Report on KITT (Kiwi Inflation Targeting Technology), the Reserve Bank of New Zealand's new macroeconomic model*

1. Key Terms of Reference, and Conditioning Factors

The key terms of reference set down for this report are:

- to provide an assessment of the quality of the KITT model, relative to international best practice;
- to provide an assessment of the KITT model as a worthy replacement for the RBNZ's existing core forecasting model (FPS), including with respect to:
  - its capability to tell sufficiently rich economic stories;
  - the estimation methods used to evaluate the match of the model to the data; and
  - the model's ability to address uncertainty, incorporate judgment, and assist in providing advice to the Bank's *Monetary Policy Committee*; and
- to identify areas where the model could be improved

Factors conditioning my report have been receipt of the draft KITT document on 21 May 2009, the requirement to report by 30 June 2009, and the resulting time frame to assimilate material in the very comprehensive write-up of around 140 pages. My assessments and recommendations are therefore primarily high level in nature. To provide more detailed assessments and recommendations on economic structure and operational aspects would require my having the benefit of (i) further interactive sessions with the modelling team, and (ii) sitting through an MPS forecasting round underpinned by KITT projections.

2. Is the quality of the KITT model consistent with international best practice?

In terms of **model type**, the quality of KITT is consistent with international best practice models used by central bank forecasters and policy-modellers. Those models reflect the best available academic models and solution procedures.

Earlier this decade, Pagan (2003, pp 6-10) established for then current best practice macroeconometric models, an illustrative frontier which reflected differing tradeoffs between a model's theoretical and empirical coherence. At that time, Pagan judged that frontier to be somewhere between "Type II hybrid" models and "ISDGE" models, with the Bank of Canada's QPM model (Coletti et al., 1996) and the RBNZ's FPS model (Black et al., 1997a) being early examples of the ISDGE type. Characteristics of a Type II hybrid model were that it possessed strong economic theoretic underpinnings, an explicit long-run equilibrium or steady state, equations for the

* In writing this Report, I have benefited considerably from comments at a consultative session with two members of the KITT modelling team, and from my experience in teaching Victoria University of Wellington's fourth year Honours courses in New Keynesian Advanced Macroeconomics (ECON 403) and Macroeconomic Modelling of the New Zealand Economy (ECON 423).

variables of interest to policymakers, and a somewhat greater emphasis on empirical coherence relative to theoretical coherence. ISDGE (Incomplete DSGE) models additionally allowed for the dynamics of adjustment paths to be intrinsic to the model, but were considered "incomplete" in not having fully specified processes for shocks.

More recently, Fukač and Pagan (2005, pp 8-13) typified policy models as having evolved through four generations. Under this classification, FPS was in the 3rd generation (3G) category, which had become dominant best practice in the 1990s. Fukač and Pagan's term for subsequent best practice models was fourth generation (4G), and at the time of the Fukač and Pagan assessment these included the Bank of Canada's ToTEM, the Bank of England's BEQM, and the Norges Bank's NEMO[1]. Key additional characteristics of 4G models are their ability to reflect a now widely agreed mix of longer run new classical and shorter run new-Keynesian economic foundations[2], and their using newer, still quite rapidly evolving estimation and evaluation methods. Their economic foundations feature considerable heterogeneity of behaviour by households and firms in imperfectly competitive goods and labour markets, more extensive use of intrinsic dynamics, and partial or full replacement of calibrated parameter values by values informed by Bayesian estimation techniques. In my view, the Sveriges Riksbank's RAMSES, the Bank of Chile's MAS, and the RBNZ's KITT all now qualify to be in this 4G international best practice category[3].

KITT's **economic structure** is consistent with still quite rapidly evolving international best practice for 4G models. The economic structure of these models has origins in the new classical closed economy real business cycle models of the 1980s (Kydland and Prescott, 1982). The models subsequently went through a period in the early to mid-2000s when the pathbreaking academic models were regarded as having an insufficiently representative set of key macroeconomic variables[4], almost always relied on calibrated parameter values, were unable to represent key macroeconomic data well enough, and hence were insufficiently useful for central bank projection and policy work. However, following on from the development of influential closed economy monetary policy DSGE models, published by Christiano et al. (2005) and by Smets and Wouters (2003), came models with important open economy features, e.g. Lubik and Schorfheide (2007), and the central bank models for Canada, Norway, Sweden, and Chile. This progress has been impressive, but remains incomplete in at least two important areas.[5] For example, the modelling of key fiscal variables and transmission mechanisms has generally been quite rudimentary, and modelling of aspects of the labour market such as unemployment remains incomplete[6]. The current KITT core model is similarly incomplete in these two areas.

In terms of **estimation methodology**, KITT is consistent with international best practice. The very early DSGE models relied on calibrated values for their

[1] Murchison and Rennison (2006), Harrison et al. (2005), and Brubakk et al. (2006).
[2] For the degree of agreement on key macroeconomic foundations and new classical-new Keynesian mix, see Blanchard (2008) and Woodford (2009).
[3] See Adolfson et al. (2007), Medina and Soto (2007), and Beneš et al. (2009).
[4] For example, real sector closed economy models were generally calibrated, and then initially extended only to reflect a key policy role for monetary policy. Credible models for small open economies had not yet been developed.
[5] This is primarily because the underpinning economic theory has not yet been sufficiently well developed.
[6] See for example, Blanchard (2008); as explained more fully in section 3.2.3 below.

parameters, often without sufficient attention to appropriate sensitivity analysis or regard to supporting empirical evidence. Subsequent results from relatively small models estimated by FIML or VAR methods were generally unable on their own to produce the right mix of theoretical economic structure, matching the data, and telling a sufficiently rich economic story. However, drawing on developments reported in Sims (1980), An and Schorfheide (2007), and Canova (2007), current best practice DSGE models now have their parameters estimated with the assistance of Bayesian VAR techniques. These techniques have been designed to provide results which not only reflect the economic structure of the DSGE model but also have the model better informed by the data. The techniques are now widely accepted, but also need to be used with very considerable specialist expertise and associated care. In the latter context, it is important that the RBNZ continue to give particular attention to hiring the necessary very skilled economic modelling personnel. This is not only for operating the model and interpreting results from it; more especially, this is for undertaking the considerably more challenging ongoing development work, involving richer model structure and refinement of estimation and evaluation methods.

The developers of KITT recognise the importance of international best practice **model evaluation methodology**, and to date have presented results in varying degrees of depth. In the 1990s and early 2000s, central bank evaluation methodology was often confined to assessing how well a model tracked the data, presenting responses to a relatively small number of temporary or permanent shocks, and publishing ex post forecast evaluations from time to time. It is now well understood that best practice model evaluation methodology should encompass a much wider and more demanding spectrum of statistical and economic properties, from parameter identification through to assessment of business cycle properties, and evaluating the match of the model output to the data. By way of background to this aspect, it can first be noted that the RBNZ was not amongst the first to consider using the potentially very challenging DSGE methodology for core model projection and policy analysis work. Rather, preliminary evaluation of the potential worth of a full DSGE model was undertaken through the benchmarking of a small prototype DSGE model against then RBNZ published forecasts (see Lees et al., 2007). Results were sufficiently encouraging.[7] A particularly important subsequent element has been the modelling team's very strong attention to the identification aspect; the conduct and write-up of this is the best I have seen to date. There has been sound but so far limited work on evaluating empirical fit, through assessing autocorrelation functions, standard deviations, a selection of contemporaneous cross correlations, and business cycle properties. A more intensive evaluation of business cycle properties has yet to be undertaken, as have evaluations of dynamic responses to a full set of permanent and anticipated shocks.

The development and ready availability of the Matlab based IRIS Toolbox[8] has enabled the KITT modelling team to take full advantage of powerful and flexible **computing software methodology,** at the forefront of international best practice. For KITT, a particular benefit from the IRIS Toolbox is that its data assembly and compilation, model estimation and evaluation, and reporting of graphical and tabular results can all be done within the one software package.

[7] Adolfson et al. (2007, 2008) have conducted similar comparative analysis for RAMSES.
[8] The IRIS Toolbox (**I R**est, **I**RIS **S**olves) has been developed by Jaromir Beněs (Beněs, 2008) since 2001, and can be accessed from http://www.iris-toolbox.com/.

The **clarity and timeliness of communication** of central bank model structures and capabilities, steady state properties and dynamics, recent changes, and empirical results has improved considerably over the past decade or so, assisted in no small measure by regular conference presentations and readily accessible website documentation. When FPS was launched and formally integrated into the forecasting and policy process, the RBNZ was a communications leader, through its releasing almost simultaneously with public launching of the model, both a non-technical write-up and technical research paper documentation (Black et al., 1997a, 1997b). The leading central banks now regard such timely releases as an important apart of producing and gaining credibility for a new model. In producing this KITT research paper, the RBNZ is continuing this element of best practice. The research paper will be very valuable for use in Honours level university courses, and this should in turn assist in producing graduates of value to the RBNZ, other economic policy institutions, and the private sector. As a complement to the technical paper, it is similarly pleasing to note that the companion non-technical version is being published as early as the June 2009 *Reserve Bank Bulletin.*[9] This has the value of reaching much wider audiences, which would include undergraduate students, past university graduates, the economics and business media, and key business, economic and political decision makers.

3. Assessment of the KITT model as a worthy replacement for FPS

3.1 Perspective

The RBNZ's core FPS model was developed in the mid-1990s, and became operational in 1997. Since then, and helped in no small measure by a series of evolutionary changes to its economic structure, steady state and other parameter values, trends in the data and dynamic adjustment mechanisms, it has generally been recognised that FPS has remained a very valuable tool to assist the regular production of projections/forecasts and OCR decisions.[10] But by 2002, it was also clear to me that FPS would either have to be replaced or fundamentally restructured by the late 2000s. This would be so as to reflect new theoretical contributions, enhanced computational developments, and a somewhat different world economy. And from the early 2000s until recently, the gap between FPS and best practice international modelling has been growing steadily wider.

What perhaps tempered the RBNZ's speed of investment in and development of a DSGE-type model, was the inability of these early models to match the data adequately (e.g. Pagan, 2003), and insufficient confidence that the modellers could communicate sufficiently credible and rich economic stories to policy makers, e.g. Alvarez-Lois et al., 2008. However, as outlined above in section 2, these inabilities have now been very considerably reduced. And as is implicit from FPS being an ISDGE model and KITT being a DSGE model, it is not unreasonable to regard KITT as a further evolutionary development of FPS, but with a richer economic structure and intrinsic dynamics, and more powerful estimation and evaluation techniques.

[9] See Reserve Bank of New Zealand (2004), for the most recent non-technical version of FPS.
[10] See Delbrück et al. (2008) for details of these evolutionary changes.

3.2 Does KITT have the capability to tell sufficiently rich economic stories?

"Sufficiently rich economic stories" now seems a term commonly used by modelbuilders and policy makers when discussing projections and their implications for policy decisions.

"Sufficiently rich" should, however, be seen in the context of the primary purpose and specific roles for a model. When reading chapter 1 of Beněs et al. (2009), I obtained valuable perspective on why KITT had been developed as the RBNZ's new core economic model, but it wasn't until p 67 that I felt sufficiently informed that its primary general purpose was to "… to act as a central forecasting and story telling device, … used to help build central forecasts that will be communicated to policy makers during a policy making round, and published in the *Monetary Policy Statement*." Similarly, I didn't see in chapter 1 a sufficiently prominent specification of the major specific roles set down for KITT. This can be contrasted with the position for FPS, where it was recently re-iterated at the outset that the major specific roles of FPS were to: provide policy advice on the Reserve Bank's interest rate decisions; produce and publish projections; and conduct economic research on the New Zealand economy." (Delbrück et al., 2008, p 1). I therefore **recommend** that the primary purpose and major specific roles for KITT should be set down more clearly and prominently in chapter 1. This might be done either as early as the second paragraph in section 1.1, or in the context of the early paragraphs of section 1.3.

3.2.1 Steady state properties and business cycle dynamics

Understanding a model's steady state properties provides an important contribution towards being able to tell sufficiently rich economic stories, as the steady state properties underpin the model's business cycle dynamics. The term 'steady state properties' covers both an economy's steady state growth paths and its steady state parameter values. I was able to work out fairly readily from Black et al. (2007a) the steady state growth paths underpinning the FPS model and most of its steady state parameter values. For KITT, steady state parameter values have been summarised clearly in Table 4.1, but I couldn't immediately detect the economy's steady state growth path, consistent with the multiple detrended growth cycle model which "models the dynamics of the economy around its steady state" (Beněs et al., 2009, p 55). I **recommend** that this aspect be made more transparent, and also that consideration be given to formally reviewing and making transparent at regular intervals all steady state values.

The combination of the core model economic structure and associated very considerably greater numbers of shock variables compared with those available in FPS, provide a very strong foundation for considerably richer stories to be told from KITT's business cycle dynamics.

3.2.2 Economic Structure – areas of particular richness

In several key areas of prime importance to a central bank operating in a small open economy, KITT exhibits considerably richer economic structures.

Production structure

Modellers for any small open economy face a key trade-off decision between the tractability of a one good model and the greater richness that might be provided by some form of multi-good model. Imported intermediate goods play a very important role in New Zealand's price and quantity transmission mechanisms, and it is still the case that a substantial proportion of New Zealand's exported goods are primary based products.

Essentially on the grounds of analytical convenience, FPS was specified as a one-good model on the production side, together with a commensurately richer relative price structure to underpin movements in the rate of inflation.[11] KITT has a particularly ambitious production sector, allowing scope for very much richer differential reflection of monopolistically competitive non-tradable and tradable goods producers, residential investment producers, and manufactured exports producers, together with price taking commodity export producers.[12] The first four production sectors utilise labour, capital and fuel as primary inputs and sector specific technology to produce an intermediate production good. Not surprisingly, KITT then imposes the somewhat simpler Cobb-Douglas aggregation rather than CES aggregation often used in other models. The Cobb-Douglas aggregation is, however, augmented uniquely for a core macroeconomic policy model, by allowing for different price trends in each of the sectors.[13]

Residential housing investment

In FPS, there was no explicit treatment of residential investment. Essentially for analytical convenience, this variable was subsumed within the FPS household sector consumption expenditure variable. In KITT, however, and unlike in other international best practice models[14], there is a comprehensive reflection of the housing sector, including explicit roles for residential investment, construction costs, housing debt and servicing costs, and their implications for effects on consumption, external debt and inflation. Particularly important here has been the specification of an explicit role for a financial intermediary to borrow from abroad on behalf of households, with implications for the country's net foreign debt.[15] Similarly very important is the introduction of an effective interest rate charged by the financial intermediary, which consists of adding a risk premium based on the loan to housing value ratio, to the policy interest rate. The risk premium is measured as the ratio of net foreign debt stock to the nominal housing stock. This now quite comprehensive range of variables and transmission mechanisms should assist very considerably in the telling of richer stories around the housing sector, and hence in relation to non-tradable inflation and implications for monetary policy. This possibility has come about through a combination of more recent developments in economic theory and

[11] This is in contrast to the approach of the New Zealand Treasury's NZTM model which, befitting Treasury's necessarily greater focus on detailed real economic growth processes, adopted a characterisation comprising domestic and exported outputs, and labour, capital and imported intermediate good inputs. See, for example, Szeto (2002), and Ryan and Szeto (2009).

[12] As price is assumed world demand determined, there is no explicit supply side behaviour for commodity-export producers. This implies no domestic supply side constraints for these exporters, and that New Zealand cannot on its own set the world price for dairy products.

[13] See Beněs et al., (2009, p 13)

[14] See ToTEM, RAMSES, NEMO and MAS, for example.

[15] The roles for a financial accelerator were developed in a closed economy context by Bernanke, Gertler and Gilchrist (1999), and in a housing context by Aoki, Proudman and Vlieghe (2004).

modelling, solution methods being less constraining, and the relative importance of housing-related activity in influencing New Zealand's inflation rate.

Relative prices, inflation and the simple monetary policy rule
FPS has a relatively rich **relative price structure**, and the recent explicit incorporation into FPS of non-tradable and tradable goods inflation variables further improved its capacity to explain diverse movements in New Zealand's tradable and non-tradable inflation components. The specifications for relative prices and inflation in KITT provide an even richer framework to assist explanations of the key transmission mechanisms underpinning inflation. These specifications go well beyond the basic Calvo-type underpinnings found in many other models, and the claim made in Beněs et al.(2009, p 13) that the treatment of relative price trends allowing for sectorally different price and technology trends and time varying elasticities of substitution between consumption goods is unique for a core policy model, seems a credible one. There is a rich set of transmission channels feeding through to **headline inflation**, reflecting tradables, non-tradables, construction costs and exchange rate converted world fuel price inflation.

In the current version of KITT, **monetary policy** is set according to a simple policy **rule** rather than from some optimisation grounded rule. **I recommend** this continue to be the case at this stage on two grounds – firstly, the current economic environment is radically different from business cycle movements prior to late 2007; secondly, Adolfson et al. (2008) have recently shown how to construct operational optimal policy projections in RAMSES, but concluded that past policy of the Riksbank until 2007q3 is better explained by following a simple instrument rule than a rule from optimal policy under commitment.

Open economy: exports, imports, external debt, exchange rate, risk premium
I found KITT's external sector specifications and variables more straightforward to understand and overall empirically richer than its FPS predecessors. As in FPS, external debt continues to play a key role. The disaggregation of exports into commodity and manufactured components, of imports into oil and non-oil imports, and the incorporation of an endogenous risk premium term into the modified uncovered interest parity equation all have the potential to add extra richness.[16]

3.2.3 Economic Structure – areas yet to be further developed

It takes time to understand fully even evolutionary new macroeconomic models, and in this respect KITT will be no exception. Moreover, it's seldom possible to incorporate all policy and non-policy variables into a model's initial core version. Initial versions have sometimes reflected pressure from decision makers to produce credible output sooner rather than later, but more often limitations in model specification reflect insufficient progress in the relevant academic literature. For the case of this version of KITT, fuller specification of a government sector and of labour market variables seems to have been somewhat constrained by the latter.

[16] An exogenous sovereign risk premium was allowed for in FPS.

The government sector

In FPS, government was specified to have the power to collect revenue from a range of distortionary direct and indirect taxes, raise debt, make transfer payments, and purchase goods and services. Government also faced an intertemporal budget constraint, and a fiscal policy rule determined the labour income tax rate that enabled satisfaction of an imposed steady state government debt to GDP ratio and several expenditure to GDP ratios. Government debt was also an explicit component of domestic net financial assets, separately from net foreign assets/liabilities. The degree of disaggregation and hence potential richness for story telling in FPS is obviously considerable.

In best practice DSGE models, the treatment of government sector and fiscal policy variables has varied considerably, and lagged well behind specifications for monetary sector variables and optimal or simple monetary policy rules. Yet recent reduced form model findings for New Zealand (Hall and McDermott, 2008; Dungey and Fry, 2009) suggest that fiscal policy variables have had a significantly greater influence on recent New Zealand business cycle paths than has monetary policy.

In DSGE model work where government sector behaviour has been specified quite basically, Gali et al. (2007), Adolfson et al. (2007, 2008) and Brubakk et al. (2006) were content to impose lump sum taxes and no government debt. These specifications can be contrasted with the treatments in ToTEM (Murchison and Rennison, 2006) which allowed for distortionary taxes in a non-Ricardian environment, and in Medina and Soto's (2007) non-Ricardian model which has a single average income tax rate and government expenditure determined by the Chilean structural balance fiscal rule.

The government sector in KITT is currently parsimonious in several ways, and would not yet seem sufficiently rich to contribute towards meaningful stories on the interactions of monetary and fiscal policy and their relative impacts on the business cycle. Government is postulated to be funded through lump sum taxes, to balance its budget every period, to have zero net transfers, and to set government expenditure according to a simple rule. The household (and external) debt ratio is postulated to move exponentially over time, with additionally adjustment for the net external trade to GDP ratio (Beněs et al., 2009, p 59).

I recommend that consideration be given to developing the government sector further, so as to assist in the telling of richer stories affecting the business cycle and monetary policy decisions.

The labour market and unemployment

Blanchard (2008, p 12) has recently expressed prominently the quite widely held view that "One striking (and unpleasant) characteristic of the basic [New Keynesian DSGE] model is that there is no unemployment. Movements take place along a labor supply curve, either at the intensive margin (with workers varying hours) or at the extensive margin (with workers deciding whether or not to participate)." KITT and other central bank DSGE models specify their labour market behaviour in this way, with households choosing to supply differentiated labour services at wage rates chosen optimally after taking into account adjustment costs, and so as to satisfy firms'

demands for labour services. Unemployment and labour force participation ratios, which of course vary over the business cycle, are therefore not treated explicitly.

The specification in the original version of FPS treated labour supply as exogenous, with labour supply being further written in terms of an explicit equilibrium unemployment rate (NAIRU) and an implicit labour force participation rate.

I recommend that the write up of KITT make transparent how non-modelled variables such as unemployment and the labour force participation rate have been produced by leveraging off KITT model variables[17], and therefore what role they can have in explaining the model's business cycle stories and/or steady state. **I also recommend** that in due course appropriate attention be given to how the modelling of labour market behaviour might be suitably enriched. For example, Blanchard has suggested (2008, p 14) that progress might be made through integrating the Diamond-Mortenson-Pissarides model[18] with efficiency wage models, while Galí (2009) has recently presented work incorporating unemployment in a wage-based Phillips curve consistent with a DSGE model.

3.2.4 Forecasts and Simulations

The central purpose of KITT is to help the RBNZ build central forecasts and associated stories that will be communicated to policy makers during OCR policy making rounds, and published in *Monetary Policy Statements.* (Beněs et al., 2009, p 67). In this context, relative to the output produced from the FPS model, the economic specification and estimation results to date from KITT have the potential to provide **forecasts which are substantially richer** in the core areas of inflation, production sectors, housing investment, external sector influences and monetary policy. The value of the central forecasts and associated stories should be further considerably improved through KITT's associated modern evaluation methodology.

The illustrative posterior-mode impulse response simulations presented in section 5.1 are primarily temporary, unanticipated, domestic and foreign cost-push shocks. In this respect, along with the risk premium shock, these provide an enhanced array of shocks, relative to FPS. However, there is currently limited capacity to present two important types of shock; these are permanent shocks, such as those reflecting "permanent" technical progress/ productivity and terms of trade changes [19]; and anticipated shocks, which are required, for example, to reflect fiscal policy changes announced in advance of date of effectiveness.

3.2.5 Communication capabilities

The leading central banks that utilise sophisticated models to assist in producing their forecasts and official interest rate decisions, have long recognised that strong two-way communication between modellers and decision makers is essential. Duguay (1998) emphasised this well over a decade ago, in the context of Bank of Canada processes. More recently, however, in the context of increasing use of the considerably more

[17] For a recent example of this methodology, see Schorfheide et al., (2009)
[18] See, for example, Pissarides (2000)
[19] It can be noted that there is currently a capacity to run permanent shocks in a full trends model with a modest number of trends (See Beněs et al., 2009, p 8)

sophisticated 4G DSGE models, the requirement of effective two-way communication has had to assume even greater importance. Alvarez-Lois et al. (2008) and Brubakk et al. (2006, p 7) have provided recent examples of this, in Bank of England and Norges Bank contexts.

The KITT modelling team and others in the RBNZ Economics Department face somewhat greater challenges of communication than did those associated with FPS. My observations during the 1990s and 2000s were that those associated with FPS steadily achieved the required clarity of communication over time, probably beginning with convincing senior management and MPC members, continuing with the public release of the Black et al. (1997a) technical paper and its accompanying non-technical version (Black et al., 1997b), and following as required by updated non technical (RBNZ, 2004) and more technical versions (Delbrück et al., 2008). These were complemented, as required, by international conference presentations and occasional Reserve Bank Bulletin articles.

So, given the somewhat greater challenges of communication associated with KITT, I would expect that education of the full range of potentially richer information to take rather longer than for FPS. Within reasonable time, however, I would expect that goal to be achieved. On the positive side, there has already been considerable input during the development phase from international experts, presentation of specialist papers on the newer methodology at international conferences, and presentation of forecasts alongside those from FPS during the June MPS forecast round. But it is also the fact that there are very few New Zealand university academics, public sector researchers and advisors, private sector specialists, and members of the wider public who have any appreciation of the value of output from DSGE model economic structures, estimation methods and evaluation methods.

3.3 Can the estimation methods used match the model to the data sufficiently satisfactorily?

The estimation methods used have the potential to match the core New Zealand data sufficiently satisfactorily.

3.3.1 The estimation methods

The KITT modelling team's 4-step estimation strategy is set down clearly in Beněs et al. (2009, p 67), as: parameterise the steady-state, check identification for both the steady state and dynamic model, formulate priors, and estimate the dynamic model using Bayesian methods. It is common accepted procedure, empirically, to parameterise the steady state ahead of estimating the dynamic parameters.

Early "estimation" of the parameters of DSGE models was achieved either through imposing or by selective econometric estimation of the models calibrated parameter values, in some cases by FIML estimation of relatively small, often closed-economy models. But the latter is no longer a preferred approach for operational sized models, often because of not particularly smooth likelihood functions. A number of operational models still use imposed calibrated parameter values, but increasingly the leading central bank modellers have turned to estimation methods and Bayesian methods in particular. The latter have the considerable advantage over calibrated or

VAR models, as they are potentially able to provide very much improved opportunities for empirical data to inform the model parameters. One clear example of this, from the prior and posterior estimates reported in Beněs et al. (2009, pp 75-76), is the marked sharpening of the monetary policy rule parameters. Other meaningful examples are provided by the parameter for the persistence of the exchange rate risk premium shock and by the smoothing parameter on government expenditure.

3.3.2 Treatment of the data, multiple trends analysis

I found the description of the observable data and justification of the multiple trends approach in Beněs et al. (2009, p 8 and chapter 3), to be clear and empirically sound. At this stage of development of full trends models, the multiple trends model (TM) approach used for KITT has the capacity to improve the ability of the dynamic model to match the data rather better than would a full trends model. Importantly, it is made clear (pp 57, 63) that TM is an empirical device, which allows for trends to converge to a well-defined steady state and the imposition of multivariate consistency of trends across the model; also that TM is flexible enough to allow the modeller to impose transparently, either modest or reasonably substantial empirical judgments.

3.3.3 "Identification" of parameter values from the data

As emphasised in Fukač and Pagan (2006, pp 13-18), and as very clearly explained for KITT in section 4.1.3 of Beněs et al. (2009), it is particularly important to give in depth attention to whether the structural parameters and structural shocks in a substantial sized DSGE model can be identified from the data. Only briefly in Brubakk et al. (2006, pp 40-41) could I see explicit reference by another central bank to the challenges associated with identification, and so it is particularly commendable to see the careful attention paid to this issue in KITT. This has been done firstly through checking the singular value decomposition of the Fisher Identification Matrix for structural steady state and transitory parameters, and secondly through using (as in Fukač, 2007) adjusted SVAR methodology for identification of structural shocks.

3.3.4 Other assessment methods – parameterising the steady state and dynamic parameters

In section 4.1.2, it is made clear that parameterisation of the mix of calibrated and estimated steady state values presented in Table 4.1 has been achieved with the assistance of a numerical algorithm. The algorithm minimises the distance between the model implied ratios and those from the TM. Then, in section 4.1.4, it is confirmed that the dynamic parameter values come from the use of Bayesian methods, in which it is possible for the prior beliefs of (senior central bank) decision-makers to be imposed, for assessment against the data. It is now standard practice to make transparent the values of steady state and dynamic parameters, and as an economy's structure changes over time, any variations made by modelbuilders to these parameter values should be made transparent.

– evaluating empirical fit through simulated model moments and assessment of business cycle properties

It is standard practice to use autocorrelation functions, standard deviations and various (contemporaneous) cross-correlations to benchmark a model's empirical fit against simulated empirical data. The model and simulated moments presented in Figures 4.2

and 4.3 for key price and real GDP component variables provide valuable information on the degrees of empirical fit achieved to date. Some fits are already impressive, including for the standard deviation of headline inflation, and thereby provide a degree of confidence in the model's ability to match the data. However, as might have been expected, results for some other variables do not match the data as well at this stage, and point towards scope for further work, such as for the monetary rule and for exports.

Assessing empirical fit through the model's ability to match business cycle properties has been reported more often for small (calibrated) business cycle models than for operational DSGE models. It is pleasing to see brief preliminary attention to this aspect in section 4.5, but as can be seen from the business cycle properties presented in Hall and McDermott (2007, 2009), properties for the period 1992q1 to 2008q2 cannot reflect significant numbers of classical New Zealand cycles. Particularly in light of KITT being designed as a model to "… replicate key stylised facts about the New Zealand economy." (Beneš et al., 2009, p 5), **I recommend** that a more in depth assessment of the model's business cycle properties be undertaken. This should take into account previous findings in this area from Kim, Buckle and Hall (1994), McCaw (2007), and Hall and McDermott (2007, 2009).

3.4 What is the model's ability to address uncertainty, incorporate judgment, and assist in providing advice to the Bank's *Monetary Policy Committee*?

In chapter 6, "The model in the policy environment", there is a very valuable largely non-technical summary of how a DSGE model-assisted forecasting process would operate at the RBNZ, and what would be the potential value in that process of recently developed tools, not yet well-known to the wider public. The latter are particularly designed to assist in throwing richer and more transparent light on uncertainties surrounding central forecasts, and to make transparent hitherto less transparent judgments incorporated into the model forecasting process. Predictive densities (fan charts) and specific event probabilities are designed to provide particular assistance.

3.4.1 Uncertainty

"Uncertainty" is a concept which is not always well-defined in modelling work, and the underpinning theoretical economics literature ranges from quite vague through to unhelpfully narrow. Early ways in which modellers and policy institutions conveyed uncertainty (sometimes termed "risks") surrounding their central forecasts included presentation of: (i) a list of upside and downside risks, sometimes with an accompanying summary of the "on balance" situation; and/or (ii) one or more upside or downside deterministic scenarios in graphical form, for the paths of key variables such as headline inflation, real GDP, 90-day interest rates and a TWI exchange rate. Some central banks and government ministries still prefer these methods. Modern stochastic models and solution methods provide an opportunity for richer depictions of stories associated with uncertainty, and the KITT modelling team have now put together a selection of tools which can be used to provide additionally useful insights.

- Density forecasts/fan charts

In their inflation reports, the Bank of England, the Norges Bank, and the Sveriges Riksbank currently publish predictive densities/fan charts for key variables. As illustrated in Figure 6.2 and described in section 6.3, KITT has the capacity to produce such fan charts. The ex-post fan charts presented there, along with movements in the actual series, provide a valuable indication of how greatly actual movements can vary from a central forecast, and in which directions. But two-sided forward-looking fan charts can also be of limited usefulness unless accompanied by a detailed accompanying set of anticipated risks consistent with the (say) 90 percent or 50 percent probability intervals. Further, routine presentation of fan charts to MPC and in MPS may be less valuable than selective use for particular economic time periods.

- Event probability analysis

The additional advantage of the event probability tool is that it can be focussed directly on a particular upside or downside situation, such as the probability of recessionary periods or of periods breaching the top or bottom of the inflation target band (e.g. as in Figure 6.3). Carefully crafted design and explanation of particular probability events could therefore also be of considerable additional use during discussions at MPC. Here too, this would be on a particular episode basis rather than routinely, and would be supplemented by additional information.

- Forecast decomposition analysis

Forecast decomposition analysis is not a tool which addresses issues of uncertainty directly; rather it is used to help the economic modellers understand their forecasts better and thereby contribute towards enriching the stories discussed at MPC and written up in the MPS. The tool has the threefold advantages of being disciplined by the economic structure built into KITT, of having the capacity to be tailored to particular areas of the model's economic activity, and of being consistently integrated into stories advanced by fan chart and event probability analysis. The ex-post decomposition examples provided in Figures 6.5 to 6.7 for ninety-day interest rates, headline inflation and *non*-tradable inflation provide useful illustrations of the tool.

3.4.2 Judgment

The best write-ups of recently developed central-bank models emphasise that their model-based forecasts have long incorporated degrees of judgment, and that given the complexity of world and national economies, this will always have to be the case. The extent of these judgments has generally not been made formally transparent in the past, including as to whether a particular judgement has been one-off in nature or has had to be on a continuing basis and therefore lead to some re-specification of the model.

Tools recently developed by the KITT modelling team (Beněs et al., 2008) look to provide important new insights in this area, by providing transparent tracking of the magnitude and type of judgment added to the forecasts. Key elements include the ability to evaluate expected and unexpected shocks, the capacity to add structural or reduced form judgment, extension of the Waggoner-Zha (1999) algorithm for use in rational expectations models, and the portrayal of no judgment versus judgmentally

adjusted forecasts in graphical form. Initially, I expect the insights in this area will be of prime use to the modelling team, but as greater experience is gained, findings could feature on a selective basis, both to enrich MPC discussions and to explain major historical episodes such as the Asian financial crisis and associated periods of drought.

3.4.3 Assist in providing advice to the MPC

In the context of summarising that policymaking can be divided into the three interrelated tasks of identification of shocks and creation of forecasts, risk and policy analysis, and communication, Brubakk et al. (2006, pp 6-7) state that "The overriding evaluation criterion for a central bank model is how useful it proves to be in helping the policymakers conduct monetary policy."

Collectively, the economic structure of KITT, the use of Bayesian estimation to assist in matching the model to the data, and the enlarged suite of evaluation tools have the potential to provide considerably richer, consistently structured information to underpin discussions at MPC, the writing of the MPS, and the information conveyed to the wider public through other sources. Of the evaluation tools, the decomposition analysis, the fan charts and predictive densities will initially be of greatest use to the modelling team and the Economics Department more widely, but should subsequently be able to be introduced on a selective basis into specifically focussed MPC discussions.

The danger associated with too much routine use of evaluation tools during MPC would be the potential for "information overload" and consequent reduction of focus on the key events of the MPS round. Another key element required in an MPS forecasting round is the ability of the modellers to re-compute, fully understand and communicate their first-pass and subsequent forecasts in a sufficiently timely fashion. For example, Delbrück et al. (2008, p 36) report that, in an FPS context, "… the forecast may be adjusted (say) ten times over a week of MPC meetings." It will take time and ongoing experience of forecast rounds for the forecasts and richer stories from the KITT modelling team to iterate towards optimal turnaround times. However, even though the experience to date with using output from KITT at MPC has been quite limited, the flexibility and integrated nature of the new software underpinning the specification, estimation and evaluation of KITT, seems to have been matching modelling team expectations on turnaround times.

4. Summary judgments and recommendations, including on areas where the model might be improved

4.1.1 Assessment of the quality of KITT, relative to international best practice

- Summary judgment

The quality of this version of the KITT model is of a standard consistent with the RBNZ's modelling being back at the current frontier for international central bank practice. The capabilities of KITT have not yet been fully evaluated in all phases of an MPS forecasting round, but the richer understandings of economic transmission

mechanisms shown to date and the capacity for this aspect to be enhanced over time are encouraging.

- Specific qualities

- In terms of **model type**, the quality of KITT is consistent with international best practice models used by central bank forecasters and policy-modellers. Those models reflect the best available academic models and solution procedures. KITT's **economic structure** is consistent with continuously evolving international best practice for fourth generation (4G) models, as is KITT's **estimation methodology**.

- The importance of international best practice model **evaluation methodology** has been well recognised by the modelling team, and to date evaluation results have been presented in varying degrees of depth. Best practice model evaluation methodology now has to encompass a much wider and more demanding spectrum of statistical and economic properties, than was the case for earlier generations of macroeconomic models. The KITT modelling team has paid particularly strong attention to the identification aspect, and the conduct and write-up of this is the best I have seen to date. There has been sound but limited work on evaluating empirical fit, through assessing autocorrelation functions, standard deviations, a selection of contemporaneous cross correlations, and business cycle properties. A more intensive evaluation of business cycle properties has yet to be undertaken, as have evaluations of dynamic responses to a full set of permanent and anticipated shocks.

- The development and ready availability of the Matlab based IRIS Toolbox has enabled the KITT modelling team to take full advantage of powerful and flexible **computing software methodology** at the forefront of international best practice. For KITT, a particular benefit from the IRIS Toolbox is that its data assembly and compilation, model estimation and evaluation, and reporting of graphical and tabular results can all be done within the one software package.

- The RBNZ was a leader in **clarity and timeliness of communication** when FPS was launched. The RBNZ is continuing this element of best practice, with its imminent publication of both a non-technical Reserve Bank *Bulletin* article on KITT, and this technical research document.

4.1.2 KITT, as a worthy replacement for FPS

- Capability to tell sufficiently rich economic stories

- The combination of the core model's **economic structure,** and associated **greater numbers of shock variables** compared with those in FPS, provides a strong foundation for considerably richer stories to be told from KITT's business cycle dynamics.

- Results to date from KITT have the potential to provide **forecasts** which have substantially richer underpinnings, in the core areas of inflation, production sectors, housing investment, external sector influences and monetary policy. The

value of the central forecasts and associated stories should be additionally improved through KITT's associated modern **evaluation methodology**.

- The illustrative **impulse response simulations** presented are primarily temporary, unanticipated shocks. They provide an enhanced array of this type of shock relative to FPS, though there is currently limited capacity to present permanent shocks and anticipated shocks.

- The KITT modelling team and others in the RBNZ Economics Department face greater **communication challenges** than did those associated with FPS, and I would expect that education of the full range of potentially richer information from KITT to take rather longer than for FPS. Within reasonable time, however, I would expect that goal to be achieved.

- Can the estimation methods match the model to the data sufficiently satisfactorily?

- The **range of estimation and evaluation methods** available for KITT is more comprehensive and discerning than those adopted for FPS, and so have the capacity to lead to considerably improved matching of the model to the data.

- At this stage of development, the **multiple trends model (TM)** approach adopted for KITT has the capacity to improve the ability of the dynamic model to match the data rather better than would a full trends model.

- It is particularly important to give in depth attention to whether the structural parameters and structural shocks in a substantial sized DSGE model can be identified from the data. In this model write-up, particularly careful attention has been paid to **identification**.

- **Parameterisation** of the mix of calibrated and estimated **steady state values** has been achieved with the assistance of a numerical algorithm, and parameterisation of the **dynamic parameters** comes from the use of Bayesian methods. Both procedures have the potential to provide improved matches to the data.

- It is standard practice to use **autocorrelation functions, standard deviations and various (contemporaneous) cross-correlations** to benchmark a model's empirical fit against simulated empirical data. The model and simulated moments presented for key price and real GDP component variables provide valuable information on the degrees of empirical fit achieved to date. Some fits are already impressive, though results for some other variables do not match the data as well at this stage and point towards scope for further work.

- There has been limited assessment to date of the model's **business cycle properties.** It is recommended below that a more in depth assessment of these be undertaken.

- The model's ability to address uncertainty, **incorporate judgment**, and **assist in providing advice** to the Bank's *Monetary Policy Committee*?

- Modern stochastic models and solution methods provide an opportunity for richer depictions of stories associated with **uncertainty**, and the KITT modelling team have put together a selection of tools which can be used to provide additionally useful insights. These include: **predictive densities/fan charts** for key variables, and **event probability analysis**. Both have the potential to enhance one's understanding of the degree of uncertainty surrounding a central forecast track, though their routine presentation to MPC and in MPS may be less valuable than selective use for particular economic time periods, and should always be accompanied by the associated descriptive stories.

- **Forecast decomposition analysis** is not a tool which addresses issues of uncertainty directly, but has the threefold advantages of being disciplined by the economic structure built into KITT, of having the capacity to be tailored to particular areas of the model's economic activity, and being consistently integrated into stories advanced by fan chart and event probability analysis.

- Tools recently developed by the KITT modelling team have the potential to provide important new insights into how **judgment** has been incorporated. Initially, I expect the output from these tools will be of prime use to the modelling team, but as greater experience is gained, the output could feature on a selective basis to enrich MPC discussions.

- Collectively, the economic structure of KITT, the use of Bayesian estimation to assist in matching the model to the data, and the enlarged suite of evaluation tools have the potential to provide considerably richer, consistently structured **advice to** underpin discussions at **MPC**, the writing of the MPS, and the information conveyed to the wider public through other sources.

- A key element required in an MPS forecasting round is the **ability** of the modellers **to re-compute, fully understand and communicate** their first-pass and subsequent **forecast information in a sufficiently timely fashion**. I expect it will take time and ongoing experience of forecast rounds for the forecasts and richer stories from the KITT modelling team to iterate towards optimal turnaround times.

4.1.3 Areas where the model and this write-up could be improved

- Lesser, more detailed comments

These are summarised in the Appendix.

- Substantive recommendations

- I recommend that the **primary purpose and major specific role**s for KITT should be set down more clearly and prominently in chapter 1.

- In the context of the multiple detrended growth cycle modelling of KITT, I recommend that the **economy's steady state growth path**, around which the dynamics of KITT are modelled, be made more transparent. I also suggest that consideration be given to formally reviewing and making transparent at regular intervals all steady state values.

- In the current version of KITT, **monetary policy** is set according to a simple policy **rule** rather than from some optimisation derived rule. Consistent with the KITT modelling team's foreshadowed further consideration of alternative forms of simple monetary policy rule, I recommend that for the foreseeable future, specification of a simple instrument rule should be preferred to a rule from optimal policy under commitment.

- I recommend that when further substantive structural development of the model is to be undertaken, first priority could be given to enriching the **government sector**.

- I recommend that the write up of KITT make transparent how non-modelled variables such as unemployment and the labour force participation rate have been produced by leveraging off KITT model variables, and that in due course appropriate attention be given to the manner in which modelling of **labour market behaviour** might be suitably enriched.

- Particularly in light of KITT being designed as a model to "… replicate key stylised facts about the New Zealand economy." (Beneš et al., 2009, p 5), I recommend that a more in depth assessment of the model's **business cycle properties** be undertaken.

Dr Viv B Hall
28 June 2009

Appendix: Some lesser, more detailed comments

p 11, Figure 2.1: Is "Output" in the Foreign Output box a suitable term, given the output is from NZ?

p 15, Figure 2.2: Is there a channel from Commodity exports through to CPI Inflation, e.g. from dairy commodity export prices, or are the latter sufficiently reflected through the tradable sector (ex fuel)?

p 16: After reading the very good summary paragraph on the microfoundations of the household sector, which followed the informative paragraph on government and the monetary sector as economic agents, it seemed to me that the section 2.1 overview lacked an equivalently clear paragraph on the microfoundations of the firm sector. This was despite the earlier description of the production sector. I would have preferred to find very early in section 2.1 a succinct summary of the microfoundations of all the economic agents in the one place, before going on to read the sectoral and agent detail. Detail for each of these, including for the external sector economic agents, becomes evident as one goes along, but having this information in summary form up front would have helped me further. It might also be worthwhile making it clear at an early stage that household and external debt (i.e. *B*) are the same thing, and that there is no (net) government debt (implied on pp 16, 40 by government balancing its budget every period).

p 19, convention 5: Dixit and Stiglitz (1997)

p 22, in the second expression in (iv), should be P_t^c ? Also on p 22, a definition for the shock term, ε_t^{ω} ? Similarly, not every shock seems to be defined later on. Would it be useful to have a summary Table of all the shock variables?

I suggest that in various places, clarity on interest rates being nominal rather than real would have assisted, including on pp 27, 40, 42, 56, and 59. I got confirmation on p 56 that $\hat{r}$ was nominal (though $\hat{r}*$ doesn't have the description as nominal), so a nominal on pp 27, 40 and 42 would have helped me. Similarly, I wondered on p 56 about the time horizon of the interest rate. Implicitly, a representative short run one?

p 38: define S_t the exchange rate more precisely? e.g. make it clear that it is nominal and in terms of units of foreign currency per 1$NZ?

p 40, the definition of κ in equation (2.66): κ is the strength of influence of the gap between expected inflation and the inflation target rather than the gap itself?

p 50, first line under Manufactured exports: (2.59) should be added to the equation numbers?

p 60: placement of Figure 3.1? Currently seems placed too early, as it's only initially referred to on p 63?

p 61, 4th and 5th components of equations (3.7): in 3 places, should be C^h rather than C^s ? The latter also appears 3 times in Table 3.2, and once in Figure 3.1, on p 64

pp 62-63 and Table 3.2: it was good to see the baseline parameter values listed in Table 3.2, and almost all were readily interpretable. But 3.0811 for *b* could do with a few words of clarification in the paragraphs on pp 62-63?

p 63 and Figure 3.1: C^h and M^o rightly get singled out on p 63 for trends appearing too inflexible and on p 64 for applying judgments, but for the 2000s perhaps this is also the case for C^n , I^k and X^{υ} ?

p 63 and in chapter 6: decide on either "judgment" or "judgement", and then have consistency of spelling? My dictionaries say either is acceptable, but with a preference for "judgment"

p 67: Is it worthwhile stating briefly why the Bayesian methods approach was preferred to FIML?

pp 70, 65, TM steady state parameter values: Table 3.2 makes it clear these are for TM. Should the heading for Table 4.1 make it clear these are for the core KITT model?

p 70, in the *Estimated* panel: the line for "consumption share of fuel" has been duplicated

p 73, footnote: provide precise link to Chris Sims' website?

p 81, 7th line in paragraph: Table 4.4, not Table 4.5?

p 85: Should the chapter heading reflect that what is presented are *dynamic* properties of the model?

p 101, in s. 5.1.3: To me, the sacrifice ratio sentence was a distraction rather than adding value. It is well known that empirical values for these vary hugely for a multitude of reasons. I would delete it, or at best consign it to a footnote, and thereby keep the focus on the shock as carried out.

p 102: Title this as an "Exchange rate shock through the risk premium", or a "Risk premium (exchange rate)" shock?

p 103: Does presentation of the TWI exchange rate panel in this form make the reader question the validity of the shock, or perhaps even the model? Maybe present this panel as movements in a real exchange rate gap, as in Delbrück et al, 2008, Figure 8?

p 108: The note to Figure 5.11 seems a typo. Simply delete the note? On p 107, it is made clear that the blue lines are KITT and the dashed red lines are for FPS, but on the latter perhaps further make clear that it is the dynamics of the 2007 version of FPS (Delbrück et al, 2008, Figure 7)?

p 109: Reference to an FPS secondary cycle adds little? Delete?

p 114, 5 lines up: distributions, not distributes?

p 123, Figure 6.7, Title and heading on the first panel: should be *non*-tradable? See reference on p 120 to Figure 6.7

p 125, line 5: should be "… agents are not surprised …", rather then "surprised"?

p 131, line 4: typo, superfluous "it is"

p 132, first full sentence: It wasn't clear to me what this sentence meant. Delete it?

Chapter 7, pp131, 132: Can the focus of this important concluding chapter be tightened further?

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