Exploring the role of permanent and transitory shocks in explaining the business cycle

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1 Introduction

This paper is concerned with the issues that arise in building a small Dynamic Stochastic General Equilibrium (DSGE) model of the Australian economy. Our ultimate objective is to build a model that can be used to study long run economic growth and the business cycle. We agree with Cooley and Prescot's (1995) view that these are phenomena to be studied jointly rather than separately. Adopting this view has several implications for what constitutes the essential components of our a model. We see these as being: a major role for a persistent technology shock in driving economic activity; and consistency with a version of the Ramsey-Cass-Koopmans (RCK) exogenous growth model. Without the former it is not possible to generate realistic business cycle features; demand shocks alone are insufficient see Harding and Pagan (2007). The RCK exogenous growth model remains the simplest model available to encompass the salient features of economic growth which is why we rate it as essential.

We also take the methodological stance that it is desirable to obtain a satisfactory baseline model before adding other desirable features such as: money; openness to international trade, capital flows, and immigration; and price and wage stickiness.

In short we see small real business cycle (RBC) models as the natural starting point for our work. The Australian literature on such models is very sparse comprising one unpublished paper by Peter Summers (1998) who estimates a subset of parameters and calibrates other parameters such as the exponential discount factor.[1]

One possible explanation for the absence of an Australian literature is that it is not possible to estimate these models on Australian data. The primary objective of this paper is to find out whether RBC models can be estimated on Australian data. If such models can be estimated we also want to establish whether they yield plausible predictions about the risk free real interest rate. The latter feature is essential if the models are to be extended to incorporate money.

The second question that we explore relates to permanent and transitory shocks. Specifically, we are interested in the question of whether

- The technology shock is best modelled as permanent or transitory;
- Whether incorporating additional transitory shocks to government consumption expenditure and population are useful; and
- Whether there is evidence that additional shocks are required.

The third question that we begin to explore relates to the role of demography in RBC models and particularly in influencing consumption. Because the Australian literature on RBC models is almost non existent the bulk of this paper is dedicated to the task of creating a baseline for our work by estimating and evaluating several models on Australian data. This means that we do not spend nearly as much time as is desirable in discussing this issue which properly deserves a separate paper. We have kept some discussion of demography (mainly the effects of population growth) in this paper because it was emphasized in our initial discussions with the conference organizers.

The plan of the paper is as follows. Section 2 provides some empirical evidence on the relationship between population growth and consumption per capita. It is this evidence that motivates our desire to include population growth in RBC models of Australia.

The baseline models that we investigate are set out in section 3. These comprise:

1. King, Plosser and Rebelo's (1988), (KPR88) model;

[1] The models estimated by Peter Summers were King, Plosser and Rebelo's (1988) model and Christiano and Eichenbaum's (1992) model.

2. Hansen's (1985) model with indivisible labour, (Hansen85);

3. Christiano and Eichenbaum's (1992) model, (CE92)

4. Burnside, Eichenbaum and Rebelo's (1993) labour hoarding model (BER93).

These models were chosen because they are representative of the literature and provide a useful starting point from which we can address some of the fundamental questions raised above. The first order conditions for these models are set out in section 4.

We estimate the models using the Generalized Method of Moments (GMM). The main reason for using GMM is that economic theory provides information about the moments but does not provide information about the distribution from which shocks are drawn. So unless one is willing to go beyond the information provided by economic theory it is not possible to use maximum likelihood or Bayesian methods to estimate these models. The moment conditions are set out in section 5.

Results from estimating these models on Australian data are discussed in section 6. The tables of parameter estimates are in Appendix C.

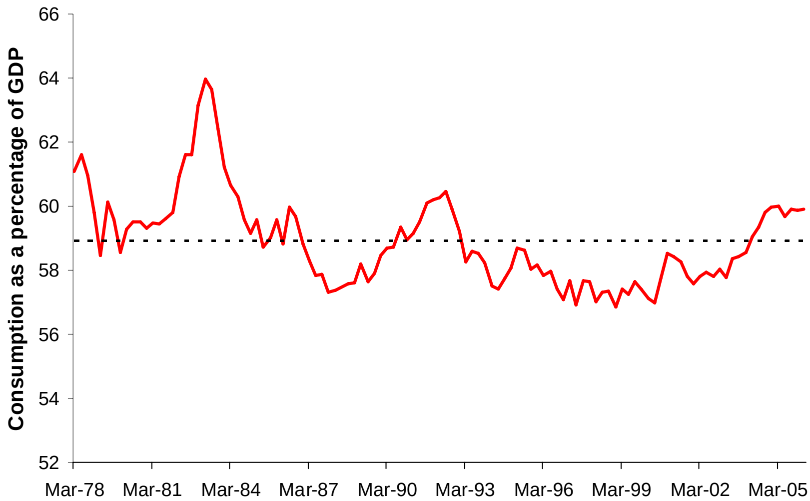
Conclusions are in section 7.

2 Demography and consumption expenditure

Figure 1 illustrates one of the difficulties facing those attempting to fit RBC models to Australian data — key ratios such as the consumption to GDP ratio exhibit considerable persistence. RBC models such as King Plosser and Rebelo (1988) and Hansen (1985) in contrast have such ratios returning quickly to their steady state. Christiano and Eichenbaum (1992) and Burnside Eichenbaum and Rebelo (1993) showed that it is possible to provide part of an explanation for such features by incorporating government expenditure which they assumed to be exogenous. BER also claim that one can improve the capacity to match some of these features if models are extended to include labour hoarding.

Demography is a potential cause of the persistence observed in important macroeconomics ratios. Equations (1), (2) and (3) show that the growth rate of the total population (n_t), the growth rate of the population net of

Figure 1: C/Y Australia, 1978.1: 2006:1



migration (nnm_t) and the growth rate of the working age population (nwa_t) are highly persistent processes.[2] Moreover, inspection of the three autoregressions reveals that they are processes with quite different dynamics. This, suggests that demographic factors such as the growth rates the population and the logarithm of the dependency ratio could potentially explain some of the persistence in macroeconomic ratios.

$$n_t = \underset{(0.000133)}{0.000318} + \underset{(0.098)}{0.954} n_{t-1} - \underset{(0.135)}{0.008} n_{t-2} + \underset{(0.135)}{0.001} n_{t-3} - \underset{(0.098)}{0.044} n_{t-4} + 0.0002\varepsilon_{nt} \quad (1)$$

$$\begin{aligned} nnm_t &= \underset{(0.0004)}{0.0007} - \underset{(0.084)}{0.047} nnm_{t-1} + \underset{(0.083)}{0.345} nnm_{t-2} + \underset{(0.083)}{0.002} nnm_{t-3} \\ &\quad + \underset{(0.083)}{0.482} nnm_{t-4} + 0.0006\varepsilon_{nnmt} \end{aligned} \quad (2)$$

$$\begin{aligned} nwa_t &= \underset{(0.0002)}{0.0002} + \underset{(0.092)}{0.890} nwa_{t-1} - \underset{(0.119)}{0.337} nwa_{t-2} + \underset{(0.084)}{0.245} nwa_{t-3} \\ &\quad + \underset{(0.053)}{0.141} nwa_{t-4} + 0.0004\varepsilon_{nwat} \end{aligned} \quad (3)$$

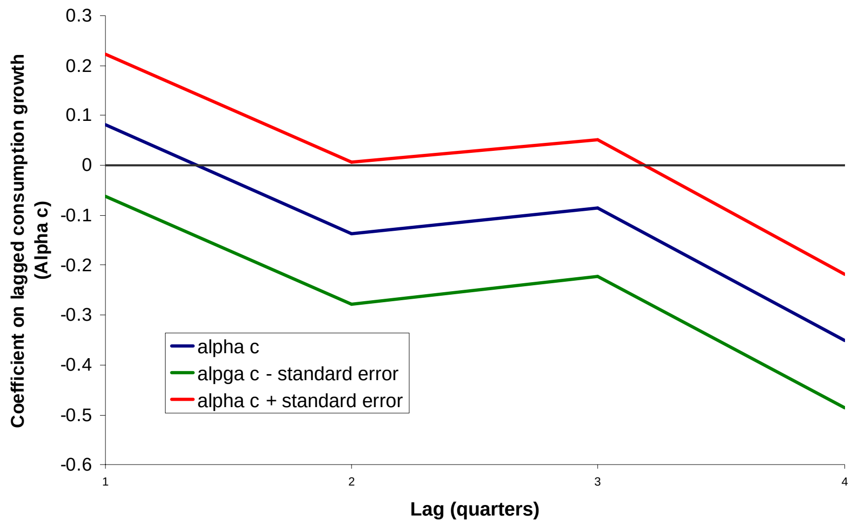
[2]The standard errors are in parentheses.

The next step is to investigate whether the various measures of population growth are correlated with the growth rate of consumption per capita (rc_t). A simple method to investigate this question involves regressing rc_t on its own lags plus the lags of n_t and nnm_t. Specifically, the following regression is estimated:

$$rc_t = \alpha_0 + \sum_{i=1}^{4} \alpha_i^c rc_{t-i} + \sum_{i=1}^{20} \alpha_i^n n_{t-i} + \sum_{i=1}^{20} \alpha_i^{nm} nnm_{t-i}$$

Plots of the various lag coefficients are shown in Figures 2, 3 and 4.

Figure 2: Plot of α_i^c coefficients and one standard error band

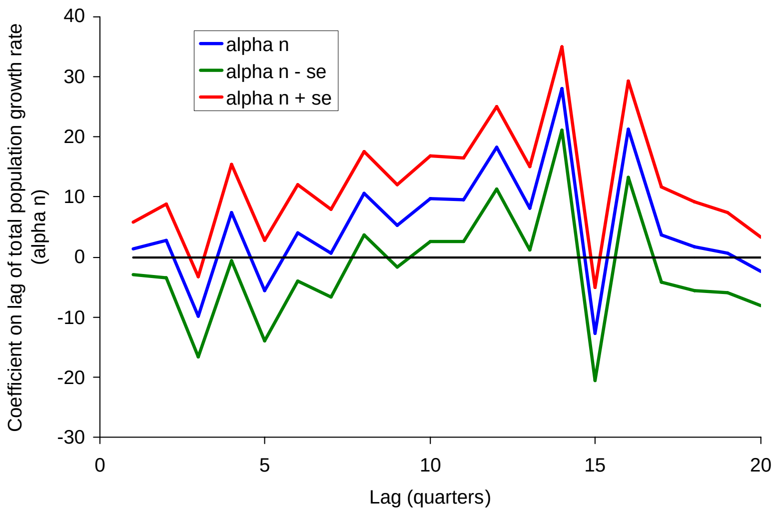


Only the fourth lag on rc_t is significantly different from zero. But I suspect this has more to do with neglected seasonality in the Australian national accounts rather than any economic phenomena.[3]

Turning to Figure 3 it is evident that total population growth has a positive effect on the growth rate of consumption per capita after 5 quarters and this effect strengthens out to about 15 quarters.

[3]See Harding (2002) for evidence on an earlier episode of neglected seasonality in the Australian National Accounts.

Figure 3: Plot of α_i^n coefficients and one standard error band



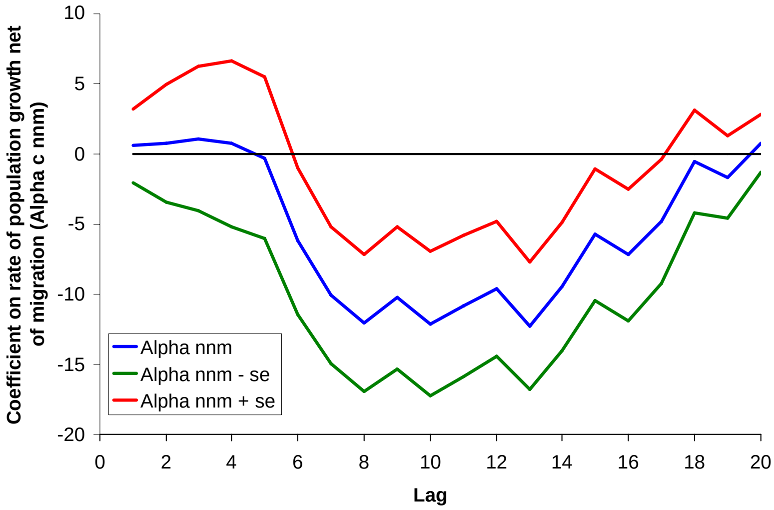
Population growth net of migration has the opposite effect on the growth rate of consumption per capita with negative lag coefficients arising after lags of five quarters and persisting out until about twenty quarters.

This evidence suggests several potential lines of research. One is to investigate these empirical relationships in more detail. Another, is to begin to explore how theory suggests population growth should be incorporated into RBC (and thus implicitly into New Keynesian) models. That is the task taken up in the next section. The evidence presented above suggests that an important issue will be how to handle natural increase versus migration. In this paper we propose to focus on the analysis assuming that all of the population growth comes from natural increase. To do otherwise we would need to depart from the representative agent assumption and that is a substantial undertaking.

3 The models

All of these models are similar in that they are Ramsey-Cass-Koopmans type exogenous growth models in which there live representative agents who

Figure 4: Plot of α_i^{nnm} coefficients and one standard error band



maximizes utility subject to the economy's resource constraints. The features of the models are discussed under the following headings: household's preferences, consumption and labour supply; production, market structure, technology and capital accumulation and first order conditions.

3.1 Households preferences, consumption and labour supply

Households have an endowment of time $(\overline{h})$ per period which they divide between hours of work (h_t) and leisure. On average, the typical household supplies h_t hours per period. They may choose to vary the effort x_t that they supply. They enjoy consumption services of c_t^{s*} units per period. It is convenient to express several of the variables in per effective units of labour terms (peul) so, for example, consumption services per effective unit of labour is $c_t^s = \frac{c_t^{s*}}{A_t}$. A complete listing of the notation for variables is in Appendix A Tables 1, 2 and 3. The notation for exogenous shocks is in table 4 and for coefficients is in table 5.

The typical households's expected discounted utility is

$$U_t = E_t L_t \sum_{j=t}^{\infty} \beta^{j-t} \frac{L_j}{L_t} u\left(A_j c_j^s, h_j, x_j\right) \tag{4}$$

where E_t denotes the expectation conditional on the information available at time (t), β is the exponential discount factor. L_t is the working age population. The term $\frac{L_j}{L_t}$ is there because the decision maker is assumed to weight future utility by the number of people enjoying that utility. This is as strong an assumption as the one that is currently made in RBC models where there no allowance made for the future population in weighting utility. Further work might include allowing for the weight given to future populations to be a function of population size thereby allowing one estimate the weight given to the future population. Another possibility would be to allow the weights to vary with the age structure of the population.

We distinguish between consumption services c_t^s and consumption expenditure c_t because in the BER and CE models the consumer may not value each dollar of expenditure on government consumption at the same rate that they value expenditure on private goods. Utility is also potentially influenced by hours worked (h_t) and labour effort (x_t).

The capital accumulation equation written in per effective units of labour (peul) terms is:[4]

$$k_t (1 + n_t)(1 + \eta) a_{t-1}^{\rho-1} e^{\varepsilon_t} = (1 - \delta) k_{t-1} + i_{t-1} \tag{5}$$

Where k_t is capital per effective unit of labour, n_t is the rate of population growth, η is the rate of growth of labour augmenting technical change, a_t is the deviation from trend of the rate of labour augmenting technical change, ρ is the AR(1) coefficient on the process for technical change, ε_t is the technology shock and i_t is investment per effective unit of labour.

The resource constraints faced by the household written in per effective units of labour (peul) terms are:

$$\begin{aligned} y_t &= c_t^p + g_t + i_t \qquad y_t = k_t^\theta (h_t x_t)^{1-\theta} \qquad a_t = a_{t-1}^\rho e^{\varepsilon_t} \\ c_t &= c_t^p + g_t \qquad c_t^s = c_t^p + \alpha g_t \qquad \frac{1+n_t}{1+n} = \left(\frac{1+n_{t-1}}{1+n}\right)^{\rho_n} e^{\varepsilon_{nt}} \end{aligned}$$

[4]See section for a discussion of how this constraint is obtained.

where c_t^p is private consumption expenditure (peul) and g_t is government expenditure (peul).

The utility functions employed are of the form[5]

$$u\left(A_t c_t^s, h_t, x_t\right) = \ln A_t c_t^s + b\left(h_t, x_t\right) \tag{6}$$

Where $b\left(h_t, x_t\right)$ represents the disutility of supplying labour effort. The various models differ in how hours worked (h_t) and labour effort (x_t) are supplied. These differences in specification are discussed below. In all of the models aggregate labour effort (H_t) is

$$H_t = L_t h_t x_t \tag{7}$$

where L_t is the number of persons.

3.2 Labour in KPR88

KPR88 assume that the typical household has $\overline{h}$ units of leisure and supplies h_t units of labour but labour effort cannot be varied and is set equal one $(x_t = 1)$. The disutility of labour function is

$$b\left(h_t, x_t\right) = \gamma \ln\left(\overline{h} - h_t\right) \tag{8}$$

3.3 Labour in Hansen85 and CE92

Hansen85 and CE92 make use of the assumption that workers face fixed costs of working ζ and trade lotteries over employment in which they work a fixed number of hours f per period. After incorporating these lotteries the disutility of labour function is

$$b^*\left(q_t, x_t\right) = \gamma q_t \ln\left(\overline{h} - \zeta\right) + \left(1 - q_t\right)\gamma \ln \overline{h}$$

Where q_t is the probability of working. In this model average hours worked is given by

$$h_t = q_t f \tag{9}$$

And we can use this to rewrite the typical agents disutility of labour function as

$$b\left(h_t, x_t\right) = \gamma_0 + \gamma^* h_t \tag{10}$$

[5] They are written this way because cst is in per effective units of labour terms recall that consumption per person is $c_t^* = A_t c_t^s$.

Where $\gamma^* = \frac{\gamma}{f}\left[\ln\left(\overline{h}-\zeta\right)-\ln\overline{h}\right]$, $\gamma_0 = \gamma\ln\overline{h}$. The result is that workers behave as if they face a disutility of labour function that is linear in average hours worked.

3.4 Labour in BER93

BER93 extend Hansen85 to allow for labour hoarding which they model as time variation in the intensity of labour effort (x_t) . They obtain the following disutility of labour function after allowing for lotteries over employment

$$b^*(q_t, x_t) = \gamma q_t \ln\left(\overline{h}-\zeta-x_t f\right)+(1-q_t)\gamma\ln\overline{h}$$

where all of the variables and coefficients are as defined for Hansen85 and CE92. We can proceed as for Hansen85 and CE92 to rewrite the typical agents utility function as

$$b(h_t, x_t) = \gamma\frac{h_t}{f}\ln\left(\overline{h}-\zeta-x_t f\right)+\left(1-\frac{h_t}{f}\right)\gamma\ln\overline{h}$$

Letting $\gamma^\dagger = \frac{\gamma}{f}$, $\gamma_0 = \gamma\ln\overline{h}$ we can rewrite this as

$$b(h_t, x_t) = \gamma_0+\gamma^*\left[\ln\left(\overline{h}-\zeta-x_t f\right)-\ln\overline{h}\right]h_t \qquad (11)$$

In this form the individual disutility of labour is linear in the hours worked but is non-linear in the intensity of labour effort,

3.5 Consumption in CE92 and BER93

In CE92 and BER93 consumption of the typical household is divided between private (c_t^{*p}) and government consumption g_t^* per person. It is convenient to assume that consumption services per person (c_t^{s*}) is a linear combination of private consumption and government consumption. So that

$$c_t^{s*} = c_t^{*p}+\alpha g_t^* \qquad (12)$$

CE92 and BER93 model government consumption expenditure as being exogenous. CE92 assume that $\alpha\in(0,1)$, meanwhile BER93 assume that government consumption expenditure provides no utility $(\alpha = 0)$. We also estimate α.

It is convenient to write government expenditure per effective unit of labour g_t as

$$g_t = \frac{g_t^*}{A_t} \tag{13}$$

We assume that g_t follows an $AR(1)$ process viz,

$$\frac{g_t}{g\left(1+\eta_G\right)^t} = \left(\frac{g_{t-1}}{g\left(1+\eta_G\right)^{t-1}}\right)^{\rho_G} e^{\varepsilon_{Gt}} \tag{14}$$

Where η_G is the difference between the trend rate of growth of government expenditure and labour augmenting technical change. Later we will test whether $\eta_G = 0$. In which case government expenditure grows at the same rate as labour augmenting technical change. In (14) ε_{Gt} is a government spending shock and has mean zero and variance σ_G. Thus, ρ_G measures the persistence in the deviation of government spending from proportionality with labour augmenting technological change.

In CE92 and BER 93 the shocks to technology and government expenditure are uncorrelated. We use a more general specification where

$$\varepsilon_{Gt} = \phi_{ga}\varepsilon_t + \phi_{gn}\varepsilon_{nt} + \nu_t$$

The idea here is that this represents a very simple model of government. It says that shocks to technology ε_t and population ε_{nt} can temporarily influence government consumption expenditure. The AR(1) coefficient ρ_G determines how long these effects last and the coefficients ϕ_{ga} and ϕ_{gn} determine the instantaneous correlation between technology shocks, population shocks and and government expenditure shocks.[6] Later we will test whether $\rho_G = 0$, $\phi_{ga} = 0$ and $\phi_{gn} = 0$.

A more general specification of the exogenous variables would model them as following a VAR.

3.6 Production and capital accumulation

Output (Y_t) is produced according to a constant returns to scale (CRS) aggregate production function

$$Y_t = F\left(K_t, H_t A_t\right) \tag{15}$$

[6] A more general specification might model the three exogenous variables, technology, population and government expenditure via a VAR.

where K_t is the aggregate capital stock, H_t is aggregate human labour effort, and A_t is the level of labour augmenting technology. We employ the assumption, common in the RBC literature, that the production function is Cobb-Douglas

$$F(K_t, H_tA_t) = K_t^\theta (H_tA_t)^{1-\theta}$$

It is convenient to use the constant returns to scale assumption to write

$$F(K_t, H_tA_t) = L_tk_t^\theta (h_tx_tA_t)^{1-\theta}$$

Where $k_t^* = \frac{K_t}{L_t}$ is capital per person. So that output per person y_t^* is produced according to

$$y_t^* = k_t^{*\theta} (h_tx_tA_t)^{1-\theta}$$

We can write the production function in terms of per effective units of labour by dividing both sides by A_t to obtain

$$y_t = k_t^\theta (h_tx_t)^{1-\theta}$$

Where $y_t = \frac{y_t^*}{A_t}$ and $k_t = \frac{k_t^*}{A_t}$ are output per effective unit of labour and capital per effective unit of labour respectively.

Labour augmenting technical change has a deterministic component $\left(A_0 (1+\eta)^t\right)$ and a stochastic component a_t where

$$a_t = \frac{A_t}{A_0 (1+\eta)^t}$$

The stochastic component evolves according to

$$a_t = a_{t-1}^\rho (1+\varepsilon_t) \qquad \textit{where } \varepsilon_t \textit{ is iid and } E\varepsilon_t = 0 \tag{16}$$

where $|\rho| \leq 1$, $\rho = 1$ for CE92 and we estimate all versions of the models for $\rho = 1$.

The aggregate capital accumulation equation is

$$K_t = (1-\delta) K_{t-1} + I_{t-1} \tag{17}$$

And the equation for the accumulation of capital per worker is

$$k_t^* (1+n_t) = (1-\delta) k_{t-1}^* + i_{t-1}^*$$

Where $i_t^* = \frac{I_t}{L_t}$ is investment per person. Dividing both sides by A_{t-1} and using the fact that investment per effective unit of labour is defined as $i_t = \frac{i_t^*}{A_t}$ and $\frac{A_t}{A_{t-1}} = (1+\eta) a_{t-1}^\rho e^{\varepsilon_t}$ yields the capital accumulation equation written in per effective units of labour

$$k_t (1+n_t)(1+\eta) a_{t-1}^\rho e^{\varepsilon_t} = (1-\delta) k_{t-1} + i_{t-1}$$

4 First order conditions

Note in most cases I have expressed the first order conditions in per effective unit of labour terms. This facilitates the derivation of the steady state and impulse responses.

4.1 Consumption and saving

For all the models the first order condition for the typical household choosing consumption optimally subject to its budget is

$$1 = E_t \beta \left(1 + n_{t+1}\right) \frac{A_t c_t^s}{A_{t+1} c_{t+1}^s} \left(1 + r_{t+1}\right) \tag{18}$$

where r_{t+1} is the real interest rate.

4.2 Hours worked

For the KPR88 model the first order condition for choosing hours worked optimally equates the marginal product of labour valued in terms of consumption goods with the marginal disutility of labour. The marginal product of labour is $MPL = (1-\theta) A_t \frac{y_t}{h_t}$. The marginal utility of consumption is $MUC = \frac{A_t}{c_t^s}$. The marginal product of labour valued in terms of consumption goods then is

$$MPL * MUC = (1-\theta) \frac{y_t}{c_t^s h_t}$$

The first order condition for hours worked in KPR88 then is

$$(1-\theta) \frac{y_t}{c_t^s h_t} - \frac{\gamma}{\overline{h} - h_t} = 0 \tag{19}$$

Notice that KPR88 implies that $\frac{y_t}{c_t^s} \frac{\overline{h} - h_t}{h_t} = \frac{\gamma}{1-\theta}$ which is a constant. Later we will evaluate the extent to which this holds in the data.

For the Hansen85 and CE92 model the first order condition for optimal choice of hours worked is

$$(1-\theta) \frac{y_t}{c_t^s h_t} - \gamma^* = 0 \tag{20}$$

For the BER93 model the first order condition for optimal choice of hours worked is

$$(1-\theta)\frac{y_t}{c_t^s h_t} = \gamma^{\dagger}\left[\ln\left(\overline{h}-\zeta-x_t f\right)-\ln\overline{h}\right] \tag{21}$$

And the first order condition for labour hoarding is

$$(1-\theta)\frac{y_t}{c_t^s x_t} - \gamma^{\dagger}\frac{h_t f}{\overline{h}-\zeta-x_t f} = 0$$

This can be rearranged to express effort in terms of $\frac{h_t c_t}{y_t}$,

$$x_t = \frac{\left(\overline{h}-\zeta\right)\frac{1}{f}}{\frac{\gamma^{\dagger}}{1-\theta}\frac{h_t c_t^s}{y_t}+1} \tag{22}$$

Substituting for x_t in (21) yields

$$(1-\theta)\frac{y_t}{c_t^s h_t} = \gamma^{\dagger}\ln\left(\left(\overline{h}-\zeta\right)\frac{\frac{\gamma^{\dagger}}{1-\theta}\frac{h_t c_t^s}{y_t}}{\frac{\gamma^{\dagger}}{1-\theta}\frac{h_t c_t^s}{y_t}+1}\right) - \gamma^{\dagger}\ln\overline{h} \tag{23}$$

Notice that this equation implies that $\frac{y_t}{h_t c_t^s}$ is a constant in BER (as it is in CE92, and Hansen85). In the evaluation of this model we will examine whether this restriction holds in the data.

An important implication of $\frac{y_t}{h_t c_t^s}$ being a constant is that effort (x_t) is constant. This feature of the BER model does not appear to be recognized in the literature.

It seems that if one wants to induce time varying effort in the BER model it is necessary to introduce exogenous variation in

- the cost of travel to work ζ perhaps though variation in the price of fuel and transport services;
- maximum available hours $\overline{h}$ perhaps through variation in factors such as the number of children which affect the time available for work; and
- a shock to $\overline{h}$.

4.3 Optimal allocation of capital

Since firms employ capital optimally we have that

$$MPK_t \equiv \theta \frac{Y_t}{K_t} = \theta \frac{y_t}{k_t} = r_t + \delta \tag{24}$$

For later reference it is worth noting that this result is based on the assumption that capital is the sole non-labour factor of production. If this assumption is false (24) will overstate the marginal product of capital. This feature is important when examining the implications of RBC models for the risk free real interest rate.

5 Moment conditions

It is useful to separate the moment conditions into those that are common across models and those that are specific to a particular model. I express the moment conditions in terms of observable variables by translating back from per effective unit of labour to per capita terms.

5.1 Common moment conditions

The following moment conditions are common across the models.

$$E\left[1 - \theta - s_{Lt}\right] = 0 \tag{25}$$

Where s_{Lt} is the share of income going to labour.

$$E\left[\beta\left(1 + n_{t+1}\right) \frac{c_t^{*p} + \alpha g_t^*}{c_{t+1}^{*p} + \alpha g_{t+1}^*} \left(1 + \theta \frac{y_{t+1}^*}{k_{t+1}^*} - \delta\right) - 1\right] = 0 \tag{26}$$

$$E\left[(1 - \delta) - \frac{k_{t+1}^*\left(1 + n_{t+1}\right)}{k_t^*} + \frac{i_t^*}{k_t^*}\right] = 0. \tag{27}$$

$$E\left[\beta\left(1 + n_{t+1}\right) \frac{c_t^{*p} + \alpha g_t^*}{c_{t+1}^{*p} + \alpha g_{t+1}^*} \left(1 + \theta \frac{y_{t+1}^*}{k_{t+1}^*} - \delta\right) - 1\right] \frac{g_t^*}{g_{t-1}^*} = 0 \tag{28}$$

Where s_{Lt} is the share of income going to labour. Notice that these four equations contain four unknown parameters $(\theta, \beta, \delta, \alpha)$ and are just identified so that we can obtain estimates via MM. We only use (28) for those cases where α is to be estimated.

5.2 Moment conditions for hours worked

The moment conditions for choice of hours worked depend on whether labour input is assumed to be divisible (29), indivisible (30) or indivisible with effort chosen optimally (31).

$$E\left[(1-\theta)\frac{y_t^*}{c_t^{*s}} - \gamma\frac{h_t}{\overline{h}-h_t}\right] = 0. \tag{29}$$

For Hansen85 and CE92 the moment condition on hours worked is

$$E\left[(1-\theta)\frac{y_t^*}{c_t^{*s}h_t} - \gamma^*\right] \tag{30}$$

And for the BER93 the moment condition is

$$E_t\left[(1-\theta)\frac{y_t^*}{c_t^{*s}h_t} - \gamma^\dagger \ln\left(\left(\overline{h}-\zeta\right)\frac{\frac{\gamma^\dagger}{1-\theta}\frac{h_t c_t^{*s}}{y_t^*}}{\frac{\gamma^\dagger}{1-\theta}\frac{h_t c_t^{*s}}{y_t^*}+1}\right) + \gamma^\dagger \ln\overline{h}\right] = 0 \tag{31}$$

Where $\gamma^\dagger = \frac{\gamma}{f}$. In the estimation we assume that $\overline{h} = 1369$ hours per quarter (a maximum of 15 hours per day) is available for work, $f = 520$ hours per quarter (40 hours per week) and $\zeta = 60$ hours per quarter which is the assumption that travel time to work is about 40 minutes per day.

5.3 Moment conditions related to the exogenous processes

Here the exogenous processes vary across the models. It is useful to define the Solow residual S_t as

$$S_t = \frac{y_t}{k_t^\theta\left(h_t x_t\right)^{1-\theta}} = A_t^{1-\theta}$$

For KPR88, Hansen85 and CE92 $x_t = 1$. And for BER93 we back out observed labour effort x_t from the first order conditions (22). Taking logs of the Solow residual we have,

$$\ln A_t = \frac{1}{1-\theta}\ln S_t$$

5.3.1 Moment conditions when technology is stationary

Technology is assumed to have a linear time trend

$$\ln A_t = \ln A_0 + \ln(1+\eta)\, t + \ln a_t$$

and we can write the moment conditions for the case where technology is a stationary AR(1) as follows

$$E_t \left[\frac{1}{1-\theta} \ln S_t - \ln A_0 - \ln(1+\eta)\, t \right] = 0 \tag{32}$$

$$E_t \left[\left(\frac{1}{1-\theta} \ln S_t - \ln A_0 - \ln(1+\eta)\, t \right) \frac{t}{T} \right] = 0 \tag{33}$$

$$E_t \left[(\ln a_t - \rho \ln a_{t-1}) \ln a_{t-1} \right] = 0 \tag{34}$$

$$E_t \left[(\ln a_t - \rho \ln a_{t-1})^2 - \sigma^2 \right] = 0 \tag{35}$$

5.3.2 Technology follows a unit root process

CE92 specify that technology is a random walk so that $\rho = 1$ and the moment conditions defining η and σ^2 become

$$E_t \left[\ln S_t - \ln S_{t-1} - \ln(1+\eta) \right] = 0 \tag{36}$$

$$E_t \left[(\ln S_t - \ln S_{t-1} - \ln(1+\eta))^2 - \sigma^2 \right] = 0 \tag{37}$$

Government expenditure CE92 and BER93 specify that government expenditure per effective unit of labour (g_t) follows an AR(1) process with steady state g. Define z_t as

$$z_t = \ln g_t - \ln g - \ln(1+\eta_G)\, t \tag{38}$$

where $\eta_G = 0$ if government expenditure per person grows at the same rate as technology

$$E z_t = 0 \tag{39}$$

$$E z_t \frac{t}{T} = 0 \tag{40}$$

$$E_t \left[(z_{t+1} - \rho_G z_t)\, z_t \right] = 0 \tag{41}$$

$$E_t \left[(z_{t+1} - \rho_G z_t)^2 - \sigma_g^2 \right] = 0 \tag{42}$$

For CE92 and BER93 models, equations (39) - (42) are sufficient to estimate g, η_G, ρ_G and σ_G^2.

6 Results

The discussion above results in 32 different specifications of the models depending on whether:

1. Population growth is included;
2. Technology is trend stationary or difference stationary;
3. The value placed on government consumption expenditure (α) in CE92 and BER93 is
   (a) Set to zero;
   (b) Set to one; or
   (c) estimated.

These 32 models were estimated via GMM on quarterly Australian data covering the period 1978:Q1 - 2006:Q1.[7] The estimated models comprise:

- Four versions of KPR88 (models 1 to 4). The estimated parameters are in table 6 of appendix C.
- Four versions of Hansen85 (models 5 to 8). The estimated parameters are in table 7 of appendix C.
- Twelve versions of CE92 (models 9 to 20). The estimated parameters are in tables 8, 9 and 10 of appendix C.
- Twelve versions of BER93 (models 21 to 32). The estimated parameters are in tables 11, 12 and 13 of appendix C.

The main findings are summarized below.

[7] A detail explanation of the data used for the estimation can be found in the Appendix B.

6.1 Main findings

It proved to possible to successfully estimate all 32 versions of the models.[8] Moreover, in those cases where theory suggested that the estimates of the deep structural parameters should be similar across the models this is what we found — often the estimates would be identical up to four or five decimal places. Importantly, this was not because the estimation stopped near the starting values. In addition, where theory suggests that estimated parameters should differ across the models this was also what we found.

Our estimates of β, the exponential rate of discount, ranged from 0.9787 to 0.983 in those cases where no population growth was allowed for and 0.9717 to 0.9764 for the cases where population growth is allowed for. The estimates of β are very precise with standard deviations of about 0.0007.

The exponential rate of discount is an important component in calculating the risk free real interest rate which is defined from the Euler equation as

$$r_f = \frac{1+\eta}{\beta\,(1+\overline{n})} - 1$$

Thus for the cases where there is no population growth the annual risk free real rate ranges from 8.8 to 10.7 per cent. Allowing for population growth yielded estimated annual risk free real interest rates of 10.4 to 12.3 per cent.[9] These are implausibly high when compared to the Literature. Fuentes and Gredig (2007), for example, report 26 studies of the risk free real interest rate in 14 economies and find estimates in the range of 1 to 4 per cent. The only study for Australia is Basdevant et. al. (2004) who report estimates in the range 2.0 to 2.5 per cent for Australia.

The explanation for our finding of an implausibly high neutral real interest rate is that we estimate the coefficient on labour in the production function $(1-\theta)$ as the average of the factor income share going to labour. That is we estimate θ as the average of the share of income going to all factors other than labour. These comprise produced factors of production such as capital and non produced factors such as a land, subsoil assets, native standing timber and the spectrum. The ABS National Accounts show that capital represents

[8]Because the models are just identified there are p non-linear equations in p unknown parameters. This feature allowed me to use equation solver in GAUSS to obtain the numerical solutions.

[9]Summers (1998) did not estimate the β, instead he sets this parameter at 0.986 so that it is consistent with a real rate of interest of 8.06 per cent per annum.

about 65 to 70 per cent of non-labour factors of production.[10] The main other factor is land (including subsoil assets). Let Z be non produced factors of production, then allowing for these the Cobb_Douglas aggregate production function can be written as

$$Y = K^{\kappa\theta} Z^{(1-\kappa)\theta} (LA)^{1-\theta}$$

Where κ is the share of capital in the value of total assets and θ is the share of factor income going to all assets.

The marginal product of capital, allowing for land in the production function, is

$$MPK = \kappa * \theta \frac{Y}{K}$$

Making allowance for the effect of land on the MPK, the consumption Euler equation becomes

$$E\left[\beta\left(1+n_{t+1}\right)\frac{c_t^{*p}+\alpha g_t^*}{c_{t+1}^{*p}+\alpha g_{t+1}^*}\left(1+\kappa\times\theta\frac{y_{t+1}^*}{k_{t+1}^*}-\delta\right)-1\right]=0$$

Using $\kappa = 0.7$ yields an estimate of β of 0.993 when population growth is not allowed for and 0.990 when population growth is allowed for. These estimates of β imply a risk free real interest rate of about 3 per cent per year which is in ball park that is typically suggested by the literature (See Fuentes (2007)).

The risk neutral real interest rate plays an important role in models used for monetary policy. And it is desirable that baseline models can produce plausible estimates of the risk free rate. The discussion above suggests that stochastic growth models need to be modified to allow for non-produced assets, particularly land, if they are to produce plausible estimates of the risk free interest rate.

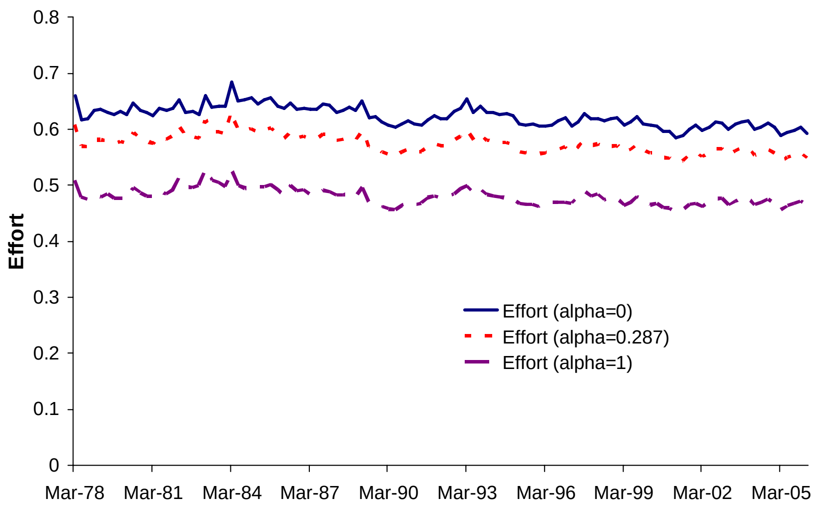
In RBC models the persistence of the technology shock ρ and the standard deviation of the technology shock σ are key parameters. We found little evidence to suggest that $\rho < 1$. Peter Summers (1998) by way of contrast estimated $\rho = 0.76$.

Setting $\rho = 1$ made little difference to our estimates of the standard deviation of the technology shock. For the KPR88 and Hansen95 models we estimated σ to be 0.028 to 0.029 respectively. We obtained slightly lower estimates of 0.027 for CE92. For BER93 we found substantially lower estimates of 0.014 for the standard deviation of the technology shock.

[10]See table 20 page 40 of Australian National Accounts 2006-07. ABS Cat No 5204.0.

The BER93 model obtains a substantially lower estimate of the standard deviation of the technology shock because effort levels are allowed to vary. Effort x_t can be backed out of the model via equation (22). The exact level of effort will vary across the models according to the extent to which government consumption is valued. We look at three cases $\alpha = 0$ (government consumption is not valued), the estimated value $\alpha = 0.287$ and $\alpha = 1$. The three implied effort levels are shown in Figure 5.

Figure 5: Implied effort levels in the BER93 model for three values of α



In the data the effort levels vary and are reasonably well approximated by an AR(1). For example when $\alpha = 1$ the AR(1)

$$x_t - 0.62 = 0.79\,(x_{t-1} - 0.62) + 0.011\epsilon_t$$

provides a reasonable approximation to the evolution of x_t.

This finding contradicts the theory which says that, in the absence of a shock to available hours, x_t is non stochastic and is constant over time. One way of interpreting this finding is that the BER model has too few shocks to be consistent with the data. In future drafts of the paper we propose to incorporate the required additional shock to available hours.

Labour labour augmenting technology is estimated to grow at a rate between 0.4 and 0.5 of one per cent per quarter (1.6 to 2.0 per cent per year) depending on the particular model that is under investigation. This is comparable with the the rate of 0.38 per cent per quarter found by Peter Summers.

Government expenditure was found to grow at almost the same rate as technology η_G ranged between -0.0004 and -0.0010 depending on the particular model. The larger values were found in the BER models and were statistically significantly different from zero.[11] But such small differences have little economic significance and we conclude that for most economic applications it is reasonable to conclude that government expenditure per capita co-trends with labour augmenting technical change.

The shock to government expenditure per effective unit of labour is highly persistent with estimates of ρ_G ranging between 0.82 and 0.88 depending on the particular model. The shocks to government expenditure per effective unit of labour have a standard deviation of between 0.030 to 0.035 depending on the model.

We estimated the depreciation rate vary between 0.6 per cent per quarter (2.5 per cent per year) to 1.2 per cent per quarter (4.9 per cent per year) depending on the model employed.

In estimating the model we allowed the working age population to follow an AR(1) process. The estimated mean rate of population growth was 0.36 per cent per quarter with $\rho_n = 0.60$ and the standard deviation of the population shocks being 0.0006.

Unlike other investigators we have allowed the three shocks in the model to be contemporaneously correlated. However, our view is that a finding a strong contemporaneous correlation between the three shocks is best viewed as a sign of misspecification of the model. It is difficult to think of a mechanism that would lead to a strong contemporaneous correlation between the shock to population and the shock to technology for example. Similarly, it is difficult to see what economic mechanism would lead to a strong contemporaneous correlation between the technology shock and the shock to government expenditure.

We find that it is only in BER93 with the value placed on government consumption (α) estimated, that the three shocks are not contemporaneously correlated. Thus it is this version of BER93 (model 32 in table 13) that is our preferred model.[12] However, for the reasons discussed above we feel that

[11] This needs further discussion as η_G is the coefficient on a time trend and some allowance may need to be made for this feature in the distribution theory.

[12] For this model the unrestricted estimate of ρ was 0.97 and there was very little differ-

this model is short one shock.

7 Conclusion

Those who favour New Keynesian (NK) models may see our approach of focusing on RBC models as unusual or even undesirable. We see NK and RBC models as complementary explanations of macroeconomic dynamics. NK models typically focus on short run macroeconomic dynamics arising from the interaction of demand shocks with nominal frictions. In such models capital accumulation, and technology shocks are in the background with the focus being on demand and quantities such as the output gap $y_t - y_t^p$ where y_t and y_t^p are the logarithms of output and potential output respectively. If one views potential output as what would occur in the absence of nominal rigidities then it makes sense to explore the use of RBC models to provide the theory behind potential output.

We have shown that a range of small RBC models can be successfully estimated on Australian data. However, we found that it will be necessary to include non-produced factors of production, such as land, if these models are to generate plausible estimates of the risk free real interest rate. We view this as an essential feature of models that are to be extended to incorporate money and are intended to discuss monetary policy.

In considering the solutions to these models we have found that one model (BER93) is incompletely specified and requires an additional (transitory) shock if it is to be consistent with the data.

We have briefly discussed the role of demographic factors in RBC models and have outlined the theory and evidence that would support inclusion of those factors. However, there is much more that could be done in this area.

ence in the other parameters if a unit root was imposed.

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A Appendix: Notation

Table 1: Definition of aggregate variables

Symbol	Formula	Definition
L_t		Population
A_t		Level of labour augmenting technology
C_t		Aggregate consumption expenditure
C_t^s		Consumption services
C_t^p		Private consumption expenditure
Y_t		GDP
I_t		Investment expenditure
G_t		Government expenditure
H_t		Aggregate labour effort
K_t		Aggregate capital stock
U_t		Aggregate utility
n_t	$\frac{L_t}{L_{t-1}}$	Population growth rate
a_t	$\frac{A_t}{A_0(1+n)^t}$	Detrended labour augmenting technology

Table 2: Definition of per capita variables and shocks

Symbol	Formula	Definition
c_t^*	$\frac{C_t}{L_t}$	Consumption expenditure per worker
c_t^{s*}	$\frac{C_t^s}{L_t}$	Consumption services per worker
c_t^{p*}	$\frac{C_t^p}{L_t}$	Private consumption expenditure per worker
y_t^*	$\frac{Y_t}{L_t}$	GDP per worker
i_t^*	$\frac{I_t}{L_t}$	Investment expenditure per worker
g_t^*	$\frac{G_t}{L_t}$	Government expenditure per worker
k_t^*	$\frac{K_t}{L_t}$	Capital per worker

Table 3: Definition of per capita variables

Symbol	Formula	Definition
c_t	$\frac{c_t^*}{A_t}$	Consumption expenditure per effective unit of labour
c_t^s	$\frac{c_t^{s*}}{A_t}$	Consumption services per effective unit of labour
c_t^p	$\frac{c_t^{p*}}{A_t}$	Private consumption expenditure per effective unit of labour
y_t	$\frac{y_t^*}{A_t}$	GDP per effective unit of labour
i_t	$\frac{I_t}{L_t}$	Investment expenditure per effective unit of labour
g_t	$\frac{g_t^*}{A_t}$	Government expenditure per effective unit of labour
k_t	$\frac{k_t^*}{A_t}$	Capital per effective unit of labour
h_t		Average hours worked per person
x_t		Effort per person
q_t		Probability of working
r_t		Real interest rate

Table 4: Definition of shocks

Shock	Definition
ε_t	Technology shock
ν_t	Shock to population growth rate
ε_{gt}	Shock to government expenditure per effective unit of labour

Table 5: Definition of coefficents

Symbol	Definition
β	Exponential discount factor[13]
ρ	AR(1) coefficient on technological change
η	Trend rate of growth of labour augmenting technology
θ	Coefficient on capital in constant returns to scale Cobb-Douglas production functio
α	Rate at which households 'value' government consumption
A_0	Initial level of labour augmenting technology
n	Trend rate of population growth
ρ_n	AR(1) coefficient on population growth
γ	Disutility of labour in Hansen model
γ_0	
γ^*	
$\gamma^\dagger$	
ζ	Fixed cost of working (travel time)
f	Fixed number of hours worked per period if employed
δ	Depreciation rate
σ	Standard deviation of technology shock
η_G	Trend growth rate of government consumption expenditure
ρ_G	AR(1) coefficient on government expenditure per effective unit of labour
σ_G	Standard deviation of shock to government expenditure
σ_{ga}	Covariance between shocks to government expenditure and technology
σ_{gn}	Covariance between shocks to government expenditure and population growth
$\underline{g}$	Steady state government expenditure per effective unit of labour
$\overline{h}$	Maximum units of leisure per quarter

B Appendix: Data

For estimation of the RBC models, I use Australian quarterly data, which is published by the Australian Bureau of Statistics (ABS). All the aggregate variables, such as investment, and consumption data are available from 1959:Q3. However, the longest available time series for hours worked is only from 1978:Q1. Therefore, all the time series are adjusted according to this date.

The data specification used in this paper is as follows:

1. Consumption is defined as total private consumption expenditures. The data is seasonally adjusted and measured in chained volume with (2003/2004) as the base year. Source: AusStats, Australian National Accounts: National Income, Expenditure and Product (Table 58. Household final consumption expenditure).

2. Investment is defined as total private investment. The data is seasonally adjusted and measured in chained volume with (2003/2004) as the base year. Source: AusStats, Australian National Accounts: National Income, Expenditure and Product (Table 9. Expenditure on GDP).

3. Output is defined as the sum of consumption (1) and investment (2).

4. Hours worked is defined as hours of wage and salary workers on private, non-farm payrolls. Source: ABS Labour Force Statistics (Total hours: wage and salary earners) (LWHQ.UQ).

5. Labour income share is defined as ratio of compensation of employees to total factor income from the National Accounts Database (SNAQ).

6. Depreciation rate is defined as the ratio of consumption of fixed capital to capital stock. The consumption of fixed capital is obtained from the National Accounts database (SNAQ), while the capital stock data is obtained from the ABS Treasury Model Database.

7. Rate of return of risk free asset is defined as the 90 day Treasury bill rate minus the inflation rate. The 90 day Treasury bill rate is obtained from the ABS Treasury Model Database (VTEQ.AR_R190). The inflation rate series is obtained from the RBA Bulletin Database (GCPIAGYP).

To convert output, consumption, investment and capital stock series to per capita terms, we divide each series by the civilian population, aged 15-64. Source: ABS Labour Force Statistics (Civilian population) (LCHM.UN).

C Estimated parameters

Table 6: GMM estimates of KPR88, Australian data 1978:1 to 2006:1

	1		2		3		4	
	Estimate	s.e	Estimate	s.e	Estimate	s.e	Estimate	s.e
β	0.9834	0.0007	0.9764	0.0008	0.9834	0.0007	0.9764	0.0008
θ	0.4393	0.0036	0.4393	0.0036	0.4393	0.0036	0.4393	0.0036
η	0.0039	0.0005	0.0039	0.00045	0.0039	0.00045	0.0039	0.00045
δ	0.0118	0.0004	0.0082	0.0005	0.0118	0.0004	0.0082	0.0005
γ	3.1322	0.0417	3.1322	0.0417	3.1322	0.0417	3.1322	0.0417
ρ	0.9228	0.0326	0.9228	0.0326	1	na	1	na
σ	0.0282	0.0027	0.0282	0.0027	0.0282	0.0029	0.0289	0.0029
A_0	1.3338	0.0556	1.3338	0.0556	1.3338	0.0556	1.3338	0.0556
n			0.0036	0.0002			0.0036	0.0002
σ_n			0.0006	0.0002			0.0006	0.0002
ρ_n			0.5972	0.2288			0.5972	0.2288
ρ_{an}			0.1108	0.0600			0.0883	0.0598

Table 7: GMM estimates of Hansen85, Australian data 1978:1 to 2006:1

	5		6		7		8	
	Estimate	s.e	Estimate	s.e	Estimate	s.e	Estimate	s.e
β	0.9834	0.0007	0.9764	0.0008	0.9834	0.0007	0.9764	0.0008
θ	0.4393	0.0036	0.4393	0.0036	0.4393	0.0036	0.4393	0.0036
η	0.0039	0.0005	0.0039	0.00045	0.0039	0.00045	0.0039	0.00045
δ	0.0118	0.0004	0.0082	0.0005	0.0118	0.0004	0.0082	0.0005
γ^*	-0.0028	3.2e-5	-0.0028	3.2e-5	-0.0028	3.2e-5	-0.0028	3.2e-5
ρ	0.9228	0.0326	0.9228	0.0326	1	na	1	na
σ	0.0282	0.0027	0.0282	0.0027	0.0288	0.0027	0.0288	0.0029
A_0	1.3338	0.0556	1.3338	0.0556	1.3338	0.0556	1.3338	0.0556
n			0.0036	0.0002			0.0036	0.0002
σ_n			0.0006	0.0002			0.0006	0.0002
ρ_n			0.5972	0.2288			0.5972	0.2288
ρ_{an}			0.1108	0.0600			0.0883	0.0598

Table 8: GMM estimates of CE92, Australian data 1978:1 to 2006:1

	9		10		11		12	
	Estimate	s.e	Estimate	s.e	Estimate	s.e	Estimate	s.e
β	0.9788	0.0006	0.9787	0.0008	0.9788	0.0006	0.9788	0.0006
θ	0.4393	0.0036	0.4393	0.0036	0.4393	0.0036	0.4393	0.0036
η	0.0041	0.0004	0.0041	0.0004	0.0041	0.0004	0.0041	0.0004
δ	0.0099	0.0004	0.0099	0.0004	0.0099	0.0004	0.0099	0.0004
γ^*	-0.0037	0.0004	-0.0026	3.2e-5	-0.0033	0.0002	-0.0037	0.0004
ρ	0.8879	0.0426	0.8879	0.0426	0.8879	0.0426	1	na
σ	0.0264	0.0030	0.0264	0.0030	0.0264	0.0030	0.0273	0.0033
η_G	-0.0004	0.0004	-0.0004	0.0004	-0.0004	0.0004	-0.0004	0.0004
ρ_G	0.8230	0.0558	0.8230	0.0558	0.8230	0.0558	0.8230	0.0558
σ_G	0.0353	0.0027	0.0353	0.0027	0.0353	0.0027	0.0353	0.0027
g	6.0837	0.0521	6.0837	0.0521	6.0837	0.0521	6.0837	0.0521
A_0	1.6566	0.0472	1.6566	0.0472	1.6566	0.0472	1.3338	0.0556
α	0	na	1	na	0.2869	0.1888	0	na
n			0.0036	0.0002			0.0036	0.0002
σ_n			0.0006	0.0002			0.0006	0.0002
ρ_n			0.5972	0.2288			0.5972	0.2288
ρ_{an}			0.1108	0.0600			0.0883	0.0598
ρ_{ag}	-0.4370	0.0859	-0.4370	0.0859	-0.4370	0.0859	-0.4030	0.0871
ρ_{ng}								

Table 9: GMM estimates of CE92 continued, Australian data 1978:1 to 2006:1

	13		14		15		16	
	Estimate	s.e	Estimate	s.e	Estimate	s.e	Estimate	s.e
β	0.9788	0.0006	0.9788	0.0006	0.9788	0.0006	0.9717	0.0010
θ	0.4393	0.0036	0.4393	0.0036	0.4393	0.0036	0.4393	0.0036
η	0.0041	0.0004	0.0041	0.0004	0.0041	0.0004	0.0041	0.0004
δ	0.0099	0.0004	0.0099	0.0004	0.0063	0.0005	0.0063	0.0005
γ^*	-0.0026	3.2e-5	-0.0033	0.0002	-0.0037	4.4e-5	-0.0037	0.0004
ρ	1	na	1	na	0.8879	0.0426	1	na
σ	0.0273	0.0030	0.0273	0.0033	0.0264	0.0030	0.0265	0.0030
η_G	-0.0004	0.0004	-0.0004	0.0004	-0.0004	0.0004	-0.0004	0.0004
ρ_G	0.8230	0.0558	0.8230	0.0558	0.8230	0.0558	0.8230	0.0558
σ_G	0.0353	0.0027	0.0353	0.0027	0.0353	0.0027	0.0353	0.0027
g	6.0837	0.0521	6.0837	0.0521	6.0837	0.0521	6.0837	0.0521
A_0	1.6566	0.0472	1.6566	0.0472	1.6566	0.0472	1.3338	0.0556
α	1	na	0.2869	0.1888	0	na	0	na
n					0.0036	0.0002	0.0036	0.0002
σ_n					0.0006	0.0002	0.0006	0.0002
ρ_n					0.5971	0.2288	0.5972	0.2288
ρ_{an}					0.1830	0.0649	0.1830	0.0649
ρ_{ag}	-0.4030	0.0871	-0.4030	0.0871	-0.4370	0.0859	-0.4370	0.0859
ρ_{ng}					-0.0800	0.0603	-0.0800	0.0603

Table 10: GMM estimates of CE92 continued, Australian data 1978:1 to 2006:1

	17		18		19		20	
	Estimate	s.e	Estimate	s.e	Estimate	s.e	Estimate	s.e
β	0.9718	0.0007	0.9718	0.0007	0.9717	0.0006	0.9718	0.0010
θ	0.4393	0.0036	0.4393	0.0036	0.4393	0.0036	0.4393	0.0036
η	0.0041	0.0004	0.0041	0.0004	0.0041	0.0004	0.0041	0.0004
δ	0.0099	0.0004	0.0099	0.0004	0.0063	0.0005	0.0063	0.0005
γ^*	-0.0033	0.0002	-0.0037	4.4e-5	-0.0026	3.2e-5	-0.0033	0.0002
ρ	0.8879	0.0426	1	na	1	na	1	na
σ	0.0273	0.0030	0.0273	0.0033	0.0273	0.0033	0.0265	0.0030
η_G	-0.0004	0.0004	-0.0004	0.0004	-0.0004	0.0004	-0.0004	0.0004
ρ_G	0.8230	0.0558	0.8230	0.0558	0.8230	0.0558	0.8230	0.0558
σ_G	0.0353	0.0027	0.0353	0.0027	0.0353	0.0027	0.0353	0.0027
g	6.0837	0.0521	6.0837	0.0521	6.0837	0.0521	6.0837	0.0521
A_0	1.6566	0.0472	1.6566	0.0472	1.6566	0.0472	1.3338	0.0556
α	0.2887	0.1903	0	na	1	na	0.2887	0.1903
n	0.0036	0.0002	0.0036	0.0002	0.0036	0.0002	0.0036	0.0002
σ_n	0.0006	0.0002	0.0006	0.0002	0.0006	0.0002	0.0006	0.0002
ρ_n	0.5971	0.2288	0.5971	0.2288	0.5971	0.2288	0.5971	0.2288
ρ_{an}	0.1830	0.0649	0.1550	0.0682	0.1550	0.0682	0.1550	0.0682
ρ_{ag}	-0.4370	0.0859	-0.4030	0.0871	-0.4030	0.0871	-0.4030	0.0871
ρ_{ng}	-0.0800	0.0603	-0.0800	0.0603	-0.0800	0.0603	-0.0800	0.0603

Table 11: GMM estimates of BER93, Australian data 1978:1 to 2006:1

	21		22		23		24	
	Estimate	s.e	Estimate	s.e	Estimate	s.e	Estimate	s.e
β	0.9788	0.0006	0.9787	0.0009	0.9788	0.0006	0.9788	0.0006
θ	0.4393	0.0036	0.4393	0.0036	0.4393	0.0036	0.4393	0.0036
η	0.0048	0.0004	0.0046	0.0004	0.0047	0.0004	0.0047	0.0004
δ	0.0010	0.0004	0.0099	0.0004	0.0099	0.0004	0.0099	0.0004
γ^*	0.0112	0.0001	0.0080	9.8e-5	0.0100	0.0007	0.0112	0.0001
ρ	0.9723	0.0197	0.9540	0.0240	0.9677	0.0212	1	na
σ	0.0136	0.0013	0.0169	0.0014	0.0144	0.0016	0.0136	0.0013
η_G	-0.0010	0.0004	-0.0009	0.0003	-0.0010	0.0004	-0.0010	0.0004
ρ_G	0.8499	0.0493	0.8752	0.0417	0.8583	0.0481	0.8499	0.0493
σ_G	0.0324	0.0026	0.0253	0.0027	0.0299	0.0032	0.0324	0.0026
g	5.6486	0.0507	5.6418	0.0530	5.6462	0.0549	5.647	0.0561
A_0	2.0917	0.0526	2.0985	0.0503	2.0941	0.0514	1.3338	0.0556
α	0	na	1	na	0.2869	0.1888	0	na
n								
σ_n								
ρ_n								
ρ_{an}								
ρ_{ag}	-0.0603	0.0774	0.2967	0.0865	0.0982	0.0980	-0.0347	0.0797
ρ_{ng}								

Table 12: GMM estimates ofBER93 continued, Australian data 1978:1 to 2006:1

	25		26		27		28	
	Estimate	s.e	Estimate	s.e	Estimate	s.e	Estimate	s.e
β	0.9787	0.0009	0.9788	0.0006	0.9788	0.0006	0.9717	0.0010
θ	0.4393	0.0036	0.4393	0.0036	0.4393	0.0036	0.4393	0.0036
η	0.0046	0.0004	0.0047	0.0004	0.0041	0.0004	0.0041	0.0004
δ	0.0099	0.0004	0.0099	0.0004	0.0063	0.0005	0.0063	0.0005
γ^*	0.0080	9.7e-5	0.010	0.0007	0.0112	0.0001	-0.0037	0.0004
ρ	1	na	1	na	0.9723	0.0197	0.9540	0.0240
σ	0.0171	0.0015	0.0145	0.0016	0.0136	0.0013	0.0265	0.0030
η_G	-0.0009	0.0003	-0.0010	0.0004	-0.0010	0.0004	-0.0004	0.0004
ρ_G	0.8752	0.0417	0.8583	0.0481	0.8499	0.0493	0.8230	0.0558
σ_G	0.0253	0.0020	0.0299	0.0032	0.0324	0.0026	0.0353	0.0027
g	5.6418	0.0530	5.6462	0.0548	5.6486	0.0561	6.0837	0.0521
A_0	2.0985	0.0503	2.0941	0.0514	2.0917	0.0526	2.0985	0.0502
α	1	na	0.2869	0.1888	0	na	1	na
n					0.0036	0.0002	0.0036	0.0002
σ_n					0.0006	0.0002	0.0006	0.0002
ρ_n					0.5972	0.2288	0.5972	0.2288
ρ_{an}					-0.0206	0.0792	0.0344	0.0643
ρ_{ag}	0.3286	0.0875	0.1257	0.1009	-0.0603	0.0774	0.2967	0.0865
ρ_{ng}					-0.0591	0.0794	0.0503	0.0790

Table 13: GMM estimates of BER93 continued, Australian data 1978:1 to 2006:1

	29		30		31		32	
	Estimate	s.e	Estimate	s.e	Estimate	s.e	Estimate	s.e
β	0.9718	0.0007	0.9718	0.0007	0.9717	0.0006	0.9718	0.0010
θ	0.4393	0.0036	0.4393	0.0036	0.4393	0.0036	0.4393	0.0036
η	0.0047	0.0004	0.0048	0.0004	0.0046	0.0004	0.0041	0.0004
δ	0.0063	0.0005	0.0063	0.0005	0.0063	0.0005	0.0063	0.0005
γ^*	0.0100	0.0007	0.0112	0.0001	0.0080	9.7e-5	-0.0033	0.0002
ρ	0.9677	0.0213	1	na	1	na	1	na
σ	0.0144	0.0015	0.0136	0.0013	0.0171	0.0015	0.0265	0.0030
η_G	-0.0010	0.0004	-0.0010	0.0004	-0.0008	0.0003	-0.0004	0.0004
ρ_G	0.8583	0.0483	0.8499	0.0493	0.8752	0.0417	0.8230	0.0558
σ_G	0.0298	0.0032	0.0324	0.0026	0.0253	0.0020	0.0353	0.0027
g	5.6462	0.0548	5.6486	0.0561	5.6418	0.0530	6.0837	0.0521
A_0	2.0941	0.0515	2.0917	0.0526	2.0985	0.0503	1.3338	0.0556
α	0.2887	0.1903	0	na	1	na	0.2887	0.1903
n	0.0036	0.0002	0.0036	0.0002	0.0036	0.0002	0.0036	0.0002
σ_n	0.0006	0.0002	0.0006	0.0002	0.0006	0.0002	0.0006	0.0002
ρ_n	0.5971	0.2288	0.5971	0.2288	0.5971	0.2288	0.5971	0.2288
ρ_{an}	0.0015	0.0753	-0.0320	0.0757	0.0193	0.0630	-0.0110	0.0720
ρ_{ag}	0.0991	0.1022	-0.0347	0.0797	0.3286	0.0875	0.1265	0.1057
ρ_{ng}	0.0564	0.0797	0.0592	0.0794	0.0503	0.0790	0.0564	0.0797