ARTICLES

Introducing KITT: The Reserve Bank of New Zealand new DSGE model for forecasting and policy design

Kirdan Lees

The Reserve Bank of New Zealand has developed a new core macroeconomic model to replace the existing FPS (Forecasting and Policy System) model. KITT (Kiwi Inflation Targeting Technology), the new model, advances our modelling towards the frontier in terms of both theory and empirics. KITT reconfirms the Reserve Bank's commitment to having a theoretically well-founded model at the heart of the monetary policy process. This article provides context about the reasons for the move to the new model, and an overview of the model itself. KITT builds a rich picture of the macroeconomic economy from specific assumptions about the microeconomic behaviour of households and firms that interact in several goods markets. The article illustrates the structure of the model, how this structure determines the way in which shocks or unexpected events propagate through the economy, and the role of the model in the forecast process.

1 Why the Reserve Bank decided to build KITT

Quantitative analysis using macroeconomic models has long been an important tool for monetary policy analysis. Central banks around the world are both customers and developers of medium to large scale macroeconomic models and have been for some time. In the RBNZ's case we have been building and using these models since 1971 (see Deane 1971) and there have been many developments since (see for example, Gallacher et al., 1977; Spencer, 1979; Brooks and Gibbs, 1991 and Black et al., 1997). Since 1997, the Reserve Bank has used and continued to develop the FPS (Forecast and Policy System) model as a core macroeconomic model for informing and organising the forecasting process. The development of the KITT model carries on this modelling tradition.

Modern macroeconomic modellers develop their models from a set of microeconomic assumptions regarding the firms, households and policymakers that populate the economy. These models are DSGE (Dynamic Stochastic General Equilibrium) models and specify very particular assumptions. Relative to earlier DSGE models, the new generation of multi-sector macroeconomic models contains sufficient richness to model the interactions between households and firms in the different sectors of the New Zealand economy for forecasting and policy purposes. "General equilibrium" models work with the assumption that markets clear across a range of sectors. The "stochastic label" refers to the shocks that hit the economy. Unlike static general equilibrium models, "dynamic" general equilibrium models explicitly map the transition across steady-state or long-run equilibria.

There are a number of reasons why the Reserve Bank decided to build a DSGE to replace the existing macroeconomic model. It had been ten years since the last model development (FPS) and since that time there has been extensive development of monetary theory and the building of a consensus in monetary theory. Woodford (2009) characterises this consensus as founded on five principles:[1] (i) a coherent set of intertemporal general equilibrium microeconomic foundations; (ii) that quantitative policy advice requires an econometrically validated structural model; (iii) that expectations should be modelled as endogenous, and crucially, endogenous with respect to monetary policy; (iv) that real disturbances and nominal rigidities are an important source of economic fluctuations; but critically (v) that monetary policy is effective in controlling inflation within the economy. FPS has some but not all of these features; KITT embodies all of them.

Multi-sector models develop the behaviour of prices from the costs faced by firms in tradable, non-tradable, and export sectors of the New Zealand economy. Explicit production functions specify the factors that drive inflation in each sector. Importantly, KITT assumes that it is firms' marginal costs that drive pricing decisions. Marginal costs increase

[1] Woodford (2003) and Gali (2008) provide a more detailed treatment of these theoretical principles.

either when the costs of firms' inputs increase, or when firms expand production to meet rising demand. While FPS told an aggregate story about how increases in demand for a single good translates into increases in inflation, KITT can tell a richer multi-sector story where inflation is determined by both a demand and supply-side story. Finally, agents' expectations are rational, which ensures that a consistent microeconomic story underpins every forecast story developed with the model. These models can explain the data relatively well and are useful for forecasting purposes.

In addition to advances in macroeconomic theory, significant breakthroughs in Bayesian econometrics and improved computing power allow the new suite of DSGE models to be estimated more easily than before. Further, since the development of FPS, fundamental advances have been made in the techniques for solving these models for rational expectations behaviour.

Several central banks (for example, the Bank of England, the Riksbank, the Bank of Canada, the Central Bank of Chile and the Norges Bank) have successfully developed and implemented DSGE models (see Murchison and Rennison, 2006; Harrison et al., 2005; Medina and Soto, 2006; and Adolfson et al., 2007). When developing our DSGE model, the Reserve Bank used the experience of other central banks. In addition, our visitor programme brought in a number of academics and central bankers who enhanced our learning.

The following section discusses how KITT was built, before turning to an overview of the structure of KITT in section 3. Section 4 discusses the operation of the model within the policy and forecasting environment. Section 5 makes some concluding comments.

2 How the Reserve Bank built KITT

Naturally, there are many aspects of models that do not translate well across economies. Rather than take an existing off-the-shelf model, the decision was made early on to develop the new macroeconomic model in-house. This allowed our in-house modellers to build on the stock of knowledge formed around the existing FPS model, and in turn, to develop human capital, in both macroeconomic theory and estimating models using Bayesian techniques.

Model builders of today have a substantive dataset on which to evaluate and calibrate models from the post 1990 inflation targeting period. Data from this period should informed the model more directly than was the case for the calibrated FPS model.

The performance of the modelling project was evaluated against four overarching objectives:

1. A model estimated on data over the inflation targeting period;
2. The capability to address uncertainty by producing "fancharts", that is, explicit probability distributions about particular future economic events;
3. The capability to tell sufficiently rich economic stories, which capture most of the policy discussions that inform monetary policy; and
4. A model that can incorporate judgement easily and effectively and, in practice, prove useable for regular forecasting and policy formulation.

Together with a strong emphasis on developing a theoretically consistent DSGE model, these objectives provided the context for a single overarching objective: "to build a model worthy of replacing FPS". We succeeded in building a model that satisfied these objectives.

3 Model structure

3.1 Overview

KITT's structure is based on four broad productive sectors that summarise the New Zealand economy: non-tradable good producers; tradable good producers, producers of residential investment (used to construct houses that provide a stream of housing services); and exporters. Each sector produces a particular good using a particular combination of inputs. Each good is demanded by domestic households with the exception of export goods that are assumed to be only available for consumption by foreigners. Figure 1 details the production structure of the model with the boxes in red depicting the goods that sum to Gross Domestic Product.

Figure 1
KITT production structure

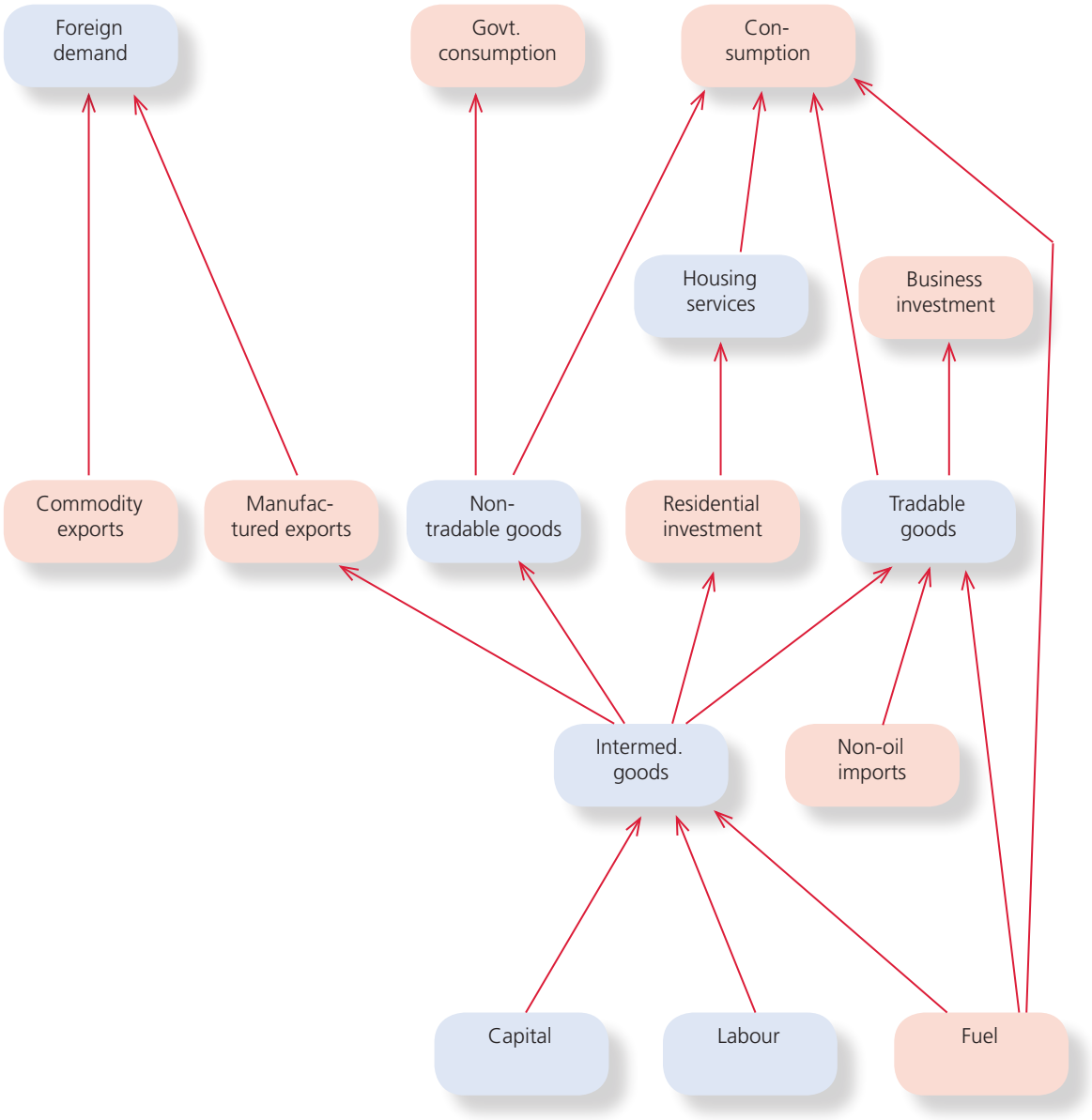


Figure 1 shows that KITT models the export sector as being comprised of two goods: (i) manufactured exports (for example, prams, luxury yachts, ship mooring systems or conveyor belts), that we assume require an intermediate good for production; and (ii) commodity exports (for example logs, meat products and dairy powder) that we assume do not require the intermediate good for production and are thus relatively isolated from the domestic economy, but responsive to movements in the exchange rate and foreign price of New Zealand export goods.

Inflation can be decomposed into inflation in tradable goods that can, in principle, be traded internationally, and inflation in non-tradable goods, that cannot be traded. This decomposition underpins much of the Reserve Bank's modelling and forecasting programme (see Matheson 2006, for supporting evidence for this strategy). Furthermore, within KITT we assign a specific role for fuel, which is both a consumption good and an input into the production of the intermediate good and tradable good. Within the model, the domestic fuel market is assumed to be a perfectly competitive market where firms simply pass on to consumers changes in the costs of importing fuel – the international price of oil and the New Zealand exchange rate.

3.2 Households

We make a number of specific assumptions regarding the consumption patterns of households to help match the patterns in macroeconomic data and consumption. We assume that households don't like working. However, they gain utility from consumption, but only relative to the level of consumption in previous periods. This makes it difficult to rapidly switch consumption patterns in response to changes in household income and wealth and the price of consumption goods. This assumption helps us match the behaviour of aggregate consumption, and is relatively standard across several macroeconomic models.

We use a technical assumption (Cobb-Douglas aggregation of the different consumption goods) that in the long run there is a unit elasticity of substitution such that households increase the quantity of each good consumed in the same proportion as increases in income. This ensures that the nominal shares of production of the different types of goods are constant, allowing us to match the persistently higher inflation observed in non-tradable goods relative to tradable goods, over the past decade.

However, in the short-run we allow households to form habits over not just their intertemporal aggregate consumption decision, but over their decisions and preference to consume the different consumption goods, for example, the preference to consume non-tradable goods relative to tradable goods. This reduces the ability of consumers to rapidly switch between types of consumption goods – consistent with not only disaggregated consumption data, but reflected in the behaviour of non-tradables and tradables inflation.

Households derive utility from consuming a mix of four consumption goods: non-tradable goods; tradable goods; housing services; and fuel. Households have a preference that the set of goods that are consumed each quarter consist of at least some of each good.

To fund their expenditure, households receive income from a number of sources. They receive income from their labour, a return from business capital that the households are assumed to own and firms' profits (that are assumed to be returned to households in their entirety). Further, the household budget constraint is affected by the household debt position and debt servicing costs.

> Inflation is decomposed into inflation in tradable goods, that can, in principle, be traded internationally, and inflation in non-tradable goods, that cannot be traded.

3.3 Firms

A stylised fact of the New Zealand business cycle is an observed negative correlation between inflation in the tradable good sector and inflation in the non-tradable sector. This is at least partly driven by the behaviour of the exchange rate over the cycle. The exchange rate tends to appreciate when demand in the non-tradable sector is strong, making the cost of importing the tradable good fall. To match the behaviour of prices over the business cycle, KITT assumes that both tradable goods and non-traded goods are produced using an intermediate good in their production. The intermediate good (steel for example) is not available for direct consumption by households but is produced by combining labour, capital and fuel in the economy. Changes in the prices of these inputs then affect prices throughout the economy. Finally, the production of tradable goods involves the use of an extra oil input (above the fraction of oil that goes into the production of the intermediate good) to transport the tradable good to suitable retail outlets.

The model contains a housing sector where the existing housing stock is used to produce a housing service for domestic households. The housing stock is developed over time through the addition of residential investment.[2] The addition of the housing sector helps us develop a story

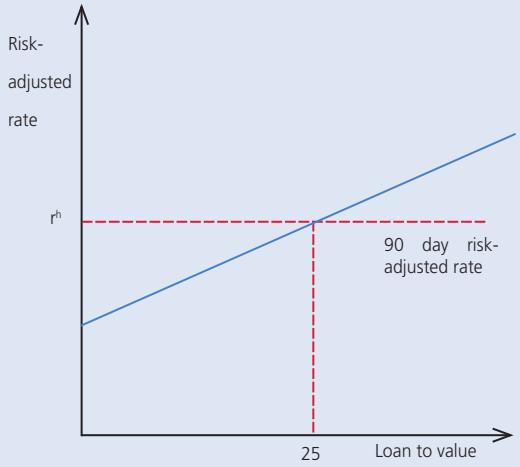
[2] **Implicitly, KITT assumes that owner occupied dwellings are simultaneously owned by a householder that buys back the flow of housing services from that dwelling.**

Box 1

The Housing Sector

Crucial for understanding the impact of the housing sector within the model is the role of the financial intermediary. This intermediary borrows funds from foreign households at the 90 day bank bill rate (with the implication that it is the 90 day interest rate that helps determine the exchange rate and New Zealand's current account position) and lends to households at the risk-adjusted rate that at times includes a premium for the extent of any borrowing. This premium is motivated by similar models where the financial intermediary must incur some cost to observe the balance sheet of households that may default on their loans. The expected costs to a financial intermediary of a defaulting household are increasing in the size of the loan relative to the amount of collateral.

The financial intermediary takes on an important role in the model. Because the magnitude of the premium is a function of the household's borrowing, relative to its assets, increases in house prices reduce the magnitude of the premium, lowering the interest rates facing the household and thus fuelling consumption and concomitantly, inflation within the model. The presence of financial intermediation allows for a direct channel from house prices to consumption and inflation. The figure below shows the relationship between the loan-to-value ratio and the risk-adjusted interest rate. When the loan-to-value ratio is above 25% the risk-adjusted rate is higher than the 90 day rate. Conversely if the loan-to-value ratio falls below 25% the risk-adjusted rate is lower than the 90 day rate. We use 25% since this approximates New Zealand's net foreign asset position relative to the existing housing stock.



about how increases in house prices impact on inflation. The recent cycle in house prices and concomitant increases in household consumption were a key driver of the most recent cycle. Box 1 explains in more technical detail, the operation of the housing sector.

3.4 Inflation

The interaction of firms and households forms the markets in which prices for the goods in the economy are determined. In terms of New Zealand's Consumers Price Index, (CPI) these markets are non-tradable goods, tradable goods, construction or residential investment goods, and fuel.

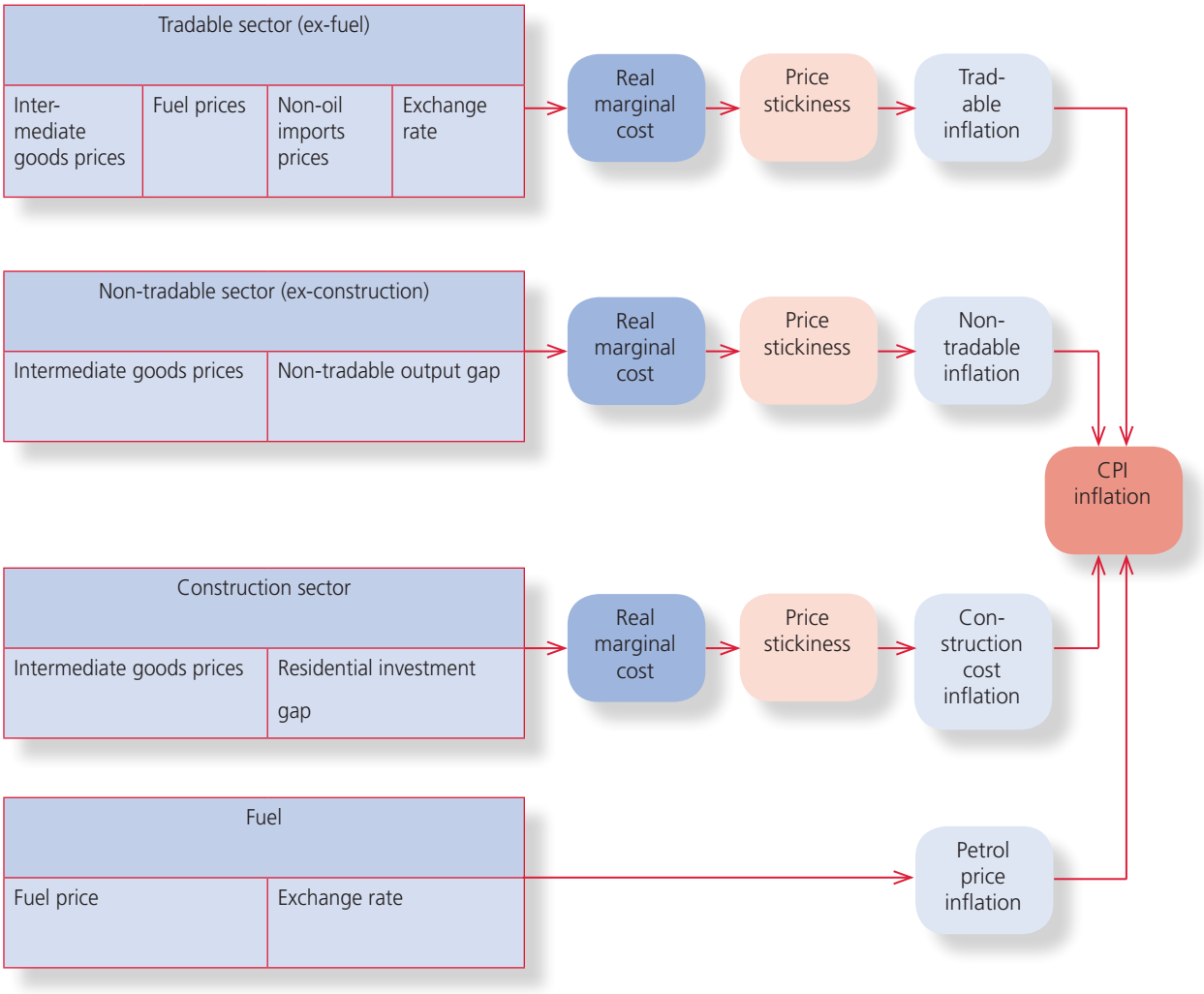
However, this system is not sufficient to generate inflation processes that would mimic the dynamics we observe in practice. In particular, prices would be perfectly flexible and market forces would rule out persistent inflation. One key, repeated empirical finding is that prices are not perfectly flexible, implying monetary policy has effects on the real economy in the short run.

To generate some inertia or stickiness in prices, we assume that firms that operate in the non-tradable, tradable, and housing sectors operate in a monopolistic competitive environment. These firms would like to set their price in each period where marginal revenue equates with marginal cost, but face costs of adjusting prices in each period.[3] This implies their markup over marginal cost varies over the cycle. In the absence of monopolistic competition, firms operating within a perfectly competitive environment would be insolvent if faced with adjustment costs that imply pricing below the breakeven point where price equals average variable cost. Figure 2 summarises the factors that determine inflation within KITT.

[3] **Note that introducing monopolistic competition prevents firms from capturing the entire market share of the sector by pricing at a point where the price is less than marginal cost.**

Figure 2

Inflation determination in KITT



On the right-hand side of the diagram, we can see that consumer price inflation is determined by a weighted summation of tradable good inflation, non-tradable good inflation, construction costs inflation and petrol price inflation. Since the observed petrol price displays relatively little inertia, we do not require the assumptions of marginal competition and sticky prices to generate the observed behaviour of petrol price inflation in the data. However, tradable inflation, non-tradable inflation and construction costs inflation are each determined by the degree of price stickiness in each sector and the marginal costs producers are confronted by in each sector.

The left-most boxes depict the factors that determine firms' marginal costs in each sector. Turning to the top box that determines cost in the tradable good sector we can see that the intermediate good price and the price of fuel helps determine marginal cost in the tradable good sector since these are key production inputs. Furthermore, tradable good production takes an imported good and effectively readies it for domestic retailing, and is thus subject to increases in the underlying price of the imported good on the world market and fluctuations in the New Zealand dollar. Importantly, we assume that for each individual firm, the production of the tradable good has constant returns to scale such that firms can scale production up and down without changing the marginal cost of production. Individual firms can thus meet additional demand for tradable goods without generating additional inflation.

However, the second box in figure 2 shows that this assumption does not hold for the production of non-tradable goods. Marginal cost in the non-tradable sector is determined by both the price of intermediate goods and the non-tradable output gap.

Marginal cost in the non-tradable sector is determined by both the price of intermediate goods and the non-tradable output gap.

Since we assume that there are diminishing returns to scale in the non-tradable goods sector, firms' costs – and their marginal costs – increase to meet additional demand. Additional demand for non-tradables directly generates inflationary pressure in the non-tradables sector.

The third box on the left of figure 2 shows the breakdown of marginal cost in the construction sector. While construction costs inflation comprises 5.5 percent of the consumer price index it is important for understanding the increases in aggregate consumer price inflation associated with the increase in house prices over the most recent cycle. Within this sector we assume that firms face diminishing returns to production such that meeting excess demand for residential investment – required to provide the housing stock necessary to provide households with the stream of housing services, requires increasing firms' marginal cost, generating inflationary pressure.

Finally, we choose to model the production of a retail petrol good as simply a combination of the fuel price (adjusted for the tax component) with the exchange rate. Production is constant returns to scale with firms simply passing on changes in fuel and the exchange rate to final retail petrol prices, which we model with a very simple error correction mechanism.

3.5 Policy setting and the transmission mechanism

Within the model, monetary policy responds to future inflationary pressure. This behaviour is captured with a simple rule that also favours smaller interest rate moves over larger movements – everything else equal. Equation (1) below shows that the rule responds only to a small number of arguments: the deviation of inflation from the inflation target $(E_t\pi_{t+1} - \bar{\pi})$; and last period's interest rate (i_{t-1}). The appropriate responsiveness to these terms (measured by the parameters and is a constant to capture the average real interest rate) reflects the requirements of the Policy Targets Agreement to avoid "unnecessary instability in output, interest rates and the exchange rate".

$$i_t = \rho i_{t-1} + (1-\rho)\left(\bar{r} + \bar{\pi} + \kappa(E_t\pi_{t+1} - \bar{\pi})\right) + \varepsilon_t \qquad (1)$$

These policy rates are transmitted through the economy via four key transmission channels: (i) the exchange rate channel; (ii) an asset price channel; (iii) the demand channel; and (iv) an expectations channel. Similar to FPS, the exchange rate channel of transmission plays a powerful role within KITT. The exchange rate directly helps determine inflation in the petrol and tradable sectors, and New Zealand's export earnings. Moreover, in addition to the impact on exports, exchange rate appreciations have a powerful expenditure switching effect that promote importing and consumption of domestic goods, dependent on the position of the exchange rate in the cycle.

The total effect of these channels gives a powerful role to monetary policy. Monetary policy is effective in controlling inflation. The role for fiscal policy within the model is particularly simple, operating in the pure model form as an autoregressive process that imparts inflationary pressure in the model. This reflects the motivation for the construction of the DSGE model to provide a tool for setting monetary policy to control medium term inflationary pressure, rather than setting fiscal policy. In the projection context, the paths for fiscal variables are set exogenously.

Exchange rate channel

To determine the impact of policy on the exchange rate almost all DSGE models, like KITT, use variations on the uncovered interest rate parity principle. The strict form of the uncovered interest rate parity condition assumes that the expected change in the exchange rate moves one-for-one with the difference between domestic and foreign interest rates. On a theoretical level, the assumption is particularly appealing because it implies the existence of a no arbitrage condition, such that investors move funds freely to take advantage of yield to the point where expectations of exchange rate movements affect the future gains from yield differentials.

On an empirical level, the theory has been widely rejected and provides a very unrealistic description of the exchange rate as a variable that jumps rapidly in the presence of new information. Instead, the exchange rate tends to move with some persistence. To reflect this, many central banks (for example the Riksbank and the Bank of Canada) have introduced variations on uncovered interest rate parity to avoid excess "jumpiness" or volatility in the exchange rate. This is also true of KITT where we assume that a fraction of agents are backward-looking and simply use last period's UIP condition to determine the expected change in the exchange rate. This term could be interpreted as an endogenous deviation within the exchange rate equation, reflecting the need for an adjustment to the general equilibrium framework to account for a particular puzzle that DSGE, and in fact a broad class of models, have failed to account for.

Asset price channel

While box 1 shows how movements in asset prices impact on the risk-adjusted interest rates households face, movements in interest rates also affect asset prices. Both the housing stock and capital stock represent key assets that deliver a rate of return. When current and expected interest rates are high, households discount the future by more. This lowers the demand and hence the price of assets within the model. Since there are costs to installing investment, investment will not equal the desired change in the capital shock instantaneously so that investment becomes responsive to the interest rate and displays some persistence.

The demand channel

Within KITT, households optimise their intertemporal decision based on their expectation of the entire future path of interest rates. That is, not only do households base their decision to consume today or tomorrow (setting the marginal utility from extra consumption equal to the marginal benefit from saving) on the current period's interest rate, this logic holds for all future periods. Importantly, this implies that households' beliefs about longer term rates impact on today's consumption decision. Within the model, longer rates and indeed the entire term structure reflects market participants' beliefs about future short rates. In comparison FPS used a combination of short rates and long rates to determine both consumption and investment.

Monetary policy is effective in controlling inflation.

The expectations channel

Expectations are critical to understanding all the transmission channels in the model. Households decide whether to consume today with reference to expected future conditions. Firms' investment decisions hinge crucially on the evolution of comparisons of expectations regarding the future economic conditions. Furthermore, expectations directly impact on the key inflation equations in the model. That monetary policy reacts directly to inflationary pressure reflects the importance of keeping expectations of future inflation closely anchored to the target inflation rate. Throughout the model, agents are assumed to be rational and to form expectations about future variables using current information in a manner consistent with the model. Critically, this includes the manner in which monetary policy is formed (see equation 1) such that households and firms internalise into their own decision-making and expectation formation, how responsive monetary policy is to inflation developments. This principle is consistent with Bernanke and

Woodford (1997) who advise policymakers to be informed by a structural model where agents form expectations based on that same structural model. Within this context, survey measures of inflation expectations provide a useful cross-check on any misspecification in the KITT model.

4 Model estimation and evaluation

4.1 Estimation

One of the key motivating factors behind replacing the existing forecasting model was to utilise the macroeconomic data more formally to estimate or inform the model parameters within KITT. In contrast, FPS is a calibrated macroeconomic model, where the values for the parameters in the model are simply chosen to produce a model that fits the data "well", in the judgement of the modeller, where "well " is defined loosely if at all.

KITT is estimated on data from the first quarter of 1992 until the last quarter of 2008. This period defines a relatively stable inflation targeting regime. Typically most empirical work at the Reserve Bank eschews using data prior to the formal adoption of inflation targeting in February 1990 and typically favours removing the recession in the early 1990s associated with the transition to a lower inflation rate. Table 1 in the appendix lists the 27 data series we use to estimate the model. It is worth noting that for estimation and forecasting purposes not all model concepts require a directly observable data counterpart. However, matching model concepts (for example, non-tradable consumption) to directly observable counterparts helps us establish (or more technically, identify) the appropriate parameter values.

We estimate the model using Bayesian techniques. These techniques formally combine prior beliefs about the model (that may come from alternative information sources such as microeconomic data, anecdotal evidence, cross-country studies, strong beliefs about particular model properties such as a negative correlation between tradable and non-tradable inflation) with the data, producing distributions of parameter estimates that reflect both the data and the set of prior beliefs. These distributions of parameter estimates provide a natural and particularly useful device for characterising uncertainty, not readily available from a calibrated model.

In addition to the formal estimation of the model, we also employed a number of informal cross checks on the estimated model. Our modelling approach weights explanation of all the series in KITT we use to estimate the model equally. However, implicitly we place a high emphasis on a model that explains the behaviour of key macroeconomic variables, particularly inflation, in addition to output, interest rates, and the exchange rate – the variables that enter clause 4b of the Policy Targets Agreement.

4.2 Model properties

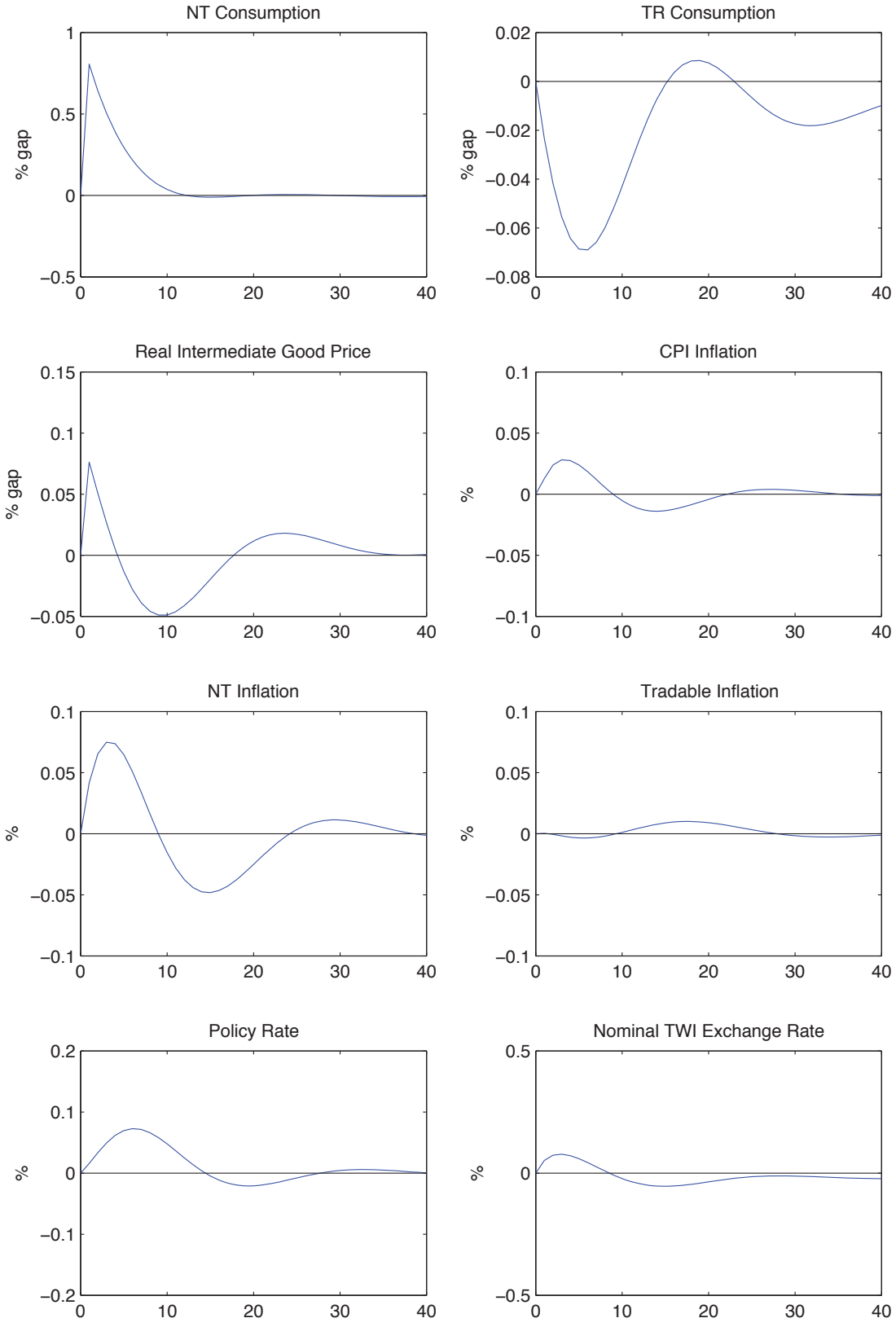
A sense of the properties of the model can be gained from looking at the impulse responses from the model, that is, the manner in which macroeconomic variables respond to the shocks within the model. For this exercise we present two of the 27 possible shocks that can be analysed in the model. Since the model is structural, these shocks will have a structural interpretation. This section presents two shocks: (i) a shock to the level of non-tradable goods demand by households; and (ii) a wage-cost push shock.

Expectations are critical to understanding all transmission channels in the model.

Figure 3, overleaf, depicts the impact of the non-tradable consumption shock to a selection of key macroeconomic variables. The panel in the top-left of the diagram shows the impact of the shock which increases non-tradables consumption. To meet increases in demand firms increase production but the decreasing returns to scale assumption implies the expansion of output increases marginal cost. The real price (deflated by the CPI) of the intermediate good increases, generating non-tradable inflation. This generates an increase in consumer price inflation and the policy rate increases in response. Tradable inflation follows a relatively

Figure 3

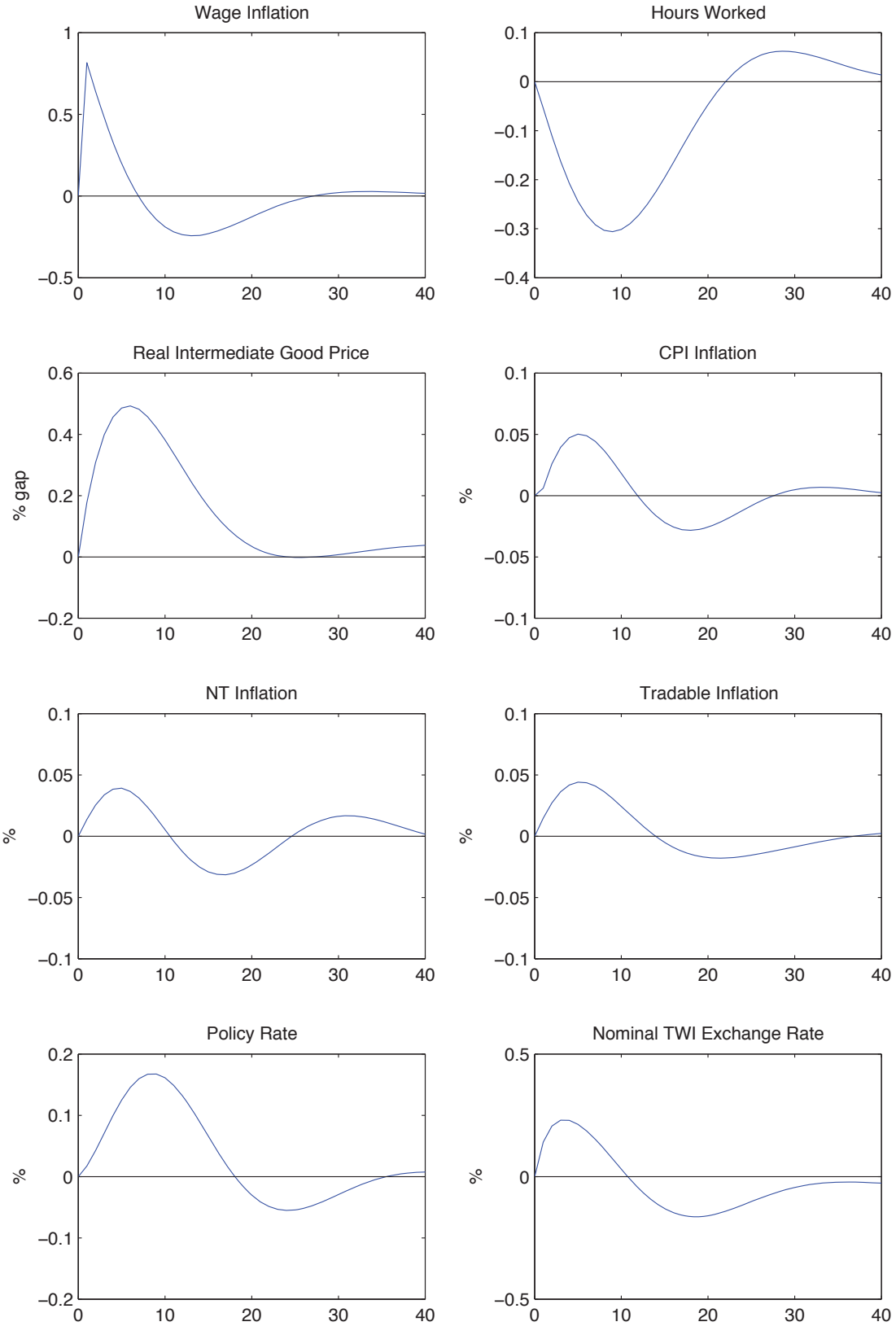
Non-tradable consumption shock



Note: The policy rate is expressed in percentage point terms, with 0.1 percentage points equivalent to 10 basis points. Horizontal axis units are quarters.

Figure 4

Wage cost shock



Note: The policy rate is expressed in percentage point terms, with 0.1 percentage points equivalent to 10 basis points. Horizontal axis units are quarters.

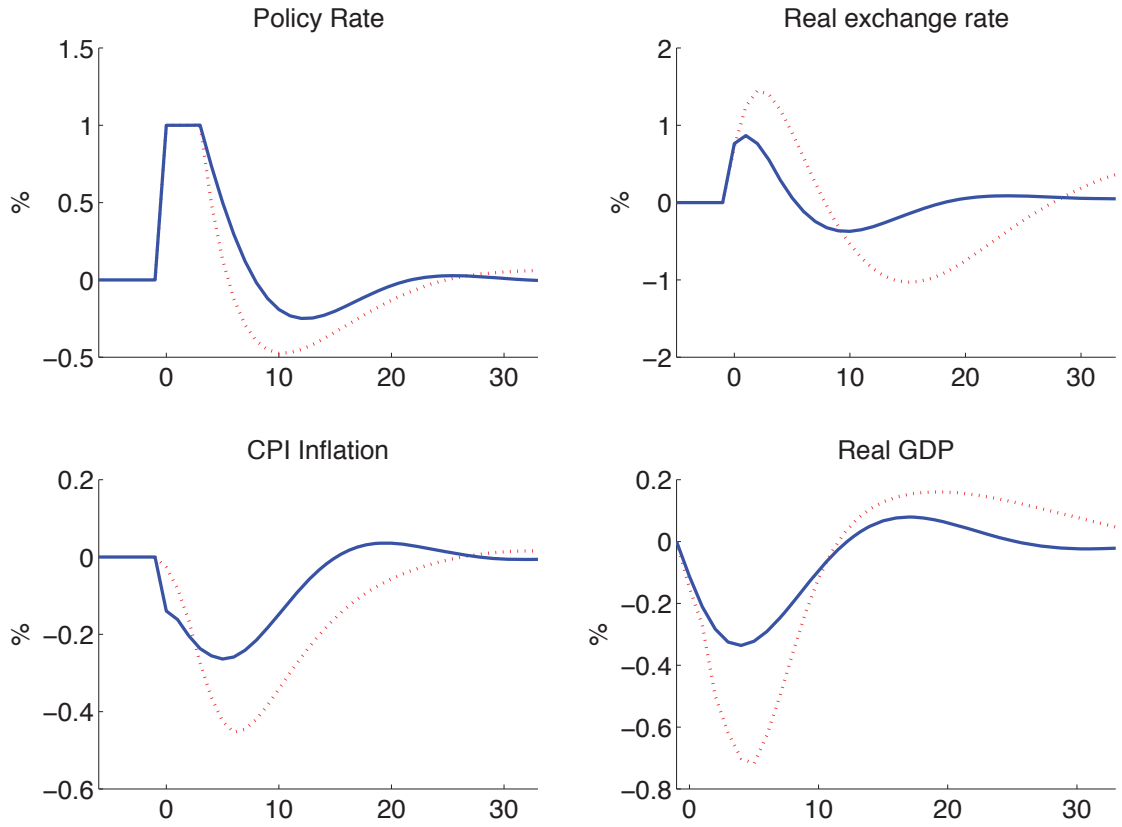
muted profile. Increasing tradable inflation from consumers switching towards tradable goods is approximately offset by an appreciation of the exchange rate in the short run.

Figure 4 shows the impact of a wage-cost shock within the model, where households demand higher compensation for a given level of labour. Such a shock increases wage inflation (depicted in the top-left panel) and hours worked by households falls since the cost of firms' labour input has increased. Since labour is an input to the production of the intermediate good, the real price (relative to the CPI) of the intermediate good increases. This generates a hump-shaped response to the shock in aggregate inflation, which is returned to its original level after approximately twelve quarters. Policy responds to this inflationary pressure which in turn generates an appreciation of the exchange rate in the short run.

Using impulse response functions to compare the new KITT model to the existing FPS model are difficult since the structure, and hence the nature of the shocks, are different across models. However, one exercise that can be used to compare both models is the following hypothetical experiment. Holding everything else in the model constant, we assume that the interest rate is raised 100 basis points above the neutral nominal rate, held for four quarters and then released such that the endogenous policy rule then sets the interest rate. Figure 5 shows the results of such an experiment for four key macroeconomic variables, with model variables from KITT depicted with a solid blue line and FPS with a dotted red line.

Following the initial increase in the 90 day rate, the policy rate declines in both models, with this decline slightly more prolonged in KITT (where the rule places relatively more weight on last period's nominal interest rate). This is effectively capturing the fact that the central bank does not want to move the interest rate in large amounts and that small movements in a similar direction are preferred, all else being equal.

Figure 5
KITT-FPS monetary policy experiment



Note: The policy rate is expressed in percentage point terms, with 0.5 percentage points equivalent to 50 basis points. Horizontal axis units are quarters.

In both models the increase in the policy rate produces a higher real interest rate and induces an appreciation in the real exchange rate as investors move funds to take advantage of higher domestic returns. This increase in the real exchange rate is marginally higher in FPS which actually displays a depreciated real exchange over the medium term. Furthermore, output declines in both models but returns to its previous level after approximately three years within KITT.

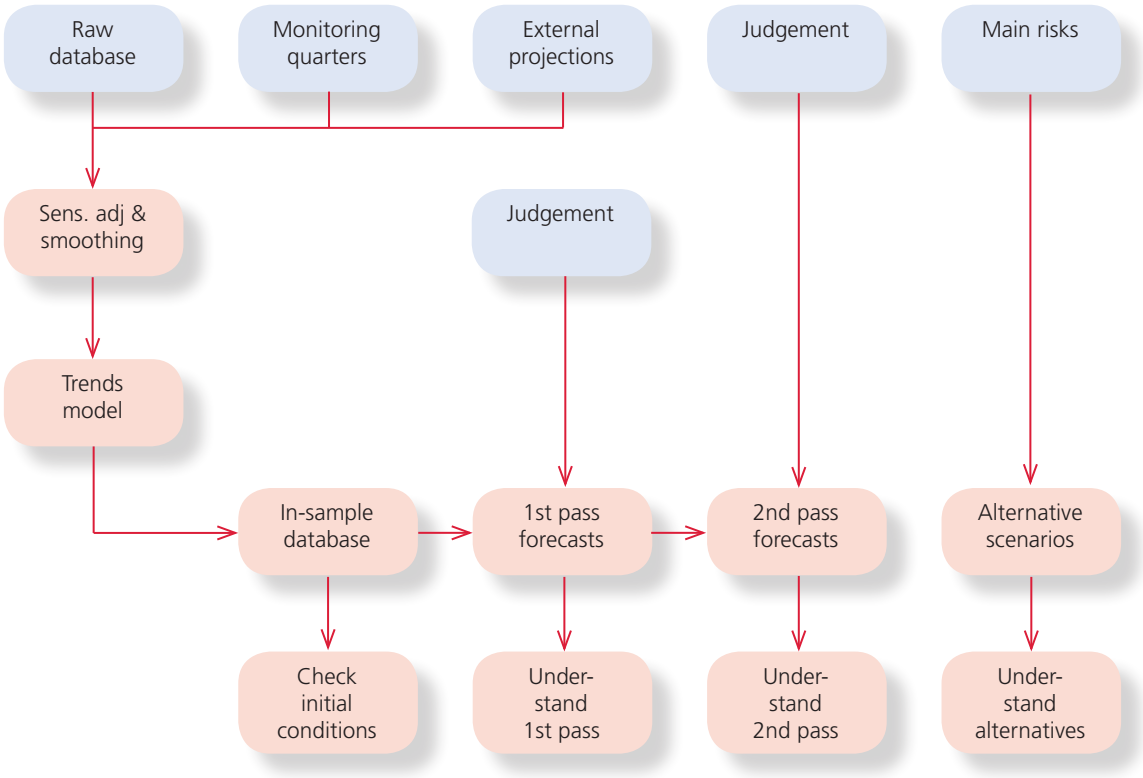
Finally, there is a somewhat smaller impact on aggregate consumer price inflation within FPS, compared to KITT. Inflation is returned to its previous value after approximately three years in KITT. This process takes longer within FPS. The initial fall in inflation is more pronounced within KITT because of the explicit role for fuel inflation within the model, which decreases sharply via the appreciation of the exchange rate.

5 Model operation in the policy environment

Throughout the development of KITT, emphasis was placed on the development of a model that would be well suited to the forecasting and policy environment of the Reserve Bank. Such a model serves a different purpose to many DSGE models within the monetary policy literature that are designed to address very specific policy questions. While KITT can address a wide range of research questions, KITT must also support the production of the forecasts that are published in the Reserve Bank of New Zealand's *Monetary Policy Statement*, quarter after quarter.

One particular feature of the central bank environment is the access to a rich and diverse set of information. It is natural that the forecasts should be informed by these alternative data sources, not readily captured by the 27 variables KITT uses as inputs. These data sources span financial market information, firm-level survey data, near-term indicators, business contact visits, sectoral experts, anecdotal information and alternative statistical models (see

Figure 6
The role of the model in the forecast process



an accompanying article, Bloor 2009). This environment has an impact on how the model is used.Aside from some treatment of the data, in this respect KITT operates in much the same way as FPS (see Drew and Frith 1998 for a more detailed treatment). Figure 6 shows a schematic of how the model is used within the forecasting process, with the additional information and timing of its incorporation within the process.

The top left of the schematic shows that the raw database is augmented with both monitoring quarter information and external projections. Monitoring quarter information is an assessment of this period's macroeconomic data that may in practice be released with a one or two quarter lag (for example, Gross Domestic Product takes time to compile and produce, and is released with approximately a two quarter lag). KITT obtains monitoring quarter information from sector experts. In addition, because New Zealand is a small open economy and the effects of the New Zealand economy on the world can be assumed to be negligible, the model focuses on domestic data rather than an explicit set of assumptions for the foreign economy. In the forecasting environment, exogenous forecasts for foreign GDP, foreign interest rates, foreign prices and commodity prices are used to provide forecasts for the world outlook. This updated dataset is filtered using a trend model that takes a large number of series and establishes trends for variables including non-tradables, tradable consumption, business investment and exports. Judgement can be applied to the initial conditions that form the starting point for the "first pass" model forecasts.

After the model produces the initial first-pass model forecasts, the forecasts are tested against alternative information sources, including alternative forecasts, business survey information, financial market information and alternative interpretations of these information sets. Substantial judgement is added to the sets of forecasts by specifying the paths of particular variables and adding structural shocks to the model. These "second pass" forecasts are subject to a second round of judgement.

KITT must also support the production of the forecasts that are published in the Reserve Bank of New Zealand's *Monetary Policy Statement*, quarter after quarter.

6 Concluding remarks

Development of KITT will enhance the economic modelling and forecasting underlying the quality of advice provided for monetary policy formulation. The model offers at least four substantive improvements over the existing FPS model: (i) a richer sectoral picture that decomposes inflation into predictions regarding non-tradables, tradables, petrol, construction costs; (ii) a structural framework that emphasises the role of firms' marginal costs in addition to the output gap; (iii) a housing sector that allows a structural role for house prices to impact on consumption; and (iv) an estimated model that can help policymakers understand the uncertainty that surrounds model-based forecasts. That said, no model captures the richness and complexity of the forces that drive the business cycle. Like all models, KITT remains an abstraction from reality in a number of respects.

As our knowledge of the New Zealand economy evolves, so will our beliefs about the appropriate modelling structure to best represent the economy. Certainly our experience with the FPS model was one of continuous evolution (see Delbrück et al, 2008) and this will surely be the case with KITT. The model moves the Reserve Bank closer to the macromodelling frontier and provides a strong foundation for our forecasting and monetary policy advice.

References

Adolfson, M, S Laseen, J Linde and M Villani (2007) "RAMSES a new general equilibrium model for policy analysis", *Riksbank Economic Review*, 2007:2.

Bernanke, B and M Woodford (1997), "Inflation forecast and monetary policy", *Journal of Money, Credit and Banking*, 29(4), November pp 653-84.

Black, R, V Cassino, A Drew, E Hansen, B Hunt, D Rose, and A Scott (1997), "The forecasting and policy system: the core model", *RBNZ Research Paper No 43*.

Bloor, C (2009) "The use of statistical forecasting models at the Reserve Bank of New Zealand", Reserve Bank of New Zealand *Bulletin*, 72:2.

Brooks, R and D Gibbs (1991) "The Reserve Bank Econometric Model of the New Zealand Economy: Model XII", Reserve Bank of New Zealand *Research Paper* No. 42.

Deane, R (1971) "Towards a model of the New Zealand economy", Reserve Bank of New Zealand *Research Paper* No. 1.

Delbrück, F, A Dunstan, D Hargreaves, A Lienert, H Pepper, and C Sleeman (2008), "The evolution of the Forecasting and Policy System (FPS) at the Reserve Bank of New Zealand", *Reserve Bank of New Zealand Discussion Paper* 2008/19.

Drew, A and M Frith, (1998) "Forecasting at the Reserve Bank of New Zealand", Reserve Bank of New Zealand *Bulletin*, 61(4), pp 317-27.

Galí, J (2008) *Monetary Policy, Inflation and the Business Cycle: an introduction to the new Keynesian framework*, Princeton University Press.

Gallacher, J, G Morgan, D Giles and P Quinn (1977) "The Reserve Bank's Model of the New Zealand Economy", *Reserve Bank of New Zealand Research Paper* No. 22.

Harrison, R, K Nikolov, M Quinn, G Ramsay, A Scott, and R Thomas (2005), *The Bank of England Quarterly Model*, Bank of England.

Matheson, T (2006) "Assessing the fit of small open economy DSGEs", Reserve Bank of New Zealand *Discussion Paper* 2006/11.

Medina, J P and C Soto (2006) "Model for Analysis and Simulations: A small open economy DSGE for Chile", Conference Paper, Central Bank of Chile

Murchison, S and A Rennison (2006). "ToTEM: The Bank of Canada's New Quarterly Projection Model". *Bank of Canada Technical Report* No. 97. Ottawa, Bank of Canada

Smets, F and R Wouters (2003) An estimated stochastic Dynamic General Equilibrium Model of the euro area, *Journal of the European Economic Association*, 1(5), pp 1123-75

Spencer, G, G Smith and P Joseph (1979) "The Reserve Bank Econometric Model: a revised structure and some policy simulations", *Reserve Bank of New Zealand Research Paper* No. 28.

Woodford, M (2003) *Interest and Prices: Foundations of a Theory of Monetary*, Princeton University Press, 2003.

Woodford, M (2009) "Convergence in Macroeconomics: Elements of the New Synthesis", *American Economic Journal: Macroeconomics*, 1(1), pp 267-79.

Appendix

Table 1

Model variables

Series name	Source
Domestic interest rate	Reuters
Headline inflation	Statistics New Zealand
Exchange rate growth	Reuters, RBNZ
Relative price of tradable	Statistics New Zealand
Relative price for non-tradable	Statistics New Zealand
Relative price of non-oil import	Statistics New Zealand
Real world price	DataStream
Real world oil price	Statistics New Zealand
Real price of non-commodity export	Statistics New Zealand
Real construction costs	RBNZ
Real price of commodity exports	Statistics New Zealand
Relative price of houses	Quotable Value Limited
Real wages	Statistics New Zealand
Real total consumption	Statistics New Zealand
Real consumption of housing services	Statistics New Zealand
Real consumption of non-tradables	RBNZ estimate
Real business investment	Statistics New Zealand
Real Housing investment	RBNZ estimate
Real non-commodity exports	Statistics New Zealand
Real commodity exports	Statistics New Zealand
Real non-oil imports	Statistics New Zealand
Real oil imports	Statistics New Zealand
Debt to nominal GDP	Statistics New Zealand
Labour (hours paid)	Statistics New Zealand
Real GDP	Statistics New Zealand
Foreign interest rate	RBNZ
Foreign real output	RBNZ