. We then discuss the structure of the model in more detail.

2.1 Characteristics

Three features broadly characterise the model. It is empirical, aggregate and non-monetary. We briefly address each of these in turn.

Macroeconomic models vary along a spectrum ranging from empirically based models to those primarily or exclusively derived from theoretical, microeconomic principles. This spectrum exists because experience has revealed an undesirable trade-off between the extent to which a macroeconomic model is based on theoretical, microeconomic principles and its capacity to fit the economic data.[1]

The model in this paper is predominantly empirically based. The model equations are estimated econometrically. Restrictions on sets of estimated coefficients in the three price equations are imposed in order to generate steady-state properties that accord with our theoretical priors.

There are both backward- and forward-looking inflation expectations in the model. Real interest rates, which appear in the equations for output and the real exchange rate, are calculated using past inflation to deflate nominal interest rates. In the equation for unit labour costs, there are both backward- and forward-looking expectations, with the latter derived from the bond market. Rational model-consistent expectations do not, however, play a role in the model.

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[1] Two examples give a flavour of this trade-off. Firstly, the joint hypothesis of uncovered interest parity and rational expectations in the foreign exchange market has impeccable theoretical credentials, but is usually rejected by the data, for reasons that have thus far defied explanation in terms of economic theory (Engel 1995). Secondly, small macroeconomic models based explicitly on optimising behaviour by representative economic agents provide a worse fit to the economic data, and appear less robust to the Lucas critique, than models that assume backward-looking adaptive behaviour on the part of economic agents (Estrella and Fuhrer 1998, 1999).

The model is highly aggregated, which is necessary to keep it as small as it is. Perhaps the most obvious example of this is that output is modelled in a single equation. In this respect, the model more closely resembles a small vector auto-regression model than a larger scale macroeconomic model in which the major expenditure components and sectors of the economy are treated separately. The model is, however, larger than most small vector auto-regression models in that, as well as the five endogenous variables explained by the model, there are a further ten exogenous variables that appear in one or more of the model equations.

Finally, the model is non-monetary – that is, there is no explicit role for monetary quantities. As in most countries, the stable relationship between money and nominal output broke down in Australia in the 1980s. By the early 1990s, a stable long-run relationship between money, income and interest rates had become hard to find (de Brouwer, Ng and Subbaraman 1993) and since then researchers have come to assign money little or no causal role in the transmission mechanism of monetary policy. Reflecting this, more recent work on the transmission of monetary policy to output has used the real interest rate to measure the stance of monetary policy (for example, Gruen, Romalis and Chandra (1997)). Furthermore, neither the inflation equation derived in de Brouwer and Ericsson (1995), nor the simultaneous system of wages and prices in Cockerell and Russell (1995) contain money.

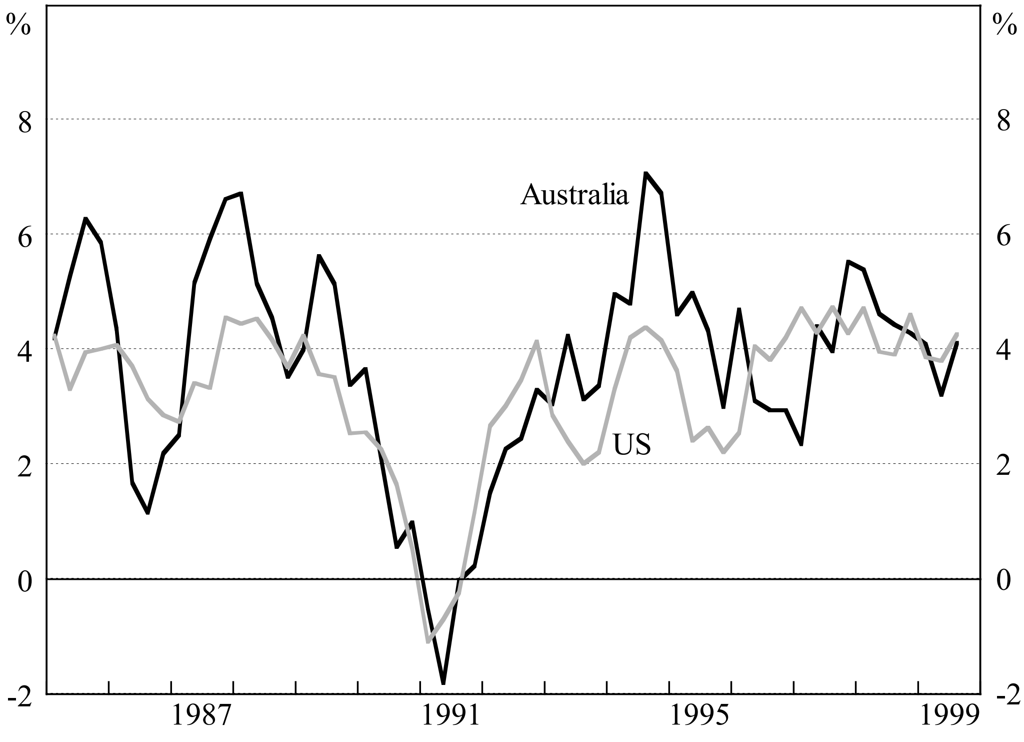
The characterisation of the model as empirical, aggregate and non-monetary stands it apart from many other macro-econometric models, both for Australia, and for other countries. Nevertheless, it provides a useful framework within which to forecast the evolution of the Australian economy and conduct policy simulations over the short to medium run.

2.2 Stylised Facts About the Australian Macroeconomy

One of the best-documented stylised facts about the Australian business cycle is its close relationship with the US business cycle, as shown in Figure 1. There have been several suggestions for the strength of this relationship. In the shorter run, links between financial markets (Gruen and Shuetrim 1994; de Roos and Russell 1996; and Kortian and O'Regan 1996), effects on Australian business confidence (Debelle and Preston 1995), and a disproportionate response of Australian exports to the US business cycle (de Roos and Russell 1996) all play a role. In the longer run, technology transfer from the US seems to be important (de Brouwer and Romalis 1996). The strong relationship between the Australian and US business cycles forms the basis for the equation for non-farm output in the model.

Figure 1: Australian Real Non-farm Output and US Real Output

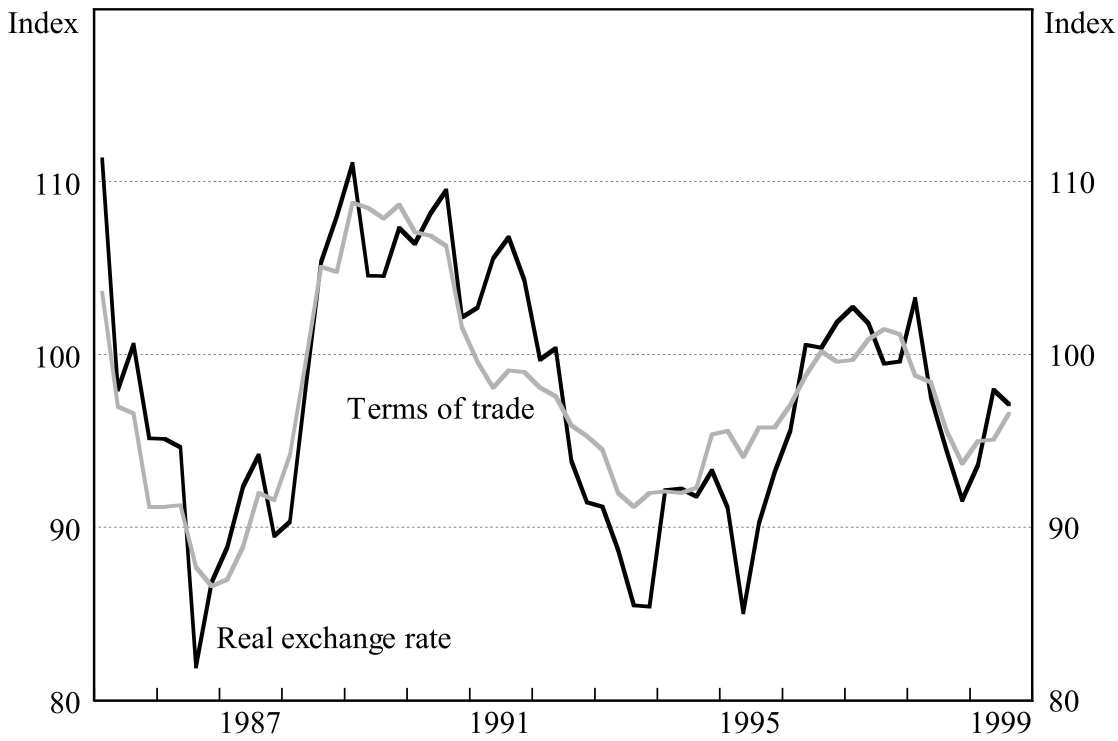
Four-quarter-ended percentage change



A second stylised fact about the macroeconomy is the strong relationship between the Australian trade-weighted real exchange rate and the terms of trade for goods and services, shown in Figure 2. With roughly three-fifths of exports accounted for by commodities, Australia's terms of trade are volatile. The close co-movement of the terms of trade and the real exchange rate remains something of a puzzle, however (Gruen and Kortian 1996). For reasons that remain unclear, the two series are much more correlated than for other advanced commodity exporting countries like Canada or New Zealand. Not surprisingly, this close relationship, particularly since the float of the Australian dollar in 1983, has formed the basis of econometric models of the Australian exchange rate for many years (see, for example, Blundell-Wignall and Gregory (1990), Gruen and Wilkinson (1991), and Tarditi (1996)). This relationship also forms the basis for the real exchange rate equation in the model described here.

Figure 2: Terms of Trade and Real Exchange Rate

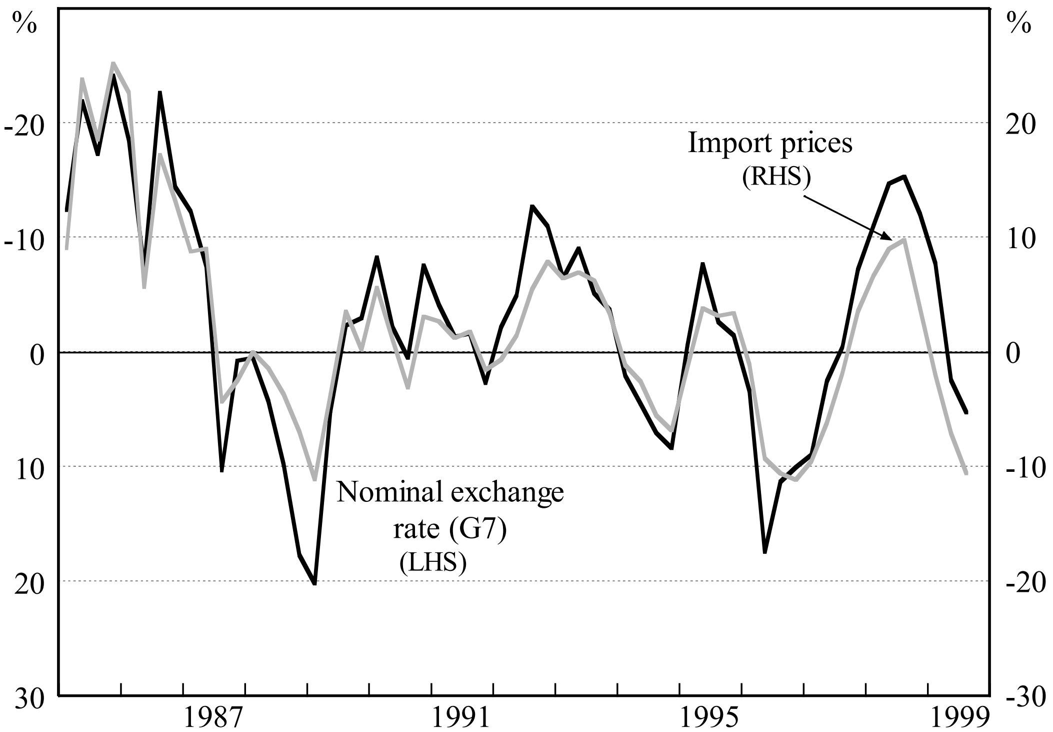
1997/98=100



Movements in the exchange rate have important implications for the domestic-currency price of imports, and hence, for consumer price inflation. Import prices affect consumer prices directly, since a proportion of the consumption basket is imported, as well as via imported intermediate and capital goods. Most of the movement in import prices is attributable to fluctuations in the exchange rate, and pass-through of exchange rate movements to import prices is rapid (Figure 3). The pass-through of exchange rate changes to import prices forms the basis of the import price equation in the model.

Figure 3: Nominal Exchange Rate and Import Prices

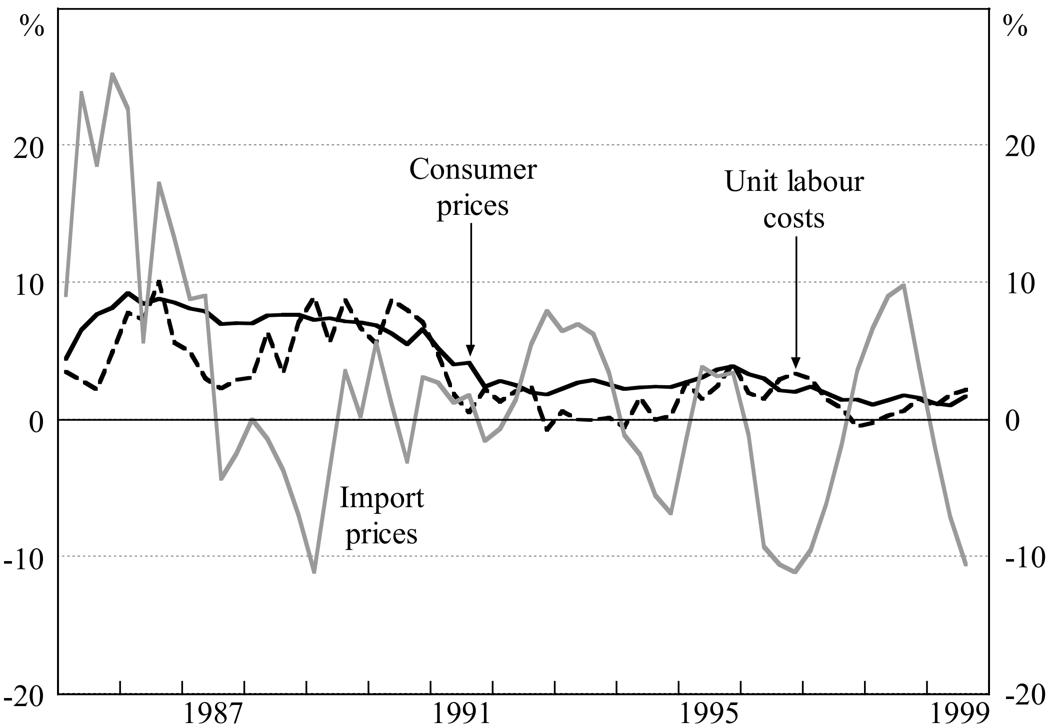
Four-quarter-ended percentage change



Consumer price changes, although influenced by import price movements, are dominated by changes in domestic unit labour costs. When nominal wages growth exceeds the growth of labour productivity, firms' margins are squeezed leading to upward pressure on prices. Figure 4 shows the fairly close relationship between growth in consumer prices and unit labour costs. At times, however, when import prices are rising or falling rapidly, their influence on consumer prices is also evident. Thus, for example, import prices were putting upward pressure on consumer price inflation in 1985, and downward pressure in 1996/97. The relationship between unit labour costs, import prices and consumer prices forms the basis of the consumer price equation in the model.

Figure 4: Consumer Prices, Unit Labour Costs and Import Prices

Four-quarter-ended percentage change



2.3 Structure

As previously mentioned, there are five endogenous and ten exogenous variables in the model. The relationships between these variables are summarised in the flow chart in Figure 5, with the endogenous variables shown in bold type.

We can use the flow chart to draw out the main linkages in the model. The effect of monetary policy on the economy is modelled in terms of the effect that changes in the policy interest rate, the nominal cash rate, have on the real cash rate. The real cash rate in turn has a direct impact on real output and the real exchange rate, with a higher real cash rate reducing output growth for a time, and appreciating the real exchange rate.

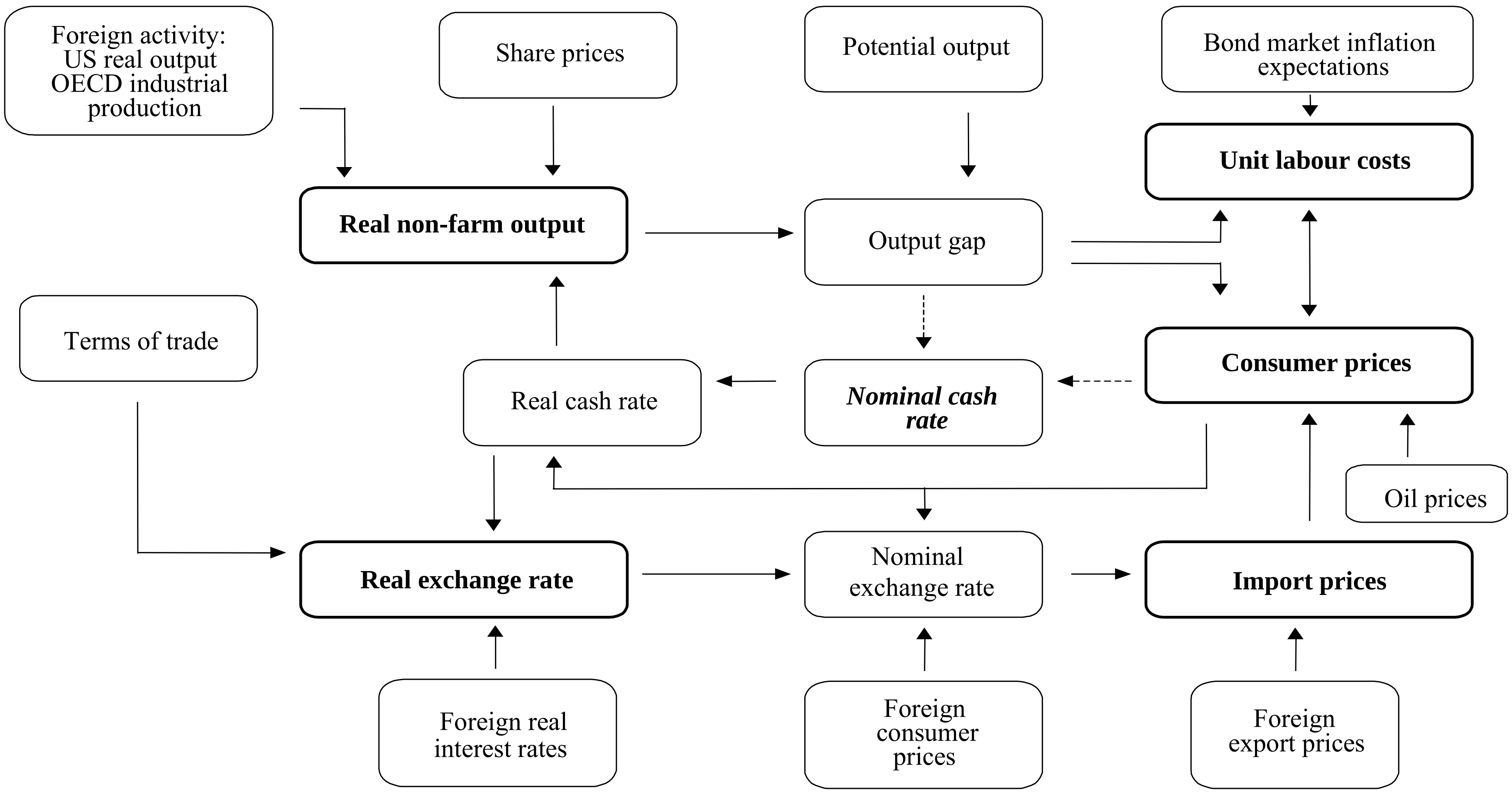
The real exchange rate is determined by the terms of trade and the differential between domestic and foreign real interest rates.

Non-farm output growth in the model is determined predominantly by foreign activity (US real output and OECD industrial production) and by lags of the domestic real interest rate. The level of share prices also plays a role. Australian output growth in the model's steady state is proportional to the assumed rate of steady-state output growth in the US. This relationship, which is quite strong in the data, can presumably be explained as a consequence of technological transfer and catch-up. Domestic output in the steady state is, however, independent of the rate of domestic consumer price inflation, a standard result for macroeconomic models that focus on the short to medium run.

The supply potential of the domestic economy is not modelled explicitly. Potential output is estimated by smoothing actual output, and adjusting the resultant series so that consumer price and unit labour cost inflation are steady when output is at potential. Potential output is also constrained to equal actual output in the steady state of the model.

The difference between actual and potential output, the output gap, has a direct influence on both unit labour cost and consumer price inflation. Changes in this gap also have an influence, so that there is upward pressure on consumer prices when output is growing faster than potential, and downward pressure when it is growing slower than potential.

Figure 5: Flow Chart Representation of the Model



Unit labour costs are influenced not only by the output gap but also by past consumer price inflation, as well as by forward-looking inflation expectations which in the model are derived from the bond market. The unit labour cost equation exhibits a vertical long-run Phillips curve in the steady state, again a standard result for macroeconomic models. Imposing this vertical long-run Phillips curve in a way that is accepted by the data is not, however, a straightforward exercise – it involves splitting the sample into two parts and imposing it only on the latter part (see Section 3.4).

Consumer prices are modelled as a mark-up on unit labour costs and import prices, with the margin between price and input costs varying cyclically with the output gap, and also depending in the short run on the domestic price of oil. Consumer prices in the steady state are, up to a constant, a linear combination of unit labour costs and import prices with weights that sum to one – that is, the equation exhibits static homogeneity.[2]

Import prices are determined jointly by foreign export prices and the nominal exchange rate, with changes in the exchange rate passing through rapidly to import prices. Traded goods prices satisfy purchasing power parity (up to a constant) in the steady state.

The dotted lines in the flow chart signify the presumed link from current (and expected future) outcomes for consumer prices and the output gap to the policy interest rate, the nominal cash rate. As the model is described in the paper, this link is not formalised. It is straightforward, however, to augment the model with a policy reaction function, such as a Taylor rule, or something more sophisticated.

2 Our theoretical priors would also lead us to expect that the consumer price equation would exhibit dynamic homogeneity, so that steady-state changes in the rate of inflation, that are shared by unit labour costs, import prices, oil prices and consumer prices, would have no real effects. This property is, however, overwhelmingly rejected by the data and is not imposed. The import price equation also fails to exhibit dynamic homogeneity. The implications of these rejections are discussed later.

3. Equations

In this section of the paper we present estimation results for the five equations in the model. The equations are estimated separately by ordinary least squares. The cross-equation variance-covariance matrix for the estimated residuals, reported in Appendix A, suggests that cross-equation correlations between these residuals are small in general and hence, that little is lost by estimating the equations individually rather than as a system. Furthermore, if one or other of the equations were mis-specified, single-equation estimation would avoid spreading this problem to the other equations in the system.

For each estimated equation, we follow a general-to-specific modelling approach. The equations are in equilibrium-correction form, with the exception of the unit labour cost equation, which is in first differences.[3] The sample period for all the equations is 1985:Q1–1999:Q3, which therefore excludes the more financially regulated 1970s and early 1980s.

We address the issue of the stability of the estimated equations in Appendix B. We test for a structural break at the beginning of 1993, after the low-inflation environment has been established. This is also around the time of an important change in monetary policy regime – the introduction of the medium-term inflation target. Appealing to the Lucas critique, this seems an appropriate time to test for possible structural breaks in the estimated equations. Our results do not show any obvious signs of instability around this time. It should be noted, however, that the sub-samples involved in this exercise are short and so many coefficients are imprecisely estimated, making it hard to draw definitive conclusions.

In all the estimations, variables are in logs, except for interest rates, and inflation expectations, which are expressed as per cent per annum, and the variable *tariff*, which appears in Appendix C. All variables in logs are multiplied by 100 so that their first differences are approximately in percentages. Appendix D provides a glossary of variables and a detailed description of the data and its sources.

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[3] The estimation techniques therefore generate consistent parameter estimates whether the variables in levels are non-stationary I(1) or borderline-stationary I(0) variables (provided the equation specifications are correct). The distributions of test statistics and some coefficient estimates would, however, differ somewhat in these two cases.

3.1 Output

The single-equation representation of growth in Australian output is based on Gruen and Shuetrim (1994) and Gruen *et al* (1997). We use this specification of the output equation:

$$\begin{aligned}\Delta y_t &= \alpha_1 + \sum_{i=2}^{7} \alpha_2^i r_{t-i} + \alpha_3 y_{t-1} + \alpha_4 y_{t-1}^{US} + \alpha_5 s_{t-1} \\ &+ \alpha_6 (\Delta y_{t-1} + \Delta y_{t-2}) + \alpha_7 \sum_{i=3}^{6} \Delta ip_{t-i}^{OECD} + \varepsilon_t\end{aligned} \tag{1}$$

where y is Australian real non-farm GDP, y^{US} is real US GDP, s is a de-trended real share price accumulation index for Australian shares, ip^{OECD} is real OECD industrial production and r is the real cash rate. We assume backward-looking inflation expectations so that the real cash rate is the nominal cash rate i less consumer price inflation over the past four quarters, $r_t = i_t - (p_t - p_{t-4})$. The estimation results are shown in Table 1.

Following Gruen *et al* (1997), we include several lags of the real cash rate and do not eliminate insignificant intermediate lags. This allows flexibility in the estimated near-term pattern of the effect of monetary policy on output. The lagged coefficients on the real cash rate are negative, on average, and jointly highly significant.

Estimation of the equation confirms that foreign output has a powerful effect on Australian output growth. Table 1 shows that US GDP has a significant long-run effect on Australian output. Growth of industrial production in the OECD also helps to explain short-run dynamics in Australian output growth.

Table 1: Australian Non-farm Output [a]

Constant	–189.827***
	(50.263)
Real cash rate (lags 2 to 7)[b]	–0.052***
	{0.001}
Non-farm GDP (lag 1)	–0.389***
	(0.090)
US GDP (lag 1)	0.425***
	(0.104)
De-trended real share prices (lag 1)	0.045***
	(0.010)
Non-farm GDP growth (lags 1 and 2)[c]	–0.201**
	(0.091)
OECD industrial production growth (lags 3 to 6)[c]	0.089**
	(0.043)
Long-run elasticity – US GDP	1.092***
	(0.021)
$\bar{R}^2$	0.506
Standard error of the residuals	0.547
F-test for joint significance of Australia and US GDP levels[d]	14.491***
LM tests for autocorrelation of residuals:	
First order	{0.073}
First to fourth order	{0.138}
Breusch-Pagan test for heteroskedasticity	{0.783}
Jarque-Bera test for normality of residuals	{0.456}

Notes: (a) The equation is estimated by ordinary least squares using quarterly data over the period 1985:Q1–1999:Q3. Numbers in parentheses () are standard errors. Numbers in braces {} are p-values. ***, ** and * represent significance at the 1, 5 and 10 per cent levels. All variables in log levels are multiplied by 100 (so growth rates are in percentages).

(b) The mean coefficient is reported for the real cash rate to summarise the coefficients on its lags. The p-value is derived from an F-test of the joint significance of the lags.

(c) For these variables, the restriction that the coefficients on each lag are equal is accepted and imposed.

(d) See Pesaran, Shin and Smith (1996) for the critical values for this F-test.

Following Fama (1990) and de Roos and Russell (1996), we include a de-trended measure of the cumulated return on Australian shares in the equation. Higher share prices raise shareholder wealth and lower the cost of equity, thereby leading to higher consumption and investment. The results suggest that share prices have a significant, and sizeable, impact on domestic output. A 10 per cent rise in the level of the accumulation index on Australian shares, sustained for a year, would raise output by 0.8 per cent over that time.

It would also be reasonable to expect that Australian output growth in the short run would rise with a rise in the terms of trade and fall with a rise in the real exchange rate. We find, however, that after controlling for the other explanatory variables in the equation, neither variable, in either levels or changes, has a significant effect on output growth. Given our uncertainty about the magnitude of the coefficients on these variables, and their limited role in explaining output growth in a freely estimated equation, these variables are excluded from the equation specification.

As a consequence of this exclusion, this equation cannot be used to estimate a monetary conditions index (as conventionally defined) for the Australian economy because there is no significant estimated effect on activity of changes in the real exchange rate.

Earlier versions of Equation (1) included growth in farm output as one of the explanatory variables. When current and lagged farm output growth are included in Equation (1), however, their contribution is small and insignificant.

We also experimented with alternative assumptions about inflation expectations. Rather than assuming exclusively backward-looking expectations in the calculation of real interest rates (as for the results in Table 1), we assumed that $r_t = i_t - [\mu(p_t - p_{t-4}) + (1-\mu)\pi_t^e]$, where μ is the assumed weight on backward-looking expectations, and π_t^e are inflation expectations derived from the bond market. Estimating Equation (1) with this alternative assumption for real interest rates, and varying the weight μ in the range $0 \le \mu \le 1$, made almost no difference to the goodness-of-fit of the equation (with the adjusted R^2 varying in a range of only 0.01).

3.2 Real Exchange Rate

For a small, open economy such as Australia, the exchange rate is an important relative price. This explains the attention devoted to it in most Australian empirical macroeconomic models. Unfortunately, however, the exchange rate has proven persistently difficult to model both theoretically and empirically. For example, a common theory of exchange rate determination is uncovered interest rate parity, according to which an interest rate differential should reflect the expected future movement of the exchange rate. Empirical testing has, however, consistently rejected the joint hypothesis of uncovered interest parity and rational expectations, consistent with some form of foreign-exchange market inefficiency or time varying risk premia. Empirical modelling of the exchange rate has not been without its difficulties either. The classic Meese-Rogoff (1983) result – that for horizons up to a year, forecasts from economic models of the exchange rate are rarely any better than a 'no-change' forecast – suggests that the current exchange rate is about as good as any predictor of the future exchange rate, at least over short horizons.

Among existing models, there have been two approaches to modelling the Australian exchange rate. The first is based on an uncovered interest rate parity condition, assuming that market participants have rational expectations. Most large Australian macroeconometric models, including the Murphy and TRYM models (Powell and Murphy 1997; Douglas, Thompson and Downes 1997), follow this approach as does Svensson's (1998) simple stylised open economy model. The second common approach, and the one adopted here, is to model the exchange rate in a reduced-form, single-equation framework. This follows the work of Blundell-Wignall and Gregory (1990), Gruen and Wilkinson (1991), Blundell-Wignall, Fahrer and Heath (1993) and Tarditi (1996).

These papers have identified three fundamental determinants of the Australian real exchange rate: the terms of trade, the differential between domestic and foreign real interest rates, and net foreign liabilities. Over our sample, however, net foreign liabilities has an insignificant effect on the real exchange rate, so it is excluded from the specification of the equation.

The real exchange rate is modelled in an unrestricted equilibrium-correction framework which accommodates a long-run relationship between the real exchange rate and the terms of trade as well as short-run dynamics. We arrive at this parsimonious specification for the real exchange rate equation:

$$\Delta\theta_t = \beta_1 + \beta_2\theta_{t-1} + \beta_3 tot_{t-1} + \beta_4(r_{t-1} - r^*_{t-1}) + \beta_5\Delta tot_t + \omega_t \qquad (2)$$

where θ is the Australian dollar against a trade-weighted average of the currencies of major trading partners, using consumer prices in each country to convert to a real exchange rate, *tot* is the terms of trade, r^* is the foreign real interest rate (proxied by a weighted average of the real short-term policy rates in the G3 economies) and r has been defined earlier.[4] Over the estimation period, the Australian dollar was floating (the float began in December 1983). The estimation results are shown in Table 2.

As one would expect, the interest rate differential is a significant determinant of the real exchange rate. Furthermore, a rise in the terms of trade appreciates the real exchange rate roughly one-for-one in the long run. The results suggest, however, that the exchange rate overshoots in the short-run.

A possible explanation for this overshooting is that the terms of trade are endogenous to the real exchange rate. Endogeneity may arise because changes in the exchange rate pass through to import prices faster than to export prices (Dwyer, Kent and Pease 1993), implying that exchange rate changes can cause terms of trade changes in the same direction that can persist for, perhaps, a year or so. Such endogeneity can bias the estimated relationship between contemporaneous changes in the real exchange rate and the terms of trade.

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4 We also experimented with commodity prices in place of the terms of trade in Equation (2). This was motivated by two observations. Most of the movement in the terms of trade is driven by commodity prices, given the large share of commodities in Australia's export basket. Furthermore, commodity markets are forward-looking, so it seems plausible that the exchange rate would respond to commodity prices rather than to the more sluggishly moving terms of trade. On the basis of goodness-of-fit, however, a model which includes the terms of trade was always superior to that with commodity prices. This result stood even when we used commodity prices only in the short-run dynamics.

Table 2: Real Exchange Rate [(a)]

Constant	–2.019 (32.118)
Real exchange rate (lag 1)	–0.484*** (0.096)
Terms of trade (lag 1)	0.473*** (0.124)
Real interest rate differential (lag 1)	0.590** (0.252)
Terms of trade growth (lag 0)	1.290*** (0.176)
Long-run elasticity – terms of trade	0.977 (0.136)
$\overline{R}^2$	0.605
Standard error of the residuals	2.819
F-test for joint significance of real exchange rate, terms of trade and real interest rate differential	8.824***
LM tests for autocorrelation of residuals:	
First order	{0.108}
First to fourth order	{0.449}
Breusch-Pagan test for heteroskedasticity	{0.048}
Jarque-Bera test for normality of residuals	{0.827}
Hausman (endogeneity) test [(b)]	–0.186 {0.611}

Notes: (a) The equation is estimated by ordinary least squares using quarterly data over the period 1985:Q1–1999:Q3. Numbers in parentheses () are standard errors. Numbers in braces {} are p-values. ***, ** and * represent significance at the 1, 5 and 10 per cent levels. All variables in log levels are multiplied by 100 (so growth rates are in percentages).

(b) Contemporaneous and lagged changes in commodity prices, OECD industrial production and lagged changes of the terms of trade are used as instrumental variables for the contemporaneous change in the terms of trade.

A response to this is to control for the possible simultaneity bias by using instrumental variables for the contemporaneous change in the terms of trade. Estimating such an instrumental variable regression, however, reveals little statistical evidence of simultaneity bias (see Table 2). Furthermore, there is minimal difference between the estimated coefficients in the instrumental-variable and ordinary-least-squares regressions (results not shown). In particular, instrumenting the terms of trade change does not reduce the extent of short-run overshooting of the real exchange rate.

3.3 Import Prices

Following Dwyer, Kent and Pease (1993) we model import prices in an equilibrium-correction framework, with the nominal exchange rate and foreign export prices as explanators. Our preferred specification is shown in Equation (3):

$$\Delta pm_t = \phi_1 + \phi_2 pm_{t-1} + \phi_3 p^{*x}_{t-1} + \phi_4 e_{t-1} + \sum_{i=0}^{1} \phi_5^i \Delta p_t^{*x} + \sum_{i=0}^{1} \phi_6^i \Delta e_{t-i} + \phi_7 D_t^1 + \phi_8 t + v_t \quad (3)$$

where pm is over-the-docks import prices in Australian dollars, p^{*x} is foreign export prices, and e is the nominal exchange rate. The estimation results are shown in Table 3. The dummy, D_t^1 (D_t^1 = 0, t < 1998:Q2; = 1, $t \geq$ 1998:Q2), and trend will be discussed shortly.

Exchange rate data are available for all of Australia's trading partners, but relevant export price data are available for relatively few countries. We therefore estimate Equation (3) using GDP-weighted export prices from the G7 countries, and the nominal Australian dollar exchange rate against a GDP-weighted basket of G7 currencies.

We can view the G7 countries as setting a notional world price in global markets for goods and services. Of course, deviations from this price by non-G7 trading partners will not be captured by the equation. This has necessitated the addition of two extra variables in the equation: a time trend to capture the gradual shift in Australia's imports toward lower-priced goods from non-G7 countries (particularly in Asia), and a dummy variable since 1998:Q2 to capture extra price-undercutting by Asian exporters following the Asian crisis. The coefficients on both of these variables are negative and significant (see Table 3).

Table 3: Import Prices [a] [b]

Constant	153.271*** (40.275)
Change in the nominal exchange rate (lag 0)	–0.657*** (0.030)
Change in the nominal exchange rate (lag 1)	–0.010** (0.046)
Change in foreign export prices (lag 0)	0.567*** (0.212)
Change in foreign export prices (lag 1)	0.389* (0.211)
Import prices (lag 1)	–0.335*** (0.089)
Foreign export prices (lag 1)	0.335*** (0.089)
Nominal exchange rate (lag 1)	–0.335*** (0.089)
Trend	–0.108*** (0.026)
Dummy 1998:Q2–1999:Q3	–2.796*** (0.699)
$\overline{R}^2$	0.920
Standard error of the residuals	0.934
F-test for joint significance of import prices, foreign export prices and nominal exchange rate	17.959***
LM tests for autocorrelation of residuals:	
First order	{0.092}
First to fourth order	{0.072}
Breusch-Pagan test for heteroskedasticity	{0.002}
Jarque-Bera test for normality of residuals	{0.030}
Test for static homogeneity (purchasing power parity)	{0.982}
Test for dynamic homogeneity	{0.0000}

Notes: (a) The equation is estimated by ordinary least squares using quarterly data over the period 1985:Q1–1999:Q3. Numbers in parentheses () are standard errors. Numbers in braces {} are p-values. ***, ** and * represent significance at the 1, 5 and 10 per cent levels. All variables in log levels are multiplied by 100 (so growth rates are in percentages).

(b) Given the evidence of heteroskedasticity (see Table above), the standard errors reported are White heteroskedasticity-consistent standard errors.

Two sets of restrictions on the equation are suggested by theory. The first is that traded goods prices should satisfy purchasing power parity in the long run (i.e., the equation should exhibit static homogeneity). This implies long-run elasticities of import prices with respect to foreign export prices and the nominal exchange rate of 1 and –1, or equivalently, $\phi_2 = -\phi_3 = \phi_4$. This restriction is easily accepted by the data, and imposed in the estimation.

The second set of restrictions is suggested by the idea that the margin between import prices and the domestic-currency cost of imports, $pm_t + e_t - p_t^{*x}$, should be unaffected by changes in the steady-state rate of inflation. For the margin to be unaffected by a change in the steady-state rate of *domestic* inflation which is matched by the same change in the steady-state rate of depreciation (and the same change in the rate of import price inflation), requires that $\phi_6^0 + \phi_6^1 = -1$. For the margin to be unaffected by a change in the steady-state rate of inflation of *foreign* export prices, matched by an offsetting change in the steady-state rate of depreciation, also requires that $\phi_5^0 + \phi_5^1 = 1$. These joint restrictions, which together imply that the equation exhibits dynamic homogeneity, are overwhelmingly rejected by the data and are not imposed (see Table 3).

Adjustment of import prices to shocks in the explanatory variables is relatively fast, with two thirds of the adjustment to an exchange rate shock, for example, occurring within two quarters.

3.4 Unit Labour Costs

We use an expectations-augmented Phillips curve to model growth in unit labour costs. Inflation expectations are assumed to be a combination of backward- and forward-looking expectations. The backward-looking component combines lags of price and unit labour cost growth, while the forward-looking one is a measure of inflation expectations in the bond market, derived from the difference between the nominal and indexed 10-year bond yields. The output gap, rather than the unemployment gap, is used to capture wage-bargaining pressures.

Our parsimonious specification is shown in Equation (4).[5]

$$\begin{aligned}\Delta_4 u_t &= \rho_1 + \rho_3 \Delta_4 p_{t-1} + \rho_4 \pi_t^e \\ &\quad + \rho_6\, \Delta_4 u_{t-1} + \rho_7 \Delta u_{t-4} + \rho_8 \Delta u_{t-5} + \rho_9 (y_{t-4} - y_{t-4}^p) + \eta_t\end{aligned} \tag{4}$$

where u is unit labour costs, π^e is the bond market's inflation expectations, and y^p is potential output, calculated as described in Section 4.

We would expect on theoretical grounds that output could remain at potential at any steady rate of inflation, provided that steady rate was shared by consumer prices, unit labour costs and inflation expectations. That is, we expect Equation (4) to exhibit a vertical long-run Phillips curve (or, equivalently, to exhibit dynamic homogeneity).[6] This implies a restriction that the coefficients on the 'inflation' variables sum to one, that is $\rho_3 + \rho_4 + \rho_6 + (\rho_7 + \rho_8)/4 = 1$. (The coefficients on quarterly changes are divided by four because the dependent variable is a four-quarter-ended change.)[7] The estimated coefficients sum to 0.74, and the restriction that they sum to one, as required, is overwhelmingly rejected by the data (see Table 4).

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5 This model of four-quarter-ended changes in the dependant variable can be interpreted as a quarterly model with restrictions on the coefficients on the first three lags. We will return to this point shortly. The numbering of the coefficients contains gaps to ease later exposition. An equilibrium-correction term, $u_{t-1} - p_{t-1}$, is insignificant when added to this equation or to Equation (5).

6 Recall that we have assumed in estimation that the variables in levels are I(1) or borderline I(0), so that their growth rates are stationary I(0) variables. This assumption implies, for example, that the rate of unit labour cost growth cannot change permanently. However, we regard it as an important property of the model that unit labour costs and prices can grow at any constant rate in the steady state, and in principle that this steady-state rate of growth could change. Furthermore, that output in the steady state is independent of this rate of growth of costs and prices. To ensure these steady-state properties, it is necessary that the unit labour cost equation exhibit a vertical long-run Phillips curve.

7 A vertical long-run Phillips curve would also require that the constant, ρ_1, is zero. We return to this observation shortly.

Table 4: Unit Labour Costs [(a)]

	Unrestricted [(b)]	Restricted [(c)]
Constant	0.539 (0.362)	–
Dummy 1985:Q1–1995:Q4	–	0.304 (0.537)
Four-quarter-ended rate of inflation (lag 1)	0.293*** (0.103)	0.298*** (0.104)
Four-quarter-ended rate of unit labour cost growth (lag 1)	0.481*** (0.110)	0.473*** (0.110)
Quarterly unit labour cost growth (lag 4)	–0.961*** (0.131)	–0.969*** (0.130)
Quarterly unit labour cost growth (lag 5)	–0.305** (0.115)	–0.316*** (0.116)
Output gap (lag 4)	0.537*** (0.114)	0.528*** (0.114)
Bond market inflation expectations	0.287*** (0.097)	0.319*** (0.101)
Average inflation over past three years (lag 1) (1996:Q1 to sample end)	–	0.231*** (0.084)
$\overline{R}^2$	0.440	0.446
Standard error of the residuals	0.914	0.909
LM tests for autocorrelation of residuals:		
First order	{0.069}	{0.063}
First to fourth order	{0.178}	{0.182}
Breusch-Pagan test for heteroskedasticity	{0.834}	{0.677}
Jarque-Bera test for normality of residuals	{0.723}	{0.603}
Test for dynamic homogeneity	{0.0003}	
Test for dynamic homogeneity since 1996:Q1	–	{0.573}
Test that quarterly model can be restricted to its four-quarter-ended form	–	{0.395}

Notes: (a) The equations are estimated by ordinary least squares using quarterly data over the period 1985:Q1–1999:Q3. Numbers in parentheses () are standard errors. Numbers in braces {} are p-values. ***, ** and * represent significance at the 1, 5 and 10 per cent levels. All variables in log levels are multiplied by 100 (so growth rates are in percentages).

(b) Estimation of Equation (4). The restriction that the coefficients on the 'inflation' variables sum to one is not imposed but an F-test of the restriction is shown.

(c) Estimation of Equation (5) imposing the restriction that the coefficients on 'inflation' variables sum to one. The estimated constant, $\hat{\rho}_1$, is not reported, because the potential output series, y_t^p, is constructed so that $\hat{\rho}_1 = 0$ (see Section 4 of the paper). Two F-tests are shown.

The reason for this rejection is not immediately apparent. It may have something to do with the series of Accords between the Federal Government and the trade union movement in the 1980s and early 1990s, which are widely thought to have restrained growth in real unit labour costs at the time (Chapman 1990, Stevens 1992). The equation then 'explains' this period of restrained unit-labour-cost growth as a less than one-for-one response to the higher inflation at that time.

Whatever the reason for the rejection, we regard a vertical long-run Phillips curve as a sufficiently important property that we split the sample into two parts, and impose this constraint on the more recent sub-sample in a way that is accepted by the data. We estimate the specification shown in Equation (5).[8]

$$\begin{aligned}\Delta_4 u_t = \rho_1 D_t^2 + \rho_2 (1 - D_t^2) + \rho_3 \Delta_4 p_{t-1} + \rho_4 \pi_t^e + \rho_5 D_t^2 \pi_{t-1} \\ + \rho_6 \Delta_4 u_{t-1} + \rho_7 \Delta u_{t-4} + \rho_8 \Delta u_{t-5} + \rho_9 (y_{t-4} - y_{t-4}^p) + \eta_t\end{aligned} \tag{5}$$

where D_t^2 is a dummy variable, $D_t^2 = 0$ for $t \le$ 1995:Q4, $D_t^2 = 1$ for $t \ge$ 1996:Q1, and π_t is the average rate of annual inflation over the past three years, $(p_t - p_{t-12})/3$.

The joint restrictions that together imply a vertical long-run Phillips curve in the more recent sub-sample are $\rho_1 = 0$ and $\rho_3 + \rho_4 + \rho_5 + \rho_6 + (\rho_7 + \rho_8)/4 = 1$. The first of these restrictions is imposed when the potential output series, y_t^p, is constructed (see Section 4) and the second, which is easily accepted by the data, is imposed in estimation (see Table 4).

3.5 Consumer Prices

Following de Brouwer and Ericsson (1995), we model consumer prices as a mark-up over the unit input costs of production, which are assumed to be unit labour costs and import prices. Unit labour costs are the cost of domestic labour inputs, adjusted for labour productivity, while the inclusion of import prices

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8 Estimating Equation (5) with quarterly rather than annual changes would imply the additional restrictions that the coefficients on Δu_{t-1}, Δu_{t-2} and Δu_{t-3} are all equal as are the coefficients on Δp_{t-1}, Δp_{t-2}, Δp_{t-3} and Δp_{t-4}. These joint restrictions are easily accepted by the data (see Table 4).

reflects the cost of imported consumer, intermediate and capital goods. The mark-up is allowed to vary cyclically with the output gap, and is also influenced by oil prices. We adopt the following equilibrium-correction specification:

$$\begin{aligned}\Delta p_t &= \lambda_1 + \lambda_2 p_{t-1} + \lambda_3 u_{t-1} + \lambda_4 pm'_{t-1} + \lambda_5 \Delta u_t + \lambda_6 \Delta pm'_t + \lambda_7 \Delta oil_{t-1} \\ &\quad + \lambda_8 (y_{t-3} - y^p_{t-3}) + \lambda_9 \sum_{i=0}^{2} \Delta (y_{t-i} - y^p_{t-i}) + \lambda_{10} D^3_t + \lambda_{11} D^4_t + \xi_t \end{aligned} \tag{6}$$

where *pm*' is import prices adjusted for tariffs and for an assumed productivity differential between the traded and non-traded sectors (as explained in Appendix C), and *oil* is the Australian dollar price of crude oil. The dummy variables (D^3_t = 1 at 1990:Q4, D^4_t = 1 at 1991:Q1, 0 otherwise) allow for the huge, short-lived spike in oil prices at the time of the Gulf War, which has an immediate, but temporary impact on consumer prices which the equation cannot otherwise explain.

Estimation results are shown in Table 5. We test the equation for static homogeneity – the restriction that (up to a constant) consumer prices in the long-run are a linear combination of unit labour costs and adjusted import prices with the sum of the coefficients equal to one, that is $\lambda_2 = -(\lambda_3 + \lambda_4)$. This long-run restriction is accepted and imposed (see Table 5).[9]

We also test for dynamic homogeneity – the restriction that the sum of the coefficients on 'inflation' terms is one, i.e., $\lambda_5 + \lambda_6 + \lambda_7 = 1$. This restriction is overwhelmingly rejected by the data (see Table 5) and is not imposed. We discuss the relevance of this rejection in Section 5 of the paper.

The explanatory power of the equation is high, with an adjusted $\bar{R}^2$ of 0.88. Long-run elasticities of 0.58 and 0.42 on unit labour costs and adjusted import prices indicate that domestic input costs dominate total production costs. The output gap, as a measure of aggregate demand pressure, has a positive effect on prices as expected. The change in the gap, which measures the rate of change of output relative to potential, also helps to explain inflation in the near term.

9 Since oil is also an input to production, we tested whether the oil price was part of the long-run relationship with consumer prices. When the lagged level of oil prices is added to the regression, its coefficient is of the correct sign but very small in magnitude and insignificant. We therefore excluded the oil price from the long-run relationship.

Table 5: Consumer Prices [a] [b]

Constant	–0.541
	(0.379)
Consumer prices (lag 1)	–0.073***
	(0.008)
Unit labour costs (lag 1)	0.043***
	(0.013)
Adjusted import prices (lag 1)	0.030***
	(0.006)
Unit labour cost growth (lag 0)	0.103***
	(0.032)
Adjusted import price growth (lag 0)	0.032**
	(0.013)
Oil price growth (lag 1)	0.008***
	(0.003)
Output gap (lag 3)	0.142***
	(0.026)
Change in the output gap (lags 0, 1 and 2) [c]	0.072**
	(0.032)
Dummy 1990:Q4	1.084***
	(0.291)
Dummy 1991:Q1	–1.254***
	(0.290)
Long-run elasticity – unit labour costs	0.585
	(0.116)
– adjusted import prices	0.415
$\overline{R}^2$	0.880
Standard error of the residuals	0.250
F-test for joint significance of consumer price, unit labour cost and import price levels [d]	74.100***
LM tests for autocorrelation of residuals:	
First order	{0.832}
First to fourth order	{0.590}
Breusch-Pagan test for heteroskedasticity	{0.042}
Jarque-Bera test for normality of residuals	{0.366}
Test for static homogeneity	{0.087}
Test for dynamic homogeneity	{0.0001}

Notes: (a) The equation is estimated by ordinary least squares using quarterly data over the period 1985:Q1–1999:Q3. Numbers in parentheses () are standard errors. Numbers in braces {} are p-values. ***, ** and * represent significance at the 1, 5 and 10 per cent levels. All variables in log levels are multiplied by 100 (so growth rates are in percentages).

(b) Given the evidence of heteroskedasticity (see Table above), the standard errors reported are White heteroskedasticity-consistent standard errors.

(c) For these variables, the restriction that the coefficients on each lag are equal is accepted and imposed.

(d) See Pesaran *et al* (1996) for the critical values for this F-test.

4. The Steady State and Potential Output

4.1 The Steady State

We begin with assumptions about the steady-state behaviour of the exogenous variables, which are summarised in Table 6.

With these assumptions for the exogenous variables, we can turn to the steady-state properties of the model's five endogenous variables. Before doing so, however, one issue needs to be resolved. The real exchange rate equation provides a description of the Australian dollar against (a weighted average of) the currencies of major trading partners, using consumer prices in each country to convert to the real exchange rate, θ_t. Because of data availability, however, the nominal exchange rate, e_t, used in the import price equation is the Australian dollar against (a weighted average of) the G7 currencies. These different definitions for the nominal and real exchange rates do not cause a problem for estimation since both variables are available over the estimation period. For simulation and forecasting purposes, and to define the properties of the steady state, however, it is necessary to relate the two variables. In the forecast period and the steady state, we assume that the two (log) measures of the real exchange rate move together, i.e.,

$$\Delta\left(e_t + p_t - p_t^{*c}\right) = \Delta\theta_t \tag{7}$$

The behaviour of the nominal exchange rate, e_t, can then be derived from the assumed behaviour of G7 consumer prices, p_t^{*c}, and from the behaviour of the real exchange rate, θ_t, and Australian consumer prices, p_t, derived from the model. In the steady state, the real exchange rate, θ_t, is constant (see below), and consequently the nominal exchange rate, e_t, appreciates (depreciates) steadily to offset any difference between domestic and G7 consumer price inflation.

Table 6: Steady State Assumptions for Exogenous Variables

Variable	Steady state assumption
y_t^{US}	At the end of the estimation period, *T*, we derive an estimate of US *potential* output, y_T^{USp}, which is then assumed to grow at $g^{US}=$ 0.875 per cent per quarter (3.5 per cent per annum), i.e., $y_{t+1}^{USp}=y_t^{USp}+g^{US}t,\ t>T$. While actual US output, y_t^{US}, may differ from potential for some time into the future, they are assumed to be equal in steady state.[(a)]
s_t	$s_t=0$. The real share price accumulation index is assumed to be at trend in steady state, so that the de-trended series, s_t, is zero.
r_t	$r_t=\overline{r}=3.5$ per cent per annum. The real cash rate is at neutral in steady state. Neutral is assumed to equal the average real cash rate since the early 1990s disinflation, 1993:Q1–1999:Q3.
Δip_t^{OECD}	$\Delta ip_t^{OECD}=\overline{\Delta ip^{OECD}}=2.4$ per cent per annum. OECD industrial production is assumed to grow at its average rate over the period 1985:Q1–1999:Q3.
tot_t	$tot_t=\overline{tot}$ where $\overline{tot}$ is the average of the terms of trade over the period 1985:Q1–1999:Q3.
r_t^*	$r_t^*=\overline{r^*}=2.1$ per cent per annum. The world (G3) real short-term interest rate is assumed to equal its average over the period 1985:Q1–1999:Q3.
π_t^e	$\pi_t^e=\overline{\Delta_4 p}$ where $\overline{\Delta_4 p}$ is the steady state annual rate of consumer price inflation, which can take any constant value in the steady state (see text).
Δp_t^{*x}	$\Delta p_t^{*x}=\overline{\Delta p^{*x}}=$ –0.1 per cent per annum. Foreign (G7) export price inflation is equal to its average over the period 1993:Q1–1999:Q3.
Δp_t^{*c}	$\Delta p_t^{*c}=\overline{\Delta p^{*c}}=2.0$ per cent per annum. Foreign (G7) consumer price inflation is equal to its average over the period 1993:Q1–1999:Q3.
Δoil_t	$\Delta oil_t=\overline{\Delta oil}=\overline{\Delta p}$. The Australian dollar price of oil is assumed to rise at the same rate as domestic consumer prices.

Note: (a) The estimate of 3.5 per cent per annum for US potential output growth is from Rudebusch (2000). We assume that at the end of the estimation period, 1999:Q3, actual US output is 1.4 per cent above potential. This estimate is based on assuming that US unemployment was 0.7 per cent below the NAIRU at that time, and that the coefficient in Okun's Law linking changes in unemployment to output growth is 2 (this latter number is also from Rudebusch (2000)).

Potential output in the model is defined (see Section 4.2.1) so that actual output is equal to potential in the steady state, and therefore the output gap, the difference between actual and potential output, is zero. Table 7 summarises the steady-state properties of the model's endogenous variables.

Table 7: Steady State Properties of Model's Endogenous Variables

Variable	Steady state property
Δy_t	$\Delta y_t = \overline{\Delta y} = (-\alpha_4/\alpha_3)g^{US} = 3.8$ per cent per annum. Steady-state Australian non-farm GDP growth is determined by the long-run relationship with US output in the output equation.(a)
$\Delta\theta_t$	$\Delta\theta_t = \overline{\Delta\theta} = 0$. The real exchange rate is constant in the steady state because the terms of trade and real interest rate differential are assumed constant.
Δp_t	$\Delta p_t = \overline{\Delta p}$. Consumer price inflation is constant in the steady state.
Δu_t	$\Delta u_t = \overline{\Delta u} = \overline{\Delta p}$. Unit labour cost growth is equal to consumer price inflation in the steady state.
Δpm_t	$\Delta pm_t = \overline{\Delta pm} = \overline{\Delta p} - (\overline{\Delta p^{*c}} - \overline{\Delta p^{*x}})$. Import price inflation is less than consumer price inflation in the steady state because of the Balassa-Samuelson effect (see Appendix C). Adjusted import price inflation, however, is equal to consumer price inflation, i.e., $\Delta pm'_t = \overline{\Delta pm'} = \overline{\Delta p}$.(b)

Notes: (a) The steady state rate of non-farm GDP growth can be derived by setting all exogenous variables in the output equation to their steady-state values, and taking first differences of the equation.
(b) The time trend in the import price equation is set to a constant in the steady state.

Recall the series of homogeneity restrictions that are imposed on the estimated equations. The unit labour cost equation exhibits dynamic homogeneity (a vertical long-run Phillips curve) in the latter part of the sample, and in the steady state. Both the consumer price and import price equations exhibit static homogeneity but neither equation exhibits dynamic homogeneity.

These restrictions have several implications for the model. The model is neutral in the long run with respect to changes in the price level; that is, no real variables are affected in the long run as a consequence of a change in the price level. With respect to changes in the steady-state rate of inflation, $\overline{\Delta p}$, however, most real variables are unaffected, but not all. Output and the real exchange rate are unaffected. But the lack of dynamic homogeneity in the consumer price equation implies that changes in the steady-state rate of inflation have a permanent effect on the level of real unit labour costs, $u - p$. This result is at odds with our theoretical expectations, although there is empirical evidence that it may be a widespread phenomenon (Banerjee and Russell 1999).

Furthermore, the lack of dynamic homogeneity in the import price equation implies that changes in the steady-state rate of import price growth (matched by changes in the rate of nominal depreciation and/or foreign export price growth) have a permanent effect on the margin between the cost of imported goods and their landed prices. While it is plausible that this margin would move in the short run (due to a variety of factors including incomplete exchange rate pass-through, lags in contract renegotiation etc), it is hard to understand why it would shift permanently in response to a change in the steady-state rate of import price growth.

Finally, note that consumer price inflation in the steady state can take on any constant value, $\overline{\Delta p}$. When the model is augmented with a policy reaction function, however, consumer price inflation in the steady state is determined by the monetary policy authorities.

4.2 Potential Output

Potential output plays two roles in the model. Firstly, it is the level of output consistent with steady inflation (assuming both inflation expectations and unit labour cost growth are equal to price inflation). It plays this role over both the estimation period and in any simulation of the model into the future (which will usually involve adjustment to the model's steady state). Secondly, potential output must be consistent with actual output in the steady state of the model.[10]

This section explains how potential output is calculated so that it plays both these roles. We begin by defining two potential output series, one in the steady state, and the other in the estimation period, which we then splice together to generate a smooth series with the required properties.

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[10] Strictly speaking, we model potential *non-farm* output but we use the simpler term 'potential output' for ease of exposition.

4.2.1 Potential output in the steady state

We derive the level of actual, and therefore potential, output in the steady state from the output equation, Equation (1). Setting all exogenous variables to their steady state values, non-farm growth at its steady state rate, $\overline{\Delta y}$ (given in Table 7), and the error term to zero, gives

$$y_t = y_t^{pss} = \left((1-2\alpha_6)\overline{\Delta y} - \alpha_1 - \bar{r}\sum_{i=2}^{7}\alpha_2^i - \alpha_4 y_t^{USp} - 4\alpha_7 \overline{\Delta ip^{OECD}} \right) / \alpha_3 \text{ for } t > T \quad (8)$$

where y_t^{pss} denotes potential output in steady state, and US potential output, y_t^{USp}, is assumed to be y_T^{USp} at the end of the estimation period, T, and $y_{t+1}^{USp} = y_t^{USp} + g^{US}t$, for $t > T$, as in Table 6.

4.2.2 Potential output in the estimation period

Potential output in the estimation period is defined so that the unit labour cost equation has a vertical long-run Phillips curve in the latter part of the sample. That equation (repeated here for convenience) is

$$\begin{aligned}\Delta_4 u_t &= \rho_1 D_t^2 + \rho_2(1-D_t^2) + \rho_3\Delta_4 p_{t-1} + \rho_4\pi_t^e + \rho_5 D_t^2\pi_{t-1} \\ &\quad + \rho_6\,\Delta_4 u_{t-1} + \rho_7\Delta u_{t-4} + \rho_8\Delta u_{t-5} + \rho_9(y_{t-4} - y_{t-4}^p) + \eta_t\end{aligned} \quad (9)$$

where $D_t^2 = 0$ for $t \le$ 1995:Q4, $D_t^2 = 1$ for $t \ge$ 1996:Q1. The restriction

$$\rho_3 + \rho_4 + \rho_5 + \rho_6 + (\rho_7 + \rho_8)/4 = 1 \quad (10)$$

is accepted by the data and imposed when the equation is estimated (see Table 4).

When $t \ge$ 1996:Q1 and output is at potential, the equation is consistent with steady inflation (with inflation expectations equal to both unit labour cost and consumer price inflation) only when $\rho_1 = 0$. We use this observation to adjust the level of potential output so that this restriction on ρ_1 is satisfied.

4.2.3 Deriving potential output

We proceed as follows. We begin by defining potential output as a Hodrick-Prescott filter of actual output, y_t^{pep}, over a period, $1 \le t \le T$, starting before the estimation period and running to its end.[11] We then estimate the unit labour cost equation, Equation (9), over the estimation period, with the restriction Equation (10) imposed. This generates a non-zero estimate for ρ_1 in general. We then generate an adjusted output series by $y_t^{(1)} = y_t - \hat{\rho}_1 / \hat{\rho}_9$, $1 \le t \le T$. This adjustment is designed so that, had the unit labour cost equation been estimated using the H-P filter of $y_t^{(1)}$ as the potential output series rather than y_t^{pep}, the resulting estimate, $\hat{\rho}_1$, would have been zero.

We now splice the two series, $y_t^{(1)}$ for $1 \le t \le T$, and y_t^{pss} for $t > T$ (from Equation (8)), to generate a single smooth series for potential output. We do this by generating a partial-adjustment series, $y_t^{p-a(1)}$, defined (for $i = 1$) by

$$y_t^{p-a(i)} = y_t^{(i)}, \text{ for } 1 \le t \le T,$$

and (11)

$$y_{t+1}^{p-a(i)} = y_t^{p-a(i)} + \overline{\Delta y} + \kappa\left(y_t^{pss} - y_t^{p-a(i)}\right), \text{ for } T < t \le T+100$$

where κ is a speed-of-adjustment parameter, set equal to 0.05. The smooth potential output series, $y_t^{hp(i)}$, is then generated as the H-P filter (with smoothness parameter 5000) of the partial-adjustment series, $y_t^{p-a(i)}$, $1 \le t \le T+100$.

In general, the smooth potential series, $y_t^{hp(1)}$, and the H-P filter of $y_t^{(1)}$, are very similar over the estimation period, but not identical. As a consequence, when the unit labour cost equation (with the restriction Equation (10) imposed) is re-estimated using $y_t^{hp(1)}$ as the potential series, the resulting estimate, $\hat{\rho}_1$, will be non-zero. We therefore iterate, defining a new adjusted output series, $y_t^{(i)}$ (for $i = 2$) by $y_t^{(i)} = y_t^{(i-1)} - \hat{\rho}_1 / \hat{\rho}_9$, $1 \le t \le T$, where $\hat{\rho}_1$ and $\hat{\rho}_9$ are the estimated

[11] Starting the H-P filter in $t = 1 =$ 1974:Q3, well before the beginning of the estimation period, avoids starting-point problems with the filter. As will become clear, we also extend the analysis for 100 quarters beyond the end of the estimation period to avoid end-point problems. We use a smoothing parameter of 5000 in the filter, because smaller values generate considerable variation in potential output growth at business-cycle frequencies.

parameters using $y_t^{hp(i-1)}$ as potential output. We then calculate a new partial-adjustment series using Equation (11) and a new smooth potential series, $y_t^{hp(2)}$.

This process is repeated until, after a few iterations, the resulting smooth potential series, $y_t^{hp(n)}$, generates an estimate, $\hat{\rho}_1$, in the unit labour cost equation that is (arbitrarily close to) zero. This is then the potential output series, y_t^p, used in the estimated equations reported in Section 3 of the paper.

Figure 6 shows the annual growth rate of potential output, $\Delta_4 y_t^p$, over the estimation period and into the future. At the end of the estimation period, potential output is estimated to be growing at around 3.8 per cent per annum, very similar to its rate of growth in the steady state.

Figure 6: Real Non-farm Output

Four-quarter-ended percentage change

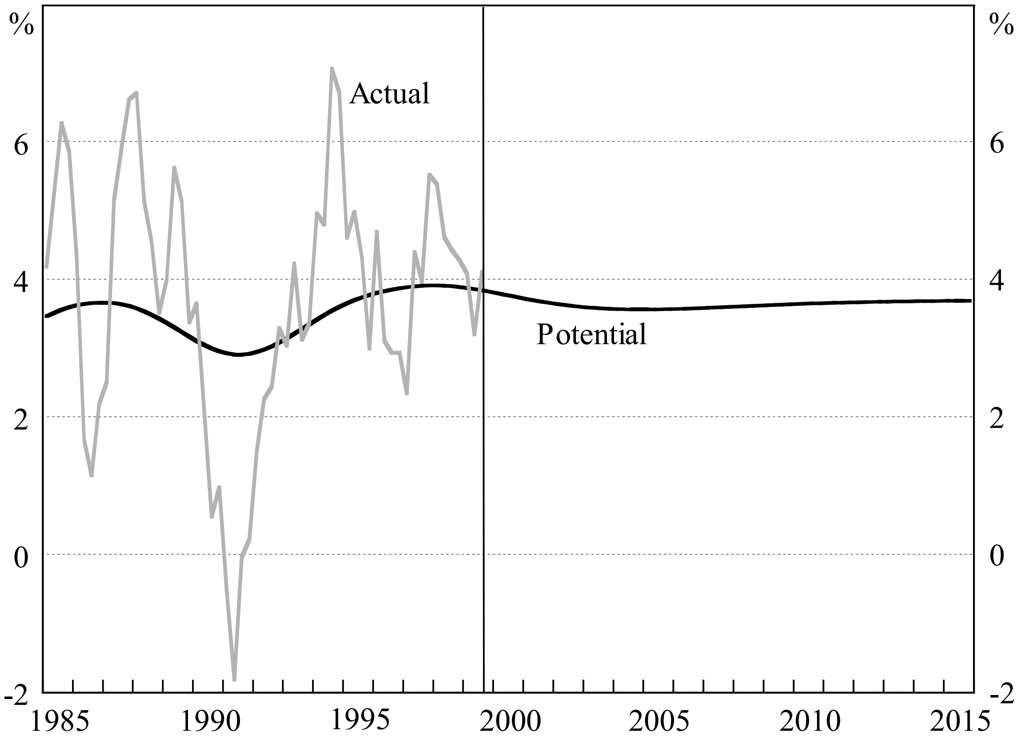
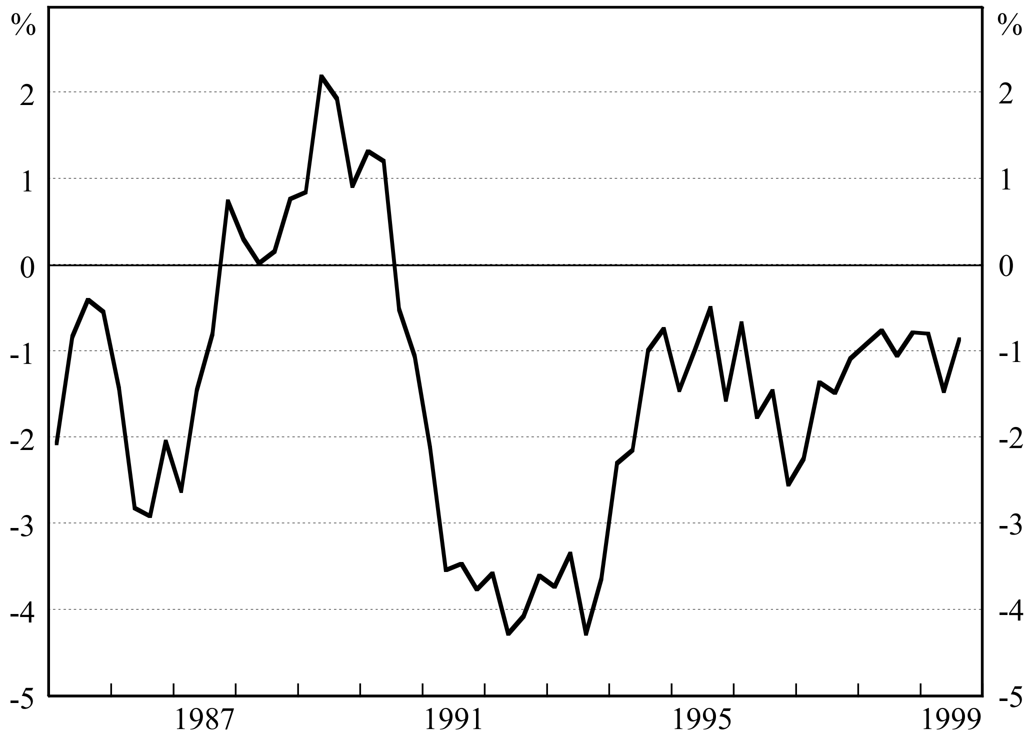


Figure 7 shows the estimated output gap over the estimation period. An output gap of zero is consistent with steady inflation when inflation expectations and unit labour cost growth are both running at the same rate as consumer price inflation. If inflation expectations are above actual inflation, however, output must be kept below potential (as defined here) in order to keep inflation steady.[12]

Figure 7: Output Gap

Per cent



[12] Over the estimation period, inflation expectations derived from the bond market have exceeded actual inflation by an average of 1.2 percentage points per annum. If this average difference were to persist, it would be necessary for output to remain an average 0.7 per cent below potential in order to keep inflation steady. (This result can be derived from the coefficients on bond market inflation expectations and the lagged output gap in the unit labour cost equation.)

5. Simulations

Having specified the model and characterised its steady state, we can now turn to its uses. The model can be used to generate forecasts of the endogenous variables, based on assumptions about the future behaviour of the exogenous variables. It can also be used to explore the linkages between the dynamics of the macroeconomy and the appropriate setting of monetary policy. To do so involves augmenting the model with a policy reaction function, such as a Taylor rule, or an objective function for policy. A number of papers have addressed these issues using earlier versions of this model (de Brouwer and O'Regan 1997; Lowe and Ellis 1997; Shuetrim and Thompson 1999).

Rather than updating this work here, we simply illustrate the model's properties with several dynamic simulations. We track the response of the model to five events: a permanent one percentage point increase in the real cash rate, and one-off one per cent shocks to the level of output, import prices, unit labour costs and consumer prices. The real cash rate is held constant throughout the simulations involving one-off shocks. Inflation expectations, π_t^e, are set equal to the previous period's four-quarter-ended inflation, $p_{t-1} - p_{t-5}$. We also assume that share prices are unaffected by any of the shocks or by changes to monetary policy.[13]

All the simulation results report deviations from the steady state. Impulse response functions and 90 per cent confidence intervals, derived using a Monte Carlo procedure, are shown in the graphs.[14]

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13 These assumptions are made for simplicity since they render the model entirely backward-looking, and therefore stable with respect to shocks away from the steady state. It would of course be possible to model inflation expectations and share prices in alternative ways.

14 In the Monte Carlo procedure, residuals are drawn from independent normal distributions with standard deviations equal to those of the residuals from the estimated equations. The point estimates shown are median outcomes from these simulations and differ slightly from OLS results.

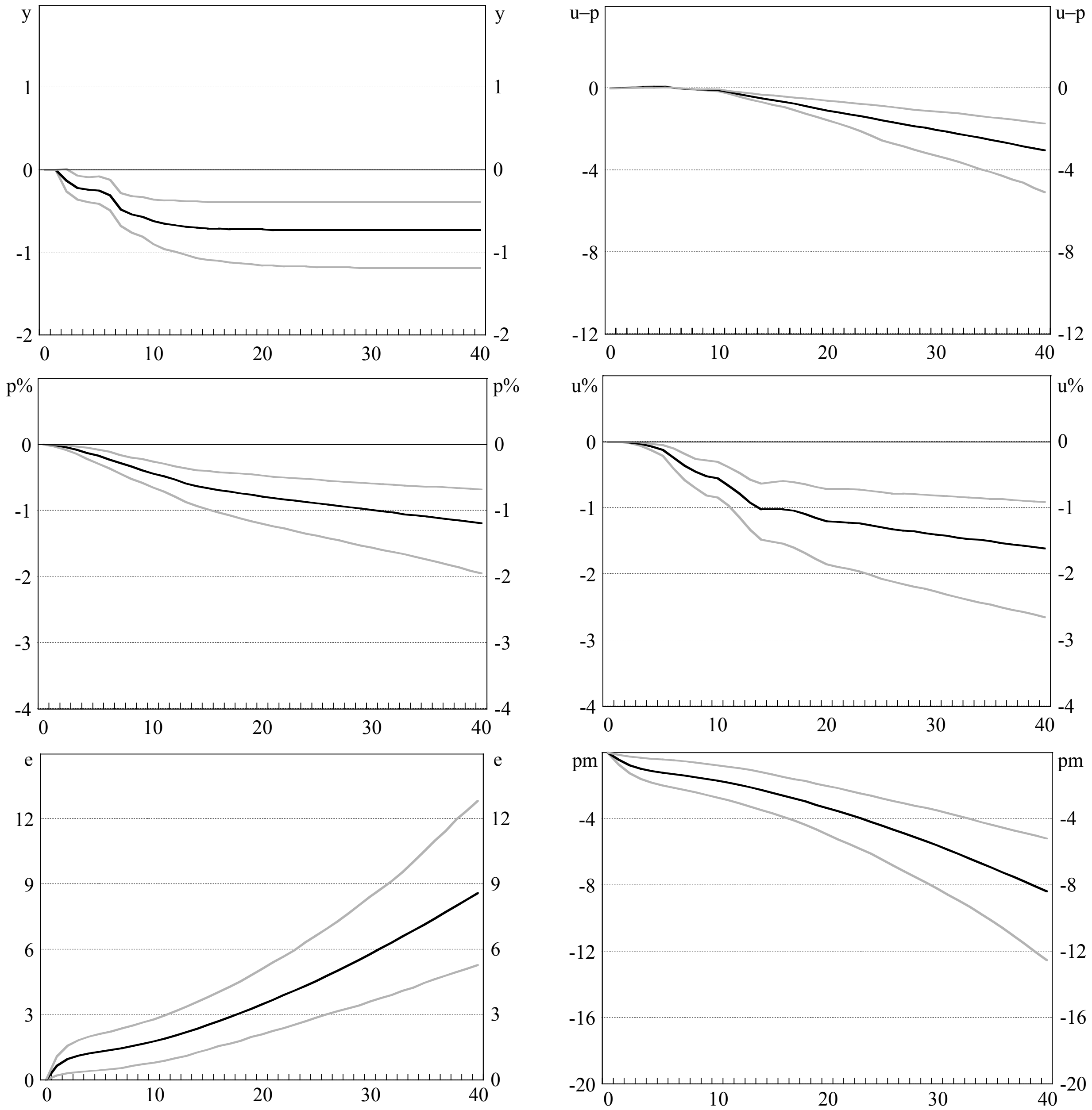
5.1 A Permanent Increase in the Real Cash Rate

As expected, the tightening of monetary policy has a contractionary effect on the economy. The level of output falls by 0.8 per cent in the long run, with the bulk of this adjustment complete after three years (see Figure 8).

The opening up of a permanent output gap leads to a deflationary cost/price spiral. Annual inflation is reduced by ½ per cent between quarters six and ten and continues to decline indefinitely. The real exchange rate appreciates to a new long-run level in response to higher domestic real interest rates (not shown), while the nominal exchange rate continues to appreciate as domestic prices fall relative to those abroad. Accordingly, import prices decline. Real unit labour costs gradually fall as the trend rate of inflation declines, which illustrates an aspect of the model's lack of neutrality with respect to changes in the inflation rate.

This simulation is, of course, unrealistic in many respects. For one thing, monetary policy would not be expected to have a permanent influence on the domestic real interest rate. For another, the Lucas critique would seem to be particularly relevant to a situation in which the inflation rate was continuously falling (or rising). Economic agents in such a situation would presumably come to anticipate further such changes rather than simply responding to them in an adaptive way. Despite the lack of realism, however, it is of interest to show the cost/price spiral that results from an extended period during which output is kept below potential.

Figure 8: Response to a Permanent Increase in the Real Cash Rate



Notes: These graphs show point estimates and 90 per cent confidence intervals of the responses of model variables over the 40 quarters following a permanent one percentage point increase in the real cash rate. The responses are shown as deviations from steady state and the confidence intervals are derived via a Monte Carlo simulation. '%' indicates a four-quarter-ended change.

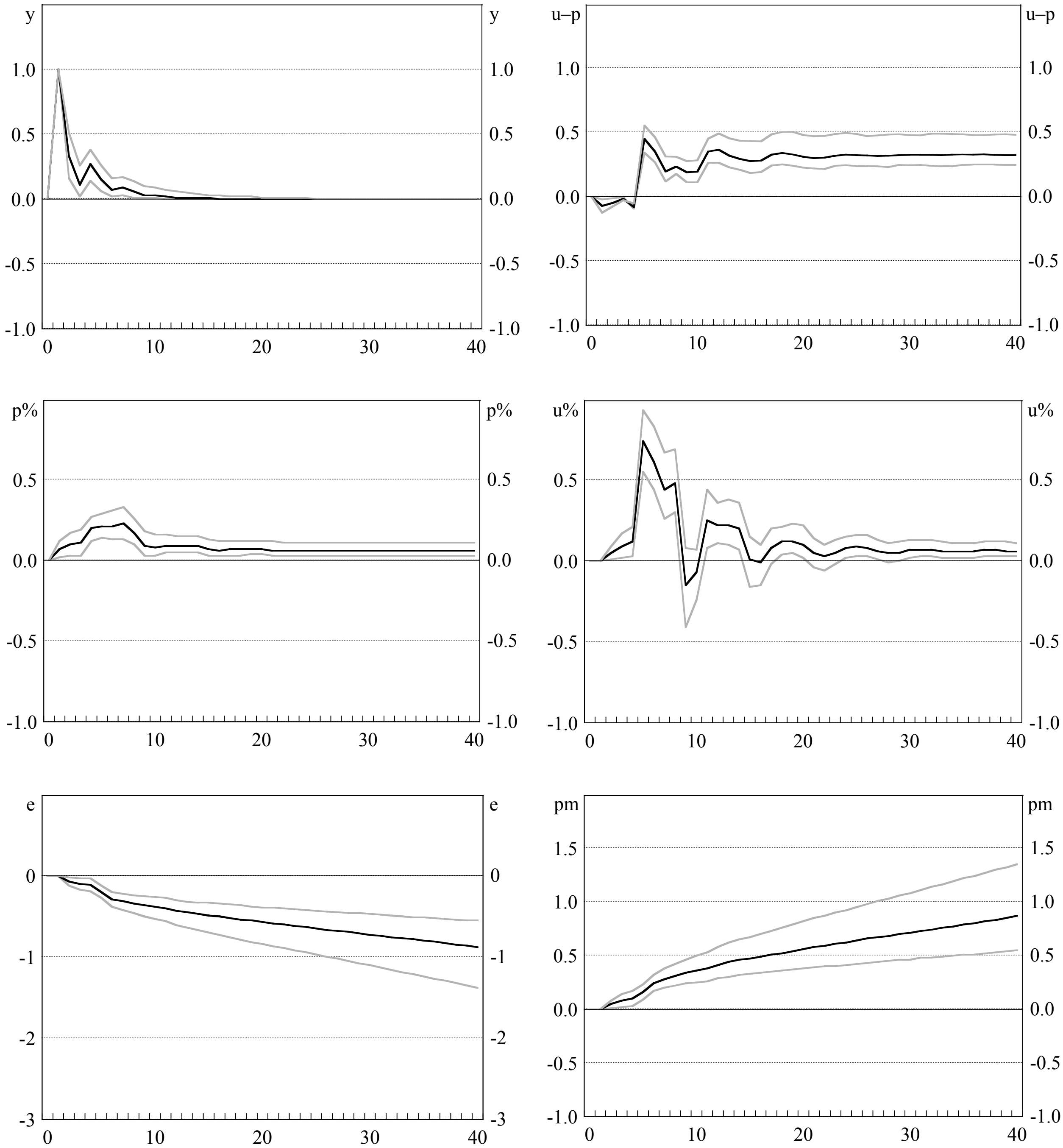
5.2 A One-off Shock to Output

Following a one-off shock, output remains above potential for several quarters while the shock slowly dissipates (see Figure 9). The temporarily higher level of output generates inflationary pressures, and leads to a higher ongoing rate of price and unit labour cost inflation. The level of real unit labour costs rises permanently. Rising domestic consumer prices generate continued nominal depreciation of the exchange rate, but the real exchange rate is unaffected by the shock to output.

5.3 A One-off Shock to Import Prices

A one-off one per cent shock to import prices has a limited effect on the model (not shown). The shock leads to a permanent rise in the levels of consumer prices and unit labour costs, but to only temporary increases in their rates of inflation. The increase in the level of consumer prices prompts an equivalent depreciation of the nominal exchange rate. Since real interest rates are kept constant by assumption, neither output nor the real exchange rate are affected by the shock.

Figure 9: Response to a Temporary Shock to Output



Notes: These graphs show point estimates and 90 per cent confidence intervals of the responses of model variables over the 40 quarters following a one per cent shock to the level of output. The responses are shown as deviations from steady state and the confidence intervals are derived via a Monte Carlo simulation. '%' indicates a four-quarter-ended change.

5.4 A One-off Shock to Unit Labour Costs

A one-off one per cent shock to unit labour costs permanently raises the rate of unit labour cost and consumer price inflation (see Figure 10). As with other shocks that raise the steady-state rate of inflation, there is a permanent rise in the level of real unit labour costs. Output and the real exchange rate are, however, unaffected by the shock. Reflecting the permanently higher rate of inflation, there is a persistent depreciation of the nominal exchange rate, and a permanently higher rate of import price growth.

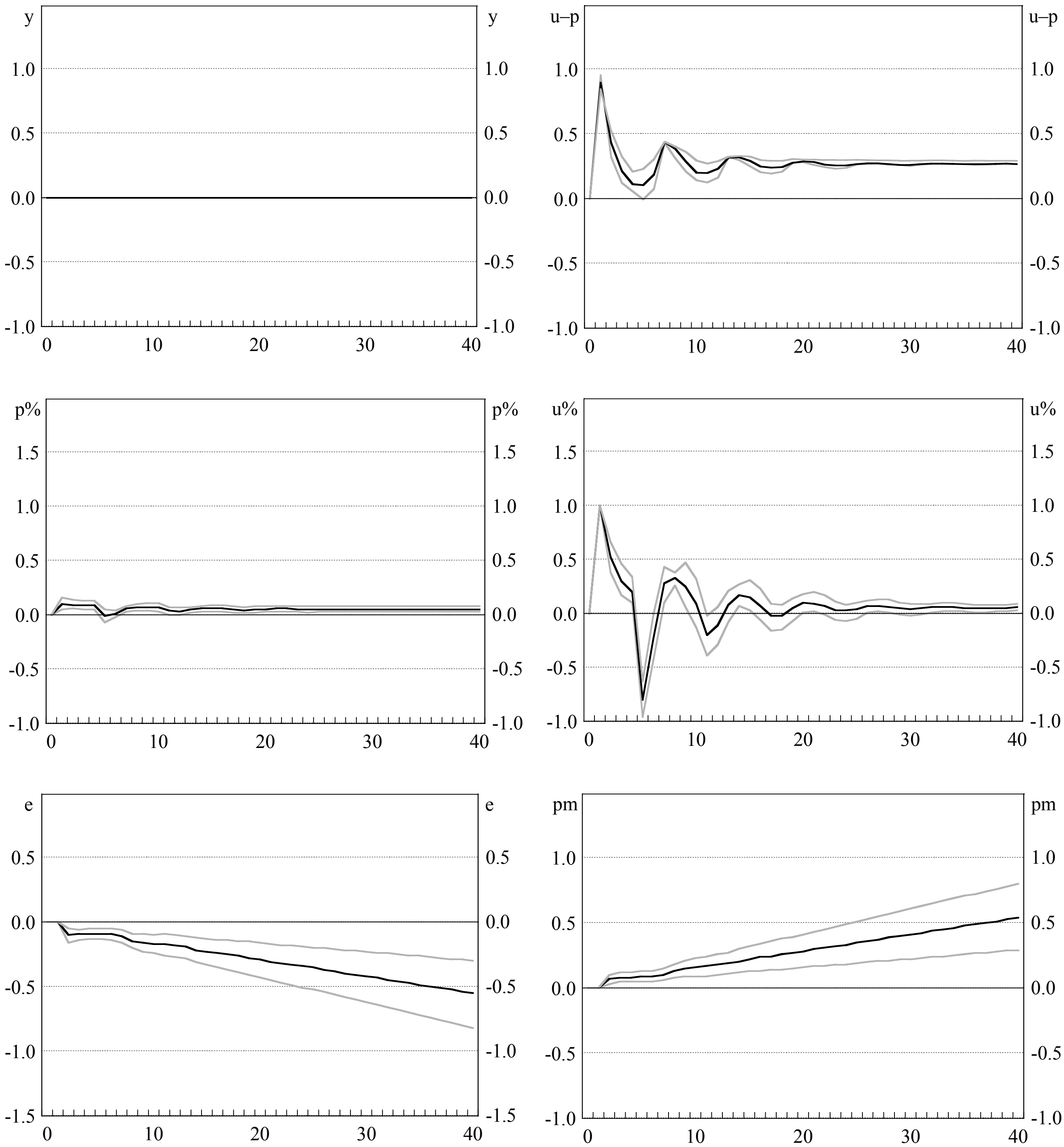
The one-off shock to unit labour costs generates oscillations around the new steady state which take several years to dissipate. This is also true of one-off shocks to consumer prices (see below). It seems implausible, however, that such shocks would have such long-lasting impacts on the economy. This feature of the model arises from the estimated dynamics in the unit labour cost equation. From a more fundamental perspective, it may be a consequence of the purely backward-looking inflation expectations that underlie these simulations (see Fuhrer 1997). If so, including a modest amount of forward-looking behaviour into the simulations might alleviate this problem. We leave this possibility as a topic for future research.

5.5 A One-off Shock to Consumer Prices

A one-off shock to consumer prices generates a temporary change to the rate of consumer price and unit labour cost inflation (see Figure 11).[15] As a consequence, no real variables in the system are permanently changed. Inflation returns to its pre-shock rate after about a year, while unit labour cost growth takes longer to adjust and oscillates around its steady state, as discussed above. The level of unit labour costs adjusts to match the shock to prices, preserving the level of real unit labour costs in the model. There is a one-off depreciation of the nominal exchange rate, and a corresponding rise in the level of import prices. Import price growth returns to zero after about a year.

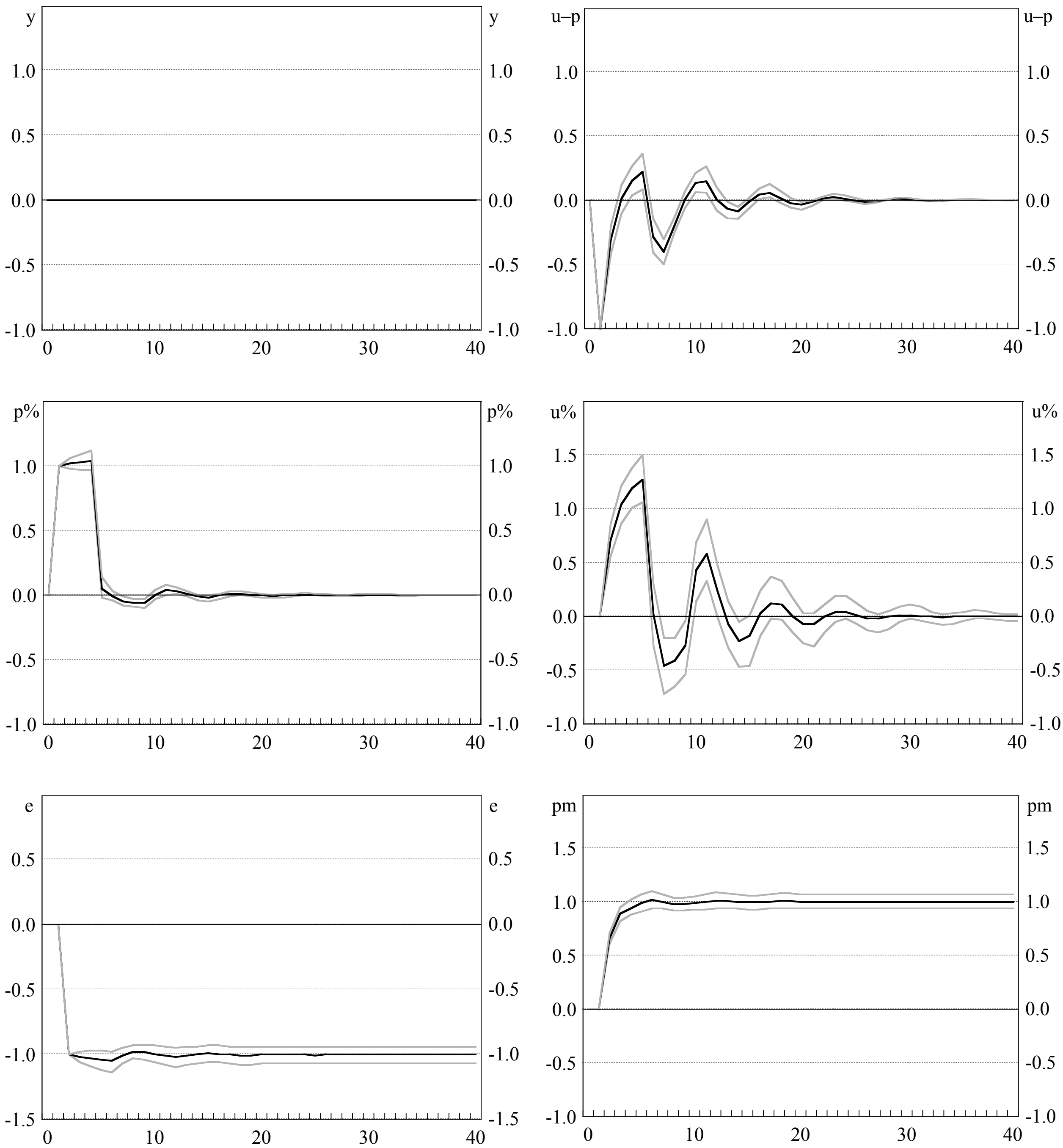
[15] This should be contrasted with the result from the previous unit-labour-cost shock, which led to a permanent change to the rate of inflation. From a purely technical perspective, this qualitatively different response to seemingly similar shocks is a consequence of different specifications in the two equations, with a long-run levels relationship present in the consumer price equation but absent from the unit labour cost equation.

Figure 10: Response to a Temporary Shock to Unit Labour Costs



Notes: These graphs show point estimates and 90 per cent confidence intervals of the responses of model variables over the 40 quarters following a one per cent shock to the level of unit labour costs. The responses are shown as deviations from steady state and the confidence intervals are derived via a Monte Carlo simulation. '%' indicates a four-quarter-ended change.

Figure 11: Response to a Temporary Shock to Consumer Prices



Notes: These graphs show point estimates and 90 per cent confidence intervals of the responses of model variables over the 40 quarters following a one per cent shock to the level of consumer prices. The responses are shown as deviations from steady state and the confidence intervals are derived via a Monte Carlo simulation. '%' indicates a four-quarter-ended change.

6. Summary

The aim of this paper has been to outline a small model of the Australian macroeconomy. The value of such a model lies in providing a simple framework with which to analyse and quantify short- to medium-term macroeconomic developments, including in particular, the effects of monetary policy on the economy. It also potentially aids in the construction of forecasts for some of the main macroeconomic aggregates of interest to policymakers.

The model is empirical and highly aggregate in nature and rests upon several stylised facts about the Australian economy over the past fifteen years. The estimated equations in the model encompass both short-run dynamics and longer-run steady-state relationships, with restrictions imposed in several of the equations to generate steady-state behaviour that accords with our theoretical expectations.

Dynamic simulations have also been included in the paper to illustrate the response of the variables in the model to changes in monetary policy and to a range of shocks. The model, which is sufficiently small that the results can be understood intuitively, represents a convenient way to summarise the main macroeconomic interrelationships in the Australian economy.

Appendix A: Covariance-correlation Matrix of the Equation Residuals

This appendix reports the variance-covariance and correlation matrices of the equations' estimated residuals. The upper triangle of Table A1 shows the correlation coefficients, the main diagonal the variances, and the lower triangle the covariances of the residuals.

Examining the diagonal of the table, the estimated residuals from the real exchange rate equation are by far the largest on average, while those from the consumer price equation are by far the smallest. The largest (absolute) correlation coefficient between estimated residuals across equations is that between the residuals from the output and unit labour cost equations, with a correlation coefficient of –0.29. This high (absolute) correlation occurs because output is used to construct unit labour costs. When fitted values from the output equation are used instead of actual output to generate the unit labour cost series, the resulting correlation coefficient between estimated residuals from the two equations is +0.25. Most of the other cross-equation correlations are very small.

Table A1: Covariance-correlation Matrix of Residuals

	Output	Real exchange rate	Import prices	Unit labour costs	Consumer prices
Output	**0.2384**	–0.0390	0.0860	–0.2873	–0.1025
Real exchange rate	–0.0513	**7.2714**	0.1292	–0.2372	–0.1388
Import prices	0.0365	0.3027	**0.7545**	0.0252	0.0898
Unit labour costs	–0.1198	–0.5460	0.0187	**0.7287**	–0.0485
Consumer prices	–0.0114	–0.0851	0.0177	–0.0094	**0.0518**

Appendix B: Testing for a Structural Break

Lucas (1976) pointed out that coefficients in reduced-form macroeconomic equations may change if there is a policy-regime shift, rendering the equations unreliable in the new regime. To assess the relevance of the Lucas critique for the model, we test for structural change in the equations, using 1993:Q1 as the break point (for reasons explained in the text). To do this, each of the equations is estimated (in its restricted form where appropriate) augmented by each variable multiplied by a dummy, which takes the value 1 from 1993:Q1 onward.

The results are shown in the following tables. In each case, the first column repeats the estimates presented in Section 3 of the paper. The second column reports the full-sample coefficients from the augmented regression and the third column reports the coefficients on the post-break dummy variables. Tests of joint significance of the coefficients on the post-break dummy variables are also shown in the tables.

There is little evidence of structural breaks in the equations in early 1993. Most of the post-break dummy variables are individually insignificant and the hypothesis that the post-break coefficients are jointly zero is easily accepted in each equation.

This suggests that the introduction of the inflation-targeting regime around 1993 has not led to significant changes in the estimated relationships. This gives us some confidence that we can use the equations to generate forecasts, and to conduct policy experiments, provided those experiments do not involve policy regimes that are ‘too far removed’ from the range of policies that have been operating over the estimation period.

Table B1: Australian Non-farm Output (a)

	Original equation	Augmented equation	
		Coefficients on full-sample variables	Coefficients on post-break dummy variables
Constant	–189.827***	–144.163	–212.543
	(50.263)	(138.576)	(165.484)
Real cash rate (lags 2 to 7) (b)	–0.052***	–0.056	–0.008
	{0.001}	{0.322}	{0.677}
Non-farm GDP (lag 1)	–0.389***	–0.302	–0.483
	(0.090)	(0.229)	(0.296)
US GDP (lag 1)	0.425***	0.327	0.498
	(0.104)	(0.277)	(0.342)
De-trended real share prices (lag 1)	0.045***	0.043***	0.014
	(0.010)	(0.013)	(0.029)
Non-farm GDP growth (lags 1 and 2) (c)	–0.201**	–0.154	–0.208
	(0.091)	(0.168)	(0.256)
OECD industrial production growth (lags 3 to 6) (c)	0.089**	0.031	0.201
	(0.043)	(0.102)	(0.141)
$\overline{R}^2$	0.506	0.497	
Standard error of the residuals	0.547	0.552	
F-test for joint significance of coefficients on post-break dummy variables		{0.528}	

Notes: (a) The equations are estimated by ordinary least squares using quarterly data over the period 1985:Q1–1999:Q3. Numbers in parentheses () are standard errors. Numbers in braces {} are p-values. ***, ** and * represent significance at the 1, 5 and 10 per cent levels. All variables in log levels are multiplied by 100 (so growth rates are in percentages).

(b) The mean coefficient is reported for the real cash rate to summarise the coefficients on its lags. The p-value is derived from an F-test of the joint significance of the lags.

(c) For these variables, the restriction that the coefficients on each lag are equal is accepted and imposed.

Table B2: Real Exchange Rate [(a)]

	Original equation	Augmented equation: Coefficients on full-sample variables	Augmented equation: Coefficients on post-break dummy variables
Constant	–2.019	13.059	–177.687
	(32.118)	(34.941)	(124.480)
Real exchange rate (lag 1)	–0.484***	–0.474***	–0.105
	(0.096)	(0.133)	(0.239)
Terms of trade (lag 1)	0.473***	0.429***	0.498
	(0.124)	(0.154)	(0.430)
Real interest rate differential (lag 1)	0.590**	0.734**	–1.328
	(0.252)	(0.340)	(1.268)
Terms of trade growth (lag 0)	1.290***	1.348***	–0.129
	(0.176)	(0.212)	(0.451)
$\overline{R}^2$	0.605	0.587	
Standard error of the residuals	2.819	2.883	
F-test for joint significance of coefficients on post-break dummy variables		{0.758}	

Note: (a) The equations are estimated by ordinary least squares using quarterly data over the period 1985:Q1–1999:Q3. Numbers in parentheses () are standard errors. Numbers in braces {} are p-values. ***, ** and * represent significance at the 1, 5 and 10 per cent levels. All variables in log levels are multiplied by 100 (so growth rates are in percentages).

Table B3: Import Prices [(a) (b)]

	Original equation	Augmented equation [(c)]	
		Coefficients on full-sample variables	Coefficients on post-break dummy variables
Constant	153.271***	150.309**	–10.833
	(40.275)	(65.194)	(74.013)
Change in the nominal exchange rate (lag 0)	–0.657***	–0.647***	–0.046
	(0.030)	(0.042)	(0.060)
Change in the nominal exchange rate (lag 1)	–0.010**	–0.111	0.036
	(0.046)	(0.074)	(0.084)
Change in foreign export prices (lag 0)	0.567***	0.244	0.605
	(0.212)	(0.405)	(0.424)
Change in foreign export prices (lag 1)	0.389*	0.605	–0.351
	(0.211)	(0.409)	(0.426)
Import prices (lag 1)	–0.335***	–0.329**	0.029
	(0.089)	(0.145)	(0.164)
Foreign export prices (lag 1)	0.335***	0.329**	–0.029
	(0.089)	(0.145)	(0.164)
Nominal exchange rate (lag 1)	–0.335***	–0.329**	0.029
	(0.089)	(0.145)	(0.164)
Trend	–0.108***	–0.102**	–0.012
	(0.026)	(0.041)	(0.050)
Dummy 1998:Q2–1999:Q3	–2.796***	–2.280***	–
	(0.696)	(0.421)	
$\overline{R}^2$	0.920	0.915	
Standard error of the residuals	0.934	0.960	
F-test for joint significance of coefficients on post-break dummy variables		{0.740}	

Notes: (a) The equations are estimated by ordinary least squares using quarterly data over the period 1985:Q1–1999:Q3. Numbers in parentheses () are standard errors. Numbers in braces {} are p-values. ***, ** and * represent significance at the 1, 5 and 10 per cent levels. All variables in log levels are multiplied by 100 (so growth rates are in percentages).

(b) Given the evidence of heteroskedasticity (see Table above), the standard errors reported are White heteroskedasticity-consistent standard errors.

(c) The assumption of purchasing power parity for traded goods prices is imposed both before and after the break.

Table B4: Unit Labour Costs [(a)]

	Original equation	Augmented equation [(b)]	
		Coefficients on full-sample variables	Coefficients on post-break dummy variables
Dummy 1985:Q1–1995:Q4	0.304 (0.537)	0.407 (0.792)	0.171 (0.702)
Four-quarter-ended rate of inflation (lag 1)	0.298*** (0.104)	0.317*** (0.110)	–0.217 (0.268)
Four-quarter-ended rate of unit labour cost growth (lag 1)	0.473*** (0.110)	0.476*** (0.117)	–0.141 (0.239)
Quarterly unit labour cost growth (lag 4)	–0.969*** (0.130)	–1.110*** (0.148)	0.751** (0.311)
(lag 5)	–0.316*** (0.116)	–0.361*** (0.140)	0.060 (0.274)
Output gap (lag 4)	0.528*** (0.114)	0.595*** (0.125)	0.188 (0.182)
Bond market inflation expectations	0.319*** (0.101)	0.324*** (0.117)	0.218 (0.232)
Average inflation over past three years (lag 1) (1996:Q1 to sample end)	0.231*** (0.084)	0.250** (0.117)	
$\overline{R}^2$	0.446	0.446	
Standard error of the residuals	0.909	0.886	
F-test for joint significance of coefficients on post-break dummy variables	–	{0.400}	

Notes: (a) The equations are estimated by ordinary least squares using quarterly data over the period 1985:Q1–1999:Q3. Numbers in parentheses () are standard errors. Numbers in braces {} are p-values. ***, ** and * represent significance at the 1, 5 and 10 per cent levels. All variables in log levels are multiplied by 100 (so growth rates are in percentages).

(b) In the augmented equation, the long-run vertical Phillips curve is imposed post 1996:Q1, as in the original equation. No restrictions are imposed on the coefficients of the post-break dummy variables.

Table B5: Consumer Prices [(a)]

	Original equation [(b)]	Augmented equation [(c)] Coefficients on full-sample variables	Augmented equation [(c)] Coefficients on post-break dummy variables
Constant	–0.541 (0.379)	–0.859* (0.462)	2.103 (1.329)
Consumer prices (lag 1)	–0.073*** (0.008)	–0.069*** (0.017)	–0.102 (0.082)
Unit labour costs (lag 1)	0.043*** (0.013)	0.034 (0.022)	0.125 (0.090)
Adjusted import prices (lag 1)	0.030*** (0.006)	0.036*** (0.007)	–0.022 (0.014)
Unit labour cost growth (lag 0)	0.103*** (0.032)	0.076* (0.041)	0.099 (0.083)
Adjusted import prices growth (lag 0)	0.032** (0.013)	0.046*** (0.016)	–0.031 (0.028)
Oil price growth (lag 1)	0.008*** (0.003)	0.003 (0.004)	0.006 (0.007)
Output gap (lag 3)	0.142*** (0.026)	0.165*** (0.033)	0.045 (0.121)
Change in the output gap (lag 0, 1 and 2) [(d)]	0.072** (0.032)	0.099** (0.041)	0.011 (0.101)
Dummy 1990:Q4	1.084*** (0.291)	1.279*** (0.324)	
Dummy 1991:Q1	–1.254*** (0.290)	–1.095*** (0.322)	
$\overline{R}^2$	0.880	0.879	
Standard error of the residuals	0.250	0.251	
F-test for joint significance of coefficients on post-break dummy variables		{0.490}	

Notes: (a) The equations are estimated by ordinary least squares using quarterly data over the period 1985:Q1–1999:Q3. Numbers in parentheses () are standard errors. Numbers in braces {} are p-values. ***, ** and * represent significance at the 1, 5 and 10 per cent levels. All variables in log levels are multiplied by 100 (so growth rates are in percentages).

(b) The standard errors reported for this equation are White heteroskedasticity-consistent standard errors.

(c) In the augmented equation, the long-run restriction of static homogeneity is imposed both before and after the break. This equation does not exhibit heteroskedasticity, so OLS standard errors are used.

(d) For these variables, the restriction that the coefficients on each lag are equal is accepted and imposed.

Appendix C: Adjusting for Tariffs and the Balassa-Samuelson Effect

The import price faced by importers has been affected by the declining rate of tariff protection on imports into Australia over much of the sample period. We therefore define

$$pm_t^{tar} = pm_t + tariff_t \tag{C1}$$

where $tariff_t$ is the average tariff rate on Australian imports (not its log), and the approximation $\ln(1+tariff) \approx tariff$ for small tariff rates has been invoked.

In the mark-up framework that forms the theoretical basis for the consumer price equation in the model, consumer prices are a mark-up over costs of production, that is, labour costs and the cost of imported goods. Assuming that the economy can be divided into traded and non-traded sectors, and that exportables are not consumed, the relevant costs are unit labour costs in the non-traded sector and import prices. In the long-run, therefore, we should have (up to a constant)

$$p_t = \delta u_t^{NT} + (1-\delta)pm_t^{tar} \tag{C2}$$

where u^{NT} is unit labour costs in the non-traded sector, and δ is the non-traded proportion of the economy. We make the common assumption, which underlies the Balassa-Samuelson effect, that the trend rate of labour productivity growth in the traded sector is higher than in the economy as a whole. As a consequence, unit labour costs rise more slowly in the traded sector than in the economy as a whole,

$$u_t^T = u_t - xt \tag{C3}$$

where u is economy-wide unit labour costs (as in the text) and x is the assumed difference between traded and economy-wide rates of productivity growth. Since $u_t = \delta u_t^{NT} + (1-\delta)u_t^T$, it follows from Equation (C3) that $\delta u_t^{NT} = \delta u_t + (1-\delta)xt$, which may be substituted into Equation (C2) to give

$$p_t = \delta u_t + (1-\delta)(pm_t^{tar} + xt)$$

or (C4)

$$p_t = \delta u_t + (1-\delta) pm'_t$$

where pm'_t are adjusted import prices, $pm'_t = (pm_t^{tar} + xt)$, which we use in estimation of the consumer price equation in the text. Since the consumer price equation includes a constant, and since $\Delta pm'_t = \Delta pm_t^{tar} + x$, we also use the $\Delta pm'_t$ series in place of the Δpm_t^{tar} series when the equation is estimated. As previously discussed, we restrict the sum of the coefficients on economy-wide unit labour costs and adjusted import prices to equal one (as required by Equation (C4)) when the consumer price equation is estimated.

We assume that the difference between the rate of labour productivity growth in the traded sector and the whole economy in Australia is the same as in the G7 economies. We therefore assume that x is given by the difference between consumer-price and export-price inflation in the G7, which is 2.1 per cent per annum over the period 1993:Q1–1999:Q3 (see Table 6).

As an alternative, it would be possible to estimate Equation (6) in the text by non-linear least squares assuming $pm'_t = (pm_t^{tar} + xt)$, and thereby generating an estimate for x. When this is done, the resulting point estimate, 2.0 per cent per annum, is remarkably close to the value calculated from the data on the G7 economies. This point estimate is, however, statistically insignificant.

Appendix D: Glossary and Data

Glossary

All variables are expressed in logs and multiplied by 100 except for interest rates, inflation rates, inflation expectations and the variable *tariff*.

p_t	Australian consumer prices
p_t^{*c}	foreign consumer prices
p_t^{*x}	foreign export prices
pm_t	import prices over the docks (in Australian dollars)
pm'_t	import prices adjusted for tariffs and the Balassa-Samuelson effect
π_t^e	inflation expectations, equal to the differential between nominal and indexed 10-year bond yields
π_t	three-year average of past inflation
r_t	real cash rate, defined as $r_t = i_t - (p_t - p_{t-4})$
r_t^*	foreign real short term policy interest rate
s_t	real share price accumulation index detrended using a Hodrick-Prescott filter with smoothing parameter of 1600
θ_t	real exchange rate (trade-weighted)
e_t	nominal exchange rate (against the G7)
$tariff_t$	average tariff rate on Australian imports
tot_t	terms of trade

i_t	nominal cash rate
u_t	unit labour costs
y_t	real non-farm output
y_t^p	potential real non-farm output
y_t^{US}	real US output
ip_t^{OECD}	OECD industrial production
oil_t	Australian dollar price of West Texas Intermediate crude oil per barrel

Data

The data used in the estimation were those available on 1 February 2000.

Real non-farm output

Definition: Real non-farm gross domestic product (chain volume, 1997/98 reference prices, seasonally adjusted).

Source: *National Income, Expenditure and Product*, ABS Cat No 5206.0

Real US output

Definition: Real US gross domestic product (chain volume, $US 1996 reference prices, seasonally adjusted).

Source: Datastream, USGDP…D

OECD industrial production

Definition: Industrial production of OECD members (constant prices, indexed to 1995=100, seasonally adjusted). Before 1995:Q1, movements of a narrower measure of industrial production have been spliced onto the series.

Source: Datastream, OCNOCIPDG 1985:Q1–1994:Q4
OCDOCIPDG 1995:Q1–1999:Q3

Nominal exchange rate

Definition: Australian dollar against a nominal GDP weighted-average of G7 currencies. Indexed to 1980 = 100.

Source: Reserve Bank of Australia, unpublished data

Real exchange rate

Definition: Australian dollar against a trade-weighted basket of major-trading-partner currencies adjusted by domestic and foreign consumer prices. Indexed to Mar 1985 = 100.

Source: Reserve Bank of Australia, unpublished data

Terms of trade

Definition: Terms of trade for goods and services. Indexed to 1997/98 = 100.

Source: *National Income, Expenditure and Product*, ABS Cat No 5206.0

Nominal cash rate

Definition: Prior to August 1996, cash market interbank overnight rate.

From August 1996 onwards, cash market 11am call rate.

Source: Reserve Bank of Australia *Bulletin*, Table F.1

Share price accumulation index

Definition: Accumulated index for share market returns on the Australian All Ordinaries, incorporating dividend yields. Indexed to 1989/90 = 100.

Source: Datastream, TOTMKAU(RI)

Real share price accumulation index

Definition: Share price accumulation index deflated by Australian consumer price index.

Consumer price index (CPI)

Definition: Acquisitions consumer price index. Indexed to 1989/90 = 100.

Source: *Consumer Price Index*, ABS Cat No 6401.0

Unit labour costs

Definition: Non-farm unit labour costs per hour per wage and salary earner. Indexed to 1989/90 = 100.

Total non-farm labour costs (wage and salary earners) per hour divided by productivity per hour in the non-farm sector.

Source: *National Income, Expenditure and Product*, ABS Cat No 5206.0.

Non-wage labour costs data obtained by special request from the ABS.

Import prices

Definition: Implicit price deflator for merchandise imports, excluding fuels and lubricants, civil aircraft and Reserve Bank of Australia imports of gold. Indexed to 1989/90 = 100.

Source: *National Income, Expenditure and Product*, ABS Cat No 5206.0.

Reserve Bank of Australia imports of gold data not publicly available.

Tariff rate

Definition: Customs duty receipts divided by the value of merchandise imports (excluding fuels and lubricants, civil aircraft and Reserve Bank of Australia imports of gold). Seasonally adjusted.

Source: Australian Customs Service

Foreign export prices

Definition: Nominal GDP weighted-average of G7 export price indices. Indexed to 1990 = 100.

Source: Export price indices from Datastream.

Foreign consumer prices

Definition: Geometric import-weighted average of core consumer prices of G7 countries. Calculated as the ratio of nominal and real G7 import weighted exchange rates. Indexed to 1989/90 = 100.

Source: Reserve Bank of Australia, unpublished data

Foreign real interest rate

Definition: Nominal GDP weighted-average of short-term policy interest rates of the US, Germany and Japan (G3) less four-quarter-ended core inflation in each country.

Source: Interest rates: Reserve Bank of Australia *Bulletin*, Table F.11.
For the German repo rate prior to 1999: Datastream, FOOIRGRR.

Core Inflation: Datastream, USCPXFDEF, JPCPXFFDF, EMESHARMF, EMCP....F

Bond market inflation expectations

Definition: Yield on the conventional Australian 10-year bond less the yield on Treasury capital indexed bonds of similar maturity.

Before 1985:Q3, movements in the Debelle and Vickery (1997) inflation expectations series have been spliced onto this series.

Source: Conventional 10-year bond yield: Reserve Bank of Australia *Bulletin*, Table F.2

Treasury capital indexed bond yields: unpublished data collected by Reserve Bank of Australia. Daily reading available on Reuters page RBA29.

Oil price

Definition: Australian dollar price of West Texas Intermediate crude oil per barrel. Calculated using the US dollar price per barrel of West Texas Intermediate crude oil and the AUD/USD exchange rate. Indexed to 1989/90=100.

Source: Bloomberg, nearest contract price CL1 CMDTY.

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