DP/12/2008
(English Version)

BANK OF THAILAND
DISCUSSION PAPER

The Bank of Thailand Structural Model for Policy Analysis

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The Bank of Thailand Structural Model for Policy Analysis*

by

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December 17, 2008

Abstract

This paper presents the Bank of Thailand's new model based on the dynamic stochastic general equilibrium (DSGE) paradigm. The paper details the model structure of a small open economy, model parameterization, and model properties. The purpose of this DSGE model is to provide a coherent economic interpretation of the workings of the Thai economy consistent with microeconomic foundation.

1. Introduction

This section provides a concise introduction to the new modeling approach associated with dynamic stochastic general equilibrium (DSGE). In what follows, we present a review of traditional macroeconometric models, and later provide a description of DSGE models, emphasizing their contributions to economic modeling and policy analysis.

1.1. Traditional Macroeconometric Models

Macro models, including the Bank of Thailand macroeconomic model (BOTMM), are intended to capture aggregate relationships between various economic variables based on historical data. In addition to being

*This working paper is prepared for a workshop on economic models at the Bank of Thailand to be held in December 2008. The views expressed in this paper are those of the author and do not necessarily reflect the views of the Bank of Thailand.

†Email: suracht@bot.or.th. The author wishes to thank members of the Bank of Thailand DSGE Working Group, namely Ashvin Ahuja, Davina Kunvipusilkul, Runchana Pongsaparn, Roong Poshyananda Mallikamas, Amporn Saengmanee, Pranee Sutthasri, and Sukpinrat Vongsinsirikul—for several helpful discussions and guidance in preparing this document.

relatively easy to construct, important advantages of these models are that they describe key linkages in the economy in a straightforward manner and that they provide short-term forecasts that are accurate to a certain extent.

However, each equation in macro models is based loosely on economic theory (for example, consumption is modeled as a function of disposable income, some measure of interest rates, and inflation) and not derived from the first principle—i.e., not explicitly derived from optimization by economic agents. In addition, a heavy emphasis on statistical fit can lead to models that lack critical features such as rational expectations. The absence of such features makes these empirically based models possibly misspecified and vulnerable to the Lucas critique.

1.2. DSGE Models

DSGE modeling, termed by Goodfriend and King (1997) as the "new neoclassical synthesis," results from two once-competing lines of economic research. The new neoclassical synthesis combines the neoclassical real business cycle framework of rational optimizing agents (*à la* Kydland and Prescott, 1982) with the New Keynesian framework of market imperfections (such as nominal rigidities and imperfect competition) to create a unified theory of business cycle analysis. Thus, in this new framework monetary policy does have real effects in the short run, while in the long run monetary policy can influence only nominal variables and is therefore neutral with respect to real variables. In short, DSGE models have Keynesian features in the short run and new classical features in the long run.

What are the main features commonly characterizing DSGE models? By *dynamic* and *stochastic* it means that random shocks affect how endogenous variables evolve over time—instead of having deterministic paths completely autonomous from uncertainty surrounding the economy. *General equilibrium* means that relationships between variables are derived based on optimizing behavior of economic agents at the micro level. For example, households maximize expected utility given budget constraints. Firms set prices by maximizing expected profit subject to household demand and production technology. The monetary authority usually operates under a rule which is endogenous to the state of the economy (for example, raising the nominal interest rate when inflation rises and raising it enough so that inflationary pressures fall). Whereas such micro behavior is implicitly assumed in macro models, it is explicitly modeled in the general equilibrium setting.

An illustration of micro foundation on the part of households is given as follows. Households must choose the optimal allocation of income between consumption and savings, as well as the optimal allocation of time between work and leisure, subject to the constraint that their spending today and planned asset holdings for tomorrow does not exceed the income they receive today plus asset holdings carried forward from yesterday. Solutions to this optimization are called first-order conditions, and these equations will constitute the dynamics of DSGE models. A well-known first-order condition is the Euler equation for consumption, according to which consumption evolves over time in such a manner that households will be indifferent between consuming today and postponing it to tomorrow. In the Euler equation there are parameters governing the underlying household behavior, for example, one specifying how much households want to consume today instead of tomorrow and another characterizing how much households are risk averse to uncertain developments in the economy. Such parameters underlying behavior of economic agents are called *deep parameters*, which are absent in macro models. In sum, the consumption equation in DSGE models is derived explicitly as a solution to the problem facing households at the micro level. It is different from its counterpart in macro models, where consumption is assumed to be a function of variables suggested by theory. Those variables are possibly chosen based on different theoretical contexts and thus not related in a coherent framework as in DSGE models.

1.3. Why DSGE Models?

Models differ depending on their intended purpose, and no single economic model can answer all questions that are relevant to monetary policy. As mentioned above, a purely statistical model usually do well as a short-term forecasting device. However, parameters in empirically based models would be chosen on the basis of statistical fit and would be difficult to relate to the underlying economics of how agents and markets behave.

With the economic structure of the model more important than fitting the data, one important benefit from DSGE models is the explicit role of expectations. Within the DSGE framework the expectations formation process is modeled explicitly. This is particularly important, given that it is one of the key channels through which monetary policy affects economic outcomes, and that the fundamental role of monetary policy is to provide an anchor for inflation and inflation expectations. In contrast to DSGE models where the role of expectations is emphasized, purely statistical forecasting models are usually silent on this issue. In fact, if expectations play any role in macro models, they are often modeled as purely adaptive—agents form their expectations about what will happen in the future based on what happened in the past—or are constructed on an ad hoc basis. Parameters are consequently assumed to be stable across policy regimes in reduced-form equations of macro models. However, Lucas (1976) argues that if expectations were formed rationally—agents do not make systematic errors when predicting the future as implied by adaptive expectations—the parameters in reduced-form equations would in fact depend on agents' expectations of policy. In short, with rational expectations, the aggregate relationships in macro models would not likely be stable if there were important changes in policy regime. It is thus naive to try to evaluate policies based on aggregated historical data. If we do want to predict the effect of a policy experiment, we must model deep parameters that govern individual behavior. It is only in that case can we predict what individuals will do conditional on changes in policy. In short, only in the general equilibrium context where aggregate behavior is motivated by deep parameters that economic dynamics are correctly captured despite policy changes.

1.4. DSGE Modeling at the Bank of Thailand

The Monetary Policy Group of the Bank of Thailand has been in the process of constructing a general equilibrium model characterizing the Thai economy (Tanboon, 2007b, 2008). Building such a model is not an easy task, as it requires thorough understanding of the economy, a good command of micro and macro theory, familiarity with data, and programming proficiency. Some central banks have been using DSGE models for some time in conjunction with existing models. Others have actively engaged in building ones only recently. We at the Bank of Thailand believe that, in addition to providing state-of-the-art tools, DSGE models will help stimulate central bank research, provide an effective framework for monetary policy analysis and forecasting, and promote further insights into the workings of the economy.

2. The Model

This section provides a detailed description of the model. There are four types of agents interacting in the model economy: households, firms, banks, and the fiscal and monetary authorities. Each of the first three explicitly maximizes an objective function subject to a set of well-defined constraints. Households maximize their utility subject to a budget constraint. Firms maximizes profits subject to production functions. Banks take deposits from households and lend to firms that face financial frictions—i.e., those that have to borrow to finance their input costs before profits are realized. Meanwhile, the government consumes and the central bank sets the policy interest rate according to stylized fiscal and monetary rules. In what follows, each type of economic agents is described in details.

2.1. Households

There is a continuum of households optimizing their utility by taking various decisions on consumption and investment, labor and capital supplied to firms, and financial asset holdings. Algebraically, the representative household maximizes

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \left[(1-\chi) \log \tilde{C}_t - \varphi^L \frac{L_t^{1+\eta}}{1+\eta} \right] \tag{2.1}$$

subject to

$$P_t^D (C_t + I_t) + D_t \leq (1 + R_{t-1}) D_{t-1} + W_t L_t + R_t^K K_t + \textstyle\sum_j \Phi_j \tag{2.2}$$

$$K_{t+1} \leq (1-\delta) K_t + F(I_t, I_{t-1}). \tag{2.3}$$

In the utility function (2.1), $\tilde{C}_t$ is the habit-adjusted consumption which depends on C_t and C_{t-1} and the parameter χ (more below). L_t is labor service supplied to firms, with η the inverse of the Frisch elasticity of labor supply and φ^L the scaling parameter for the disutility of supplying labor. β is the discount factor. E_0 is the expectation operator conditional on the information at time 0.

In the budget constraint (2.2), C_t and I_t denote respectively consumption and investment at time t, K_t denotes capital service supplied to firms, and D_t denotes deposits with banks. The price of consumption and investment goods are similar and given by P_t^D. W_t and R_t^K are the prices of labor and capital—namely, the nominal wage and the nominal rental price of capital—respectively. R_t is the interest rate on deposits that is also equal to the policy interest rate. Φ_j denotes firm's j's profits that are remitted to the households who are the ultimate owners of firms.

In the capital accumulation constraint (2.3), $F(\cdot)$ is an investment function (to be described below).

The timing convention in this quarterly model is as follows. In each period t, D_{t-1} is predetermined and D_t is the stock of deposits to be determined at the end of period, which will earn the gross rate of interest $1 + R_t$ when held for one period. Also, at the conclusion of each period t, households determine K_{t+1}—the amount of capital to accumulate into the next period.

2.1.1. Consumption and Investment Decisions In order to generate persistent consumption and investment dynamics that roughly match stylized facts of the Thai economy (see Appendix A), we introduce consumption habit persistence and investment adjustment costs in the model setup before deriving the first-order conditions that characterize short-term dynamics.

Consumption habit persistence. It is assumed that utility obtained from consumption in this period does not depend on how much goods are consumed today, but instead depends on this period's consumption with respect to some "habit," which is in turn related to the previous period's consumption. Algebraically,

$$\tilde{C}_t = \frac{C_t - \chi h_t}{1-\chi} \quad \text{with} \quad h_t = (1+\alpha)C_{t-1}. \tag{2.4}$$

$\tilde{C}_t$ is the habit-adjusted consumption that enters the household's utility function, C_t is today's consumption, and h_t is the level of habit. In the simple setting where the steady-state growth rate of the economy, α, is zero, we have $h_t = C_{t-1}$. Here the household obtains utility from consumption only if today it consumes more than some fraction χ of yesterday's consumption. When $\alpha > 0$, the reference point needs to be adjusted up instead of simply taking some fraction of yesterday's consumption as a benchmark. How strongly the household refers to past consumption depends on the value of the parameter χ that governs habit persistence. When $\chi = 0$, the household completely disregards the previous period's consumption. Finally, note that in the steady state

$$\tilde{C}_t^{ss} = \frac{C_t^{ss} - \chi(1+\alpha)C_{t-1}^{ss}}{1-\chi} = \frac{C_t^{ss} - \chi C_t^{ss}}{1-\chi} = C_t^{ss}.$$

That is, habit persistence is irrelevant along the balanced growth path.

Investment adjustment costs. In a simple case where adjustment costs are absent, $F(I_t, I_{t-1}) = I_t$ in the capital accumulation dynamics (2.3). That is, investment that the household makes this period is fully transformed into capital in the next period, and we have in equilibrium the usual capital dynamics

$$K_{t+1} = (1-\delta)K_t + I_t.$$

However, when it is costly to adjust investment, the amount of capital accumulated throughout this period is not equal to investment made in the period, but is instead a function of investment this period and the period before. Such real rigidities can be algebraically expressed as

$$K_{t+1} = (1-\delta)K_t + F(I_t, I_{t-1})$$

where $F(I_t, I_{t-1})$ is less than I_t. In the present model $F(I_t, I_{t-1})$ takes the form:

$$F(I_t, I_{t-1}) = \left[1 - \frac{\xi^I}{2}\left(\frac{I_t}{I_{t-1}} - (1+\alpha)\right)^2\right] I_t \tag{2.5}$$

where ξ^I is the investment adjustment cost parameter. Note that when $\xi^I = 0$, $F(I_t, I_{t-1}) = I_t$. For $\xi^I > 0$, there will be real costs incurred when the (gross) rate growth of investment, I_t/I_{t-1}, is different from the rate at which the economy grows along the balanced growth path, $1 + \alpha$.

Given the household's setting as specified in (2.1)–(2.3) and the real rigidities in consumption and investment described in (2.4)–(2.5), the household's intertemporal problem with respect to consumption and investment decisions can be solved as follows. First, the Lagrangian is given by

$$
\begin{aligned}
\mathcal{L} = \mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \Bigg\{ & (1-\chi) \log \tilde{C}_t - \varphi^L \frac{L_t^{1+\eta}}{1+\eta} \\
& + \lambda_t \Big[(1 + R_{t-1}) D_{t-1} + W_t L_t + R_t^K K_t + \textstyle\sum_j \Phi_j \\
& \quad - (1-\chi) P_t^D \tilde{C}_t - \chi P_t^D h_t - P_t^D I_t - D_t \Big] \\
& + \lambda_t Q_t^K \left[(1-\delta) K_t + F(I_t, I_{t-1}) - K_{t+1} \right] \Big\}
\end{aligned}
$$

where λ_t is the marginal utility of nominal income and Q_t^K is the shadow price of capital (in nominal terms). Note that we have used the fact that $P_t^D C_t = (1-\chi) P_t^D \tilde{C}_t + \chi P_t^D h_t$ that follows from equation (2.4).

The first-order condition obtained from setting $\partial\mathcal{L}/\partial\tilde{C}_t = 0$ is given by

$$\frac{1}{\tilde{C}_t} = \lambda_t P_t^D.$$

In words, utility forsaken by consuming one unit less $(1/\tilde{C}_t)$ is equal to the nominal income gained from not consuming that unit of consumption (i.e., P_t^D—the price of one unit of the consumption good) converted into utility terms by multiplying by the marginal utility of one unit of nominal income (the Lagrange multiplier, λ_t).

The first-order condition obtained from setting $\partial\mathcal{L}/\partial K_{t+1} = 0$ is given by

$$Q_t^K = \beta \mathrm{E}_t \frac{\lambda_{t+1}}{\lambda_t} \left[R_{t+1}^K + (1-\delta) Q_{t+1}^K \right].$$

That is, the price of one unit of capital this period is equal to the expected discounted gain in the next period from renting out the acquired unit of capital plus its remaining value after depreciation.

The first-order condition obtained from setting $\partial\mathcal{L}/\partial I_t = 0$ is given by

$$\frac{Q_t^K}{P_t^D} = \frac{1}{F_1(I_t, I_{t-1})} \left[1 - \beta \mathrm{E}_t \frac{\lambda_{t+1}}{\lambda_t} \frac{Q_{t+1}^K}{P_t^D} F_2(I_{t+1}, I_t) \right].$$

The left hand side is Tobin's q, which is the ratio of the shadow value of capital to the replacement cost of capital. In the simple case where

$F(I_t, I_{t-1}) = I_t$, $F_1(I_t, I_{t-1}) = \partial I_t/\partial I_t = 1$ and $F_2(I_{t+1}, I_t) = \partial I_{t+1}/\partial I_t = 0$, we have the well-known equilibrium condition given by $Q_t^K/P_t^D = 1$. On the contrary, there will be more (less) investment if the ratio of the shadow value of capital to the cost of acquiring it is greater (less) than unity. Given the functional form of $F(I_t, I_{t-1})$ above, we can write out the first-order condition for investment as

$$\frac{Q_t^K}{P_t^D} = \frac{1}{1 - \xi^I \frac{I_t}{I_{t-1}}\left[\frac{I_t}{I_{t-1}} - (1+\alpha)\right] - \frac{\xi^I}{2}\left[\frac{I_t}{I_{t-1}} - (1+\alpha)\right]^2} \times \left[1 - \xi^I \beta \mathrm{E}_t \frac{\lambda_{t+1}}{\lambda_t}\frac{Q_{t+1}^K}{P_t^D}\left(\frac{I_{t+1}}{I_t}\right)^2 \left[\frac{I_{t+1}}{I_t} - (1+\alpha)\right]\right].$$

2.1.2. Wage Setting and Labor Supply Decisions It is assumed that the continuum of monopolistically competitive households supplies differentiated labor to firms as a production input. As in Erceg, Henderson, and Levin (2000) and Christiano, Eichenbaum, and Evans (2005), it is instructive to assume a labor aggregator (or an "employment agency") that combines households' differentiated labor into a bundle and sets the price of that bundle on behalf of the households.

In the first stage the representative household makes the labor supply decision. The first-order condition obtained from setting $\partial\mathcal{L}/\partial L_t = 0$ is given by

$$\lambda_t Q_t^L = \varphi^L L_t^\eta.$$

In utility terms, the shadow value of labor service—which is the product of the shadow price of labor, Q_t^L, times the Lagrange multiplier, λ_t—equals the disutility of supplying labor, $\varphi^L L_t^\eta$. Note that the above equation is a generalization of the competitive wage setting where the price of labor service is equal to the marginal cost, $W_t = Q_t^L$, with the usual first-order condition for labor supply given by $\lambda_t W_t = \varphi^L L_t^\eta$.

In the second stage the labor aggregator sets the nominal wage on behalf of the household. In a hypothetical flexible-price setting, the optimal wage (W_t^*) is set as a wage markup (μ^W) over marginal cost (Q_t^L):

$$W_t^* = \mu^W Q_t^L.$$

In the present model where wage rigidities are present, the labor aggregator wishes to set wage, W_t, as close as possible to W_t^*, but also needs to take account of wage indexation such that this period's wage inflation, ΔW_t, is not too different from the previous period's wage inflation, $\Delta\bar{W}_{t-1}$, which is taken as given. That is, the labor aggregator solves

$$\min_{W_t} \mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \left[(W_t - W_t^*)^2 + \xi^W(\Delta W_t - \Delta\bar{W}_{t-1})^2\right]$$

where ξ^W represents the degree of wage rigidity. The case for which no rigidity is present is given by $\xi^W = 0$; here the labor aggregator will indeed set W_t equal to W_t^* in each period. When $\xi^W > 0$, the first-order condition with respect to W_t is given by

$$W_t = W_t^* + \xi^W \left[-\left(\Delta W_t - \Delta \bar{W}_{t-1}\right) + \beta \left(\mathrm{E}_t \Delta W_{t+1} - \Delta \bar{W}_t\right)\right].$$

According to the first term in the square brackets, if this period's wage inflation is higher than the previous period's, then W_t is too high and needs to be adjusted down. The second term in the square brackets states that, if the expected wage inflation in the next period happens to be higher than this period's, $\Delta W_{t+1} - \Delta \bar{W}_t > 0$, then the present period's wage is too low relative to W_{t+1} and is suboptimal, and thus needs to be adjusted up.

2.1.3. Saving and Borrowing Decisions The representative household has two decisions to make regarding holdings of financial instruments: depositing with local banks and borrowing from international financial markets.

With regard to the household's decision on deposits, as shown in the budget constraint (2.2), the household at the beginning of each period t receives the gross amount of $(1 + R_{t-1}) D_{t-1}$, and it decides D_t at the end of the period. Consequently, the first-order condition with respect to D_t is given by

$$\lambda_t = \beta \mathrm{E}_t \lambda_{t+1} (1 + R_t).$$

In words, the optimal deposit must be such that this period's marginal utility of nominal wealth is equal to the expected discounted marginal utility of wealth in the next period.

With regard to the household's decision on foreign financial instruments, it is assumed that there is a foreign exchange agent which acts on behalf of the household. Toward the end of each period, a foreign exchange agent accumulates foreign debt denominated in the foreign currency, B_t^*, by solving the following intertemporal problem

$$\max_{B_t^*} \mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \lambda_t S_t \left\{ B_t^* - \left[1 + \frac{\xi^B}{2}\left(\frac{S_{t-1} B_{t-1}^*}{4 Y_{t-1}^N} - \psi\right)\right] \left(1 + R_{t-1}^*\right) B_{t-1}^* \right\}.$$

S_t is the nominal exchange rate—the price of one unit of the foreign currency in terms of the local currency—and R_t^* is the foreign interest rate. The term in the square brackets is the premium on the rate at which the household can borrow, and this premium is increasing in the ratio of debt to nominal GDP with the factor of proportionality $\xi^B/2$. (Because GDP is a quarterly flow variable, Y_{t-1}^N needs to be multiplied by 4 before comparing it with B_{t-1}^* which is a stock variable.) The parameter ψ is the steady-state debt-to-GDP ratio. In essence, the term in the square brackets is an interest rate premium which works to ensure that the household will not run up infinite debt: it will be increasingly costly to borrow as the household becomes more indebted.

The first-order condition with respect to B_t^* gives a variant of the uncovered interest parity (UIP) condition:

$$R_t - R_t^* = \mathrm{E}_t dS_{t+1} + \xi^B \left(\frac{S_t B_t^*}{4Y_t^N} - \frac{\psi}{2} \right)$$

where dS_{t+1} is the rate of nominal exchange rate depreciation in the next period. It will be helpful later on when taking the model to data to define a variable $B_t = S_t B_t^*$, which is the foreign debt that is denominated in the local currency. Moreover, to create a differential between the domestic and foreign interest rates in the steady state, we introduce a constant parameter υ so that the UIP condition becomes

$$R_t - R_t^* = \mathrm{E}_t dS_{t+1} + \xi^B \left(\frac{B_t}{4Y_t^N} - \frac{\psi}{2} \right) + \upsilon.$$

Finally, the law of motion of B_t is given by

$$B_t = (1 + R_{t-1}) B_{t-1} - \left(P_t^X X_t - P_t^M M_t \right).$$

Note how earnings on net exports work to reduce the foreign debt position.

2.2. *Firms*

There are two types of firms in the economy: one selling to the local market, the other selling to the foreign market. In terms of production technology, both domestic and export firms share the Cobb–Douglas production function, with the only difference residing in the relative input share. In terms of pricing, motivated by pervasive government price administration in Thailand, the domestic firms are modeled as monopolistically competitive firms that have pricing power but face price rigidities. On the other hand, as Thailand is a small open economy, the exporters are price takers and must instantaneously adjust their prices consistently with those set in the world market.

2.2.1. Domestic Firms The representative domestic firms' production function is given by

$$Y_t^D = \left(A_t L_t^D \right)^{\gamma_L^D} \left(M_t^D \right)^{\gamma_M^D} \left(K_t^D \right)^{1-\gamma_L^D-\gamma_M^D}$$

where domestic output is denoted by Y_t^D and the three factor inputs are labor (L_t^D), imported intermediate goods (M_t^D), and capital services (K_t^D).

A_t is the labor-augmented productivity. Given the production function, the domestic firms' Lagrangian can be written as

$$\begin{aligned}\mathcal{L}^D &= \left(1+R_t^L\right) W_t L_t^D + P_t^M M_t^D + R_t^K K_t^D \\ &+ Q_t^D \left[Y_t^D - \left(A_t L_t^D\right)^{\gamma_L^D} \left(M_t^D\right)^{\gamma_M^D} \left(K_t^D\right)^{1-\gamma_L^D-\gamma_M^D} \right]\end{aligned}$$

where W_t, P_t^M, and R_t^K are the input prices, namely the nominal wage, the import price, and the rental price of capital respectively. It is assumed that the domestic firms, which compared with export firms are likely to be small firms facing financial constraints, need to borrow from banks to pay for labor. Hence we have the term $1+R_t^L$ which is the gross loan rate charged by banks (on the other hand, this term is absent in the case of export firms which are assumed to be able to raise funds independently). Q_t^D represents the marginal cost for producing one additional unit of the domestic good. The first-order conditions with respect to factor inputs are given by

$$\begin{aligned}\left(1+R_t^L\right) W_t L_t^D &= \gamma_L^D Q_t^D Y_t^D \\ P_t^M M_t^D &= \gamma_M^D Q_t^D Y_t^D \\ R_t^K K_t^D &= \left(1-\gamma_L^D-\gamma_M^D\right) Q_t^D Y_t^D.\end{aligned}$$

In addition to choosing how much to produce, given that domestic firms are monopolistically competitive by the virtue of their differentiated products, they also set prices. As in the case of wage setting by households, the price setting problem of the representative domestic firm takes the following form

$$\min_{P_t^D} \mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \left[(P_t^D - P_t^{D*})^2 + \xi^D (\Delta P_t^D - \Delta \bar{P}_{t-1}^D)^2 \right].$$

The solution of the above problem is given by

$$P_t^D = P_t^{D*} + \xi^D \left[-\left(\Delta P_t^D - \Delta \bar{P}_{t-1}^D\right) + \beta \left(\mathrm{E}_t \Delta P_{t+1}^D - \Delta \bar{P}_t^D\right) \right]$$

where $P_t^{D*} = \mu^D Q_t^D$.

2.2.2. Export Firms The representative export firms' production function is given by

$$Y_t^X = \left(A_t L_t^X\right)^{\gamma_L^X} \left(M_t^X\right)^{\gamma_M^X} \left(K_t^X\right)^{1-\gamma_L^X-\gamma_M^X}$$

where notation is analogous to that for the domestic firm, except for replacing the superscript D with X. The first-order conditions with respect to factor inputs are given by

$$\begin{aligned} W_t L_t^X &= \gamma_L^X Q_t^X Y_t^X \\ P_t^M M_t^X &= \gamma_M^X Q_t^X Y_t^X \\ R_t^K K_t^X &= \left(1 - \gamma_L^X - \gamma_M^X\right) Q_t^X Y_t^X. \end{aligned}$$

In contrast to the domestic firm which is a monopolistically competitive firm, the export firm is a perfectly competitive firm which takes the market price as given. Thus in equilibrium we have

$$Q_t^X = P_t^X$$

where the export price (in the local currency terms), P_t^X, depends on the nominal exchange rate, S_t, and the exogenous export price, P_t^{Xf}, that is in foreign currency terms:

$$P_t^X = S_t P_t^{Xf}.$$

2.3. Banks

The purpose of banks in the model is to allow monetary policy to transmit via the bank-lending channel. As in Bernanke and Blinder (1988), the bank-lending channel works through the supply side of credit in that a tight monetary policy reduces the supply of bank loans, which in turn reduces spending by firms. In the present model the balance sheet channel *à la* Bernanke and Gertler (1995)—which works through the demand side of credit in that a tight policy weakens borrowers' balance sheets, lowers net worth, and increases external finance premiums, which in turn reduce firms' ability to borrow and discourage bank-dependent borrowers' activity—is not considered.

Below banks are modeled as in Atta-Mensah and Dib (2008). Competitive banks take deposits from households and lend to domestic firms, which face a financial constraint in financing hiring of labor. Bank loans are denoted by LN_t and assumed to take the form

$$LN_t = \Lambda_t D_t$$

where Λ_t denotes the fraction of deposits lent out to firms and D_t denotes deposits. The loan-to-deposit ratio depends on the growth rate of the economy relative to its steady-state growth rate:

$$\Lambda_t = \left[\frac{Y_t^D}{(1+\alpha)Y_{t-1}^D}\right]^\tau$$

where τ is the elasticity of the willingness to lend with respect to the relative growth rate of the economy. Note that in the steady state $\Lambda_t^{ss} = 1$, i.e., loans equal deposits.

To see how the bank-lending channel works, suppose the policy interest rate decreases temporarily so that Y_t^D grows faster than the steady state growth. Consequently, $\Lambda_t > 1$. Given the loan expansion, output increases. This expansionary effect due to financial intermediation (that is in addition to the effect of the fall in the intertemporal price due to the policy rate decrease) characterizes the monetary policy transmission via the bank-lending channel.

The equilibrium condition in the banking sector is as follows. Given that bank profits are loan interests earned ($R_t^L LN_t$) less deposit interests paid ($R_t D_t$), the zero profit condition gives

$$R_t^L = \frac{1}{\Lambda_t} R_t$$

where the relation $LN_t = \Lambda_t D_t$ has been used.

2.4. Fiscal and Monetary Authorities

The government is assumed to follow a simple fiscal rule:

$$P_t^D G_t = \rho^G \left(P_{t-1}^D G_{t-1}\right) + \left(1 - \rho^G\right) \left(\sigma Y_t^N\right).$$

That is, while this period's nominal government expenditure, $P_t^D G_t$, is targeted as a constant fraction σ of nominal GDP, Y_t^N, it also depends on the previous period's expenditure, $P_{t-1}^D G_{t-1}$, so as to model the persistence in nominal government spending. The degree of persistence is captured by ρ^G.

The central bank is assumed to follow a simple monetary rule:

$$R_t = \rho^R R_{t-1} + \left(1 - \rho^R\right) \left[R^{ss} + \kappa \left(dP_{t+1}^D - \bar{\pi}\right)\right].$$

Analogous to the fiscal rule, this period's policy interest rate, R_t, is a weighted average of the previous period's rate and the target policy interest rate for the present period, with the weights given by ρ^R and $1 - \rho^R$ respectively. The targeted interest rate depends on the steady-state nominal interest rate, R^{ss}, and the extent to which the next period's inflation, dP_{t+1}^D, is projected to exceed the inflation target, $\bar{\pi}$. The parameter $\kappa > 0$ characterizes the degree of responsiveness of the central bank's reaction to the inflation deviation.

2.5. Exogenous Processes

Exogenous processes are as follows:

$$\begin{aligned}
A_t &= A_{t-1} + \alpha + \varepsilon_t^A \\
T_t &= \rho^T T_{t-1} + \varepsilon_t^T \\
dP_t^{M^*} &= \pi^* + \varepsilon_t^{P^{M^*}} \\
R_t^* &= \rho^{R^*} R_{t-1}^* + \left(1 - \rho^{R^*}\right) R^{ss*} + \varepsilon_t^{R^*}
\end{aligned}$$

where A_t, T_t, $dP_t^{M^*}$, and R_t^* are respectively technology, the terms of trade, foreign inflation, and the foreign interest rate at time t, with the associated steady state values normalized to 1 for technology and the terms of trade and given by π^* and R^{ss*} for foreign inflation and the foreign interest rate. ρ^T and ρ^{R^*} are parameters governing persistence of the processes. The $\varepsilon_t^{'}$s are innovations.

2.6. Market Clearing Conditions

The market clearing conditions at any time t for the factor inputs are given by

$$\begin{aligned}
L_t &= L_t^D + L_t^X \\
M_t &= M_t^D + M_t^X \\
K_t &= K_t^D + K_t^X
\end{aligned}$$

and the market clearing conditions for outputs are given by

$$\begin{aligned}
Y_t^D &= C_t + I_t + G_t \\
Y_t^X &= X_t.
\end{aligned}$$

2.7. Steady-State Conditions

Steady-state conditions—essentially, the terminal conditions of transition equations described above—are determined according to balanced growth. That is, the steady state is defined such that macro variables *grow* at constant rates such that no variable explodes or implodes over time. Three key parameters that determine steady-state growth of variables in the model are the economy's productivity growth rate (α) and the domestic and foreign inflation targets (π and π^*).

Real variables in the steady state grow at the rate of productivity growth. Thus, output (Y^D, Y^X), output components (C, I, G, X), production inputs except labor (K^D, K^X, M^D, M^X) grow at a constant rate

α along the balanced growth path. The steady-state growth rate of labor (L^D, L^X), however, is set to zero to prevent labor from growing indefinitely.

Domestic prices grow at the target rate of inflation. Thus, prices (P^D, P^X, P^M, R^K) and shadow prices (Q^D, Q^X, Q^K) grow at π. Exceptions are interest rates (R, R^L, R^*), which remain constant in the steady state, and the nominal wage and the shadow price of labor (W, Q^L), which grow at $\alpha + \pi$. Nominal GDP and foreign bond holdings (Y^N, B) also grow at $\alpha + \pi$. Furthermore, any ratio of nominal variables along the balanced growth path (e.g., the loan-to-deposit ratio) must be unity.

The foreign export and import prices (P^{Xf} and P^{Mf}) grow at π^*. Hence, the terms of trade (T) is constant in the steady state. Finally, the exchange rate depreciates at the rate of $\pi - \pi^*$ along the balanced growth path.

2.8. Equilibrium

The equilibrium is a collection of prices and quantities that satisfy the first-order conditions, fiscal and monetary rules, laws of motion, the market clearing conditions, and the steady-state conditions.

3. Model Parameterization

Our goal is to solve for the equilibrium given the structure of the model described above and given model parameters to be described in this section. There are two broad methods for parameterizing DSGE models: calibration and estimation. We can formally estimate the parameters for the model; however, estimation potentially involves a number of complications. For example, the likelihood corresponding to the model may contain flat regions, discontinuities, or multiple local maxima. Although recent developments in Bayesian estimation have been shown to solve such problems, we reserve it for the future as it potentially entails a number of technicalities. For the moment we choose to calibrate the model, i.e., we select the values of parameters based on empirical findings that result in a model that can characterize the Thai economy to the best of our understanding.

Information from various sources has been used as an input for calibration, including stylized facts of the Thai economy (see the Appendix and Tanboon, 2007a), the input–output matrix (National Economic and Social Development Board, 2000), OLS, GMM, and VAR estimation (Sutthasri, 2007), and the Bank of Thailand Macroeconometric Model. We also compare our calibrated parameters with the counterparts in the literature.

In what follows we discuss our methodology for calibrating model parameters, which are classified into two groups. Details on the parameters are summarized in Tables 1 and 2.

3.1. Parameters Governing the Steady State

Steady-state parameters consist of those of households (β, δ, η, φ^L, μ^W, ψ), firms (γ_L^D, γ_M^D, μ^D, γ_L^X, γ_M^X), fiscal and monetary authorities (σ, π), and exogenous processes (α, π^*).

Table 1: Steady-State Parameters

Parameter	Value	Description
Households		
β	0.9926	Discount factor (real interest rate 3% per year)
δ	0.0105	Depreciation rate (4.2% per year)
η	3.0303	Inverse of Frisch elasticity
φ^L	1	Scaling parameter for labor disutility
μ^W	1.05	Wage markup
ψ	0.25	Ratio of foreign debt to nominal GDP
Firms		
μ^D	1.20	Price markup, domestic firms
γ_L^D	0.70	Labor income share, domestic firms
γ_M^D	0.15	Imported input income share, domestic firms
γ_L^X	0.64	Labor income share, export firms
γ_M^X	0.18	Imported input income share, export firms
Government		
σ	0.20	Ratio of govt. expenditure to nominal GDP
π	0.0074	Inflation target (3% per year)
Exogenous processes		
α	0.0059	Productivity growth rate (2.4% per year)
π^*	0.0074	Foreign inflation target (3% per year)

Details on the representative household's parameters are as follows. We set $\beta = 1.03^{-0.25} = 0.9926$ which implies a steady-state annualized real interest rate of 3 percent. We set $\delta = 0.0105$ corresponding to the average annual depreciation rate between 1970 and 2006 of 4.2 percent; δ is calculated as the annual depreciation divided by gross capital stock (at 1988 price). η^{-1} is set to 0.33, which corresponds to the wage elasticity of labor supply that is obtained from an OLS estimation of the first-order condition with respect to L_t. Relative to other findings in the literature, this value is within the ranges of 0.25–0.45 and 0–0.35, respectively obtained by McCurdy (1981) and Altonji (1986) using the University of Michigan

PSID data. We set φ^L to 1, i.e., no scaling for the disutility of labor supply. The parameter μ^W is set to 1.05 calculated using on data from the National Statistical Office and the National Economic and Social Development Board. ψ is set to 0.25. This ratio of foreign debt to nominal GDP has been on a declining trend from an unusually high level after the 1997 financial crisis and appears to stabilize recently: from 0.82 in 1999Q1 to 0.28 when averaged over 2004Q1–2008Q2 and 0.24 over 2007Q1–2008Q2.

The parameters of firms are calibrated based on a calculation using the input–output matrix. μ^D is set to 1.2. This value is within the range of 1.13–1.32 reported in Sutthasri (2007), where the markup is calculated as the ratio of the total value of production to the total cost of production—the latter computed as the difference between the total value of production and the operating surplus. The estimated range is comparable with the average markup for 14 OECD countries computed by Martins, Scarpetta, and Pilat (1996) of 1.20 (1.23 for the U.S. and 1.35 for the Euro area). We set $\gamma_L^D = 0.70$ and $\gamma_L^X = 0.64$, implying domestic firms are more labor intensive relative to export firms. (These sectoral labor income shares are roughly in line with Ahuja, Puengchanchaikul, and Piyakarnchana, 2004, who find the representative firm's labor income share in a one-sector model to be 0.6856.) For each type of firms, the remaining shares of imported intermediate good and capital are set to equal magnitude. That is, we set $\gamma_M^D = (1 - 0.70)/2 = 0.15$ and $\gamma_M^X = (1 - 0.64)/2 = 0.18$, implying that, relative to domestic firms, export firms use more imported inputs (and also more capital) in the production function.

The ratio of government expenditure to nominal GDP, σ, is set to 0.20, close to the mean and the median over 1993Q1–2008Q2. The central bank's inflation target, π, is set to $\frac{1}{4} \times \log(1.03)$, i.e., 3 percent per annum.

With regard to parameters of exogenous processes, we set α to 2.4 percent per annum according to Sutthasri's (2007) calculation based on data from 1978 to 2006. This value is comparable with Chuenchokesan and Nakornthab's (2008) findings that Thailand's total factor productivity (TFP) growth is 1.8 percent over 1987–1996 and 2.0 percent over 2000–2007 (the average TFP growth during the unusual financial crisis years registers –6.7 percent). π^* is set to 3 percent per annum.

3.2. Parameters Governing the Transition Dynamics

Dynamic parameters consist of those of households (χ, ξ^I, ξ^W, ξ^B, υ), firms (ξ^D), banks (τ), fiscal and monetary authorities (ρ^G, ρ^R, κ), and exogenous processes (ρ^{R^*}, ρ^T).

We set the consumption habit-persistence parameter, χ, to 0.85. This value is within the range of 0.84–0.88 obtained from GMM estimation of the Euler equation using data during 1994Q1–2006Q4. The estimate is comparable with 0.86 and 0.90 calculated respectively by Ravn, Schmitt-Grohe, and Uribe (2006) and Fuhrer (2000) using the U.S. data. We set $\xi^I = 1$, $\xi^W = 10$, and $\xi^B = 0.4$ such that the impulse responses of investment, wage, the exchange rate, as well as other related variables are consistent with our understanding of dynamics of the Thai economy. We set $\upsilon = \frac{1}{4} \times \log(1.02)$, implying the wedge between the domestic and the foreign interest rates of 2 percent per annum in the steady state.

Table 2: Dynamics Parameters

Parameter	Value	Description
Households		
χ	0.85	Consumption habit persistence
ξ^I	1	Investment adjustment cost
ξ^W	10	Wage adjustment cost
ξ^B	0.4	Interest rate premium on foreign debt holdings
υ	0.005	Differential between domestic and foreign interest rate
Firms		
ξ^D	10	Degree of price rigidities
Banks		
τ	0.5	Elasticity of willingness to lend with respect to domestic output growth
Government		
ρ^G	0.80	Persistence in government expenditure
ρ^R	0.85	Persistence in policy interest rate
κ	25	Responsiveness of policy rate to inflation
Exogenous processes		
ρ^{R^*}	0.8	Persistence in foreign interest rate
ρ^T	0.8	Persistence in terms of trade

The parameter governing the degree of nominal rigidity in the domestic firm's price setting, ξ^D, is set to 10 so that inflation dynamics are roughly close to what we observe in the data.

We have followed Atta-Mensha and Dib's (2008) in calculating τ. However, the Thai data on the interest rate spread between the effective lending rate and the effective deposit rate are difficult to explain. When the economy is softening, the interest rate spread should become larger to compensate for the lender's risk. Nevertheless, the data show that the interest rate spread is mostly invariant to the state of the economy, and it is suspected that this observation is due to the quality of data rather than an empirical regularity. So we choose the value of τ that renders the workings of the bank-lending channel in the model most realistic. The elasticity of the willingness to lend with respect to the growth rate of the economy, τ, is set to 0.5.

The parameters for the fiscal and monetary authorities are set as follows: $\rho^G = 0.8$ to reflect a moderately high degree of persistence in government spending over 1993–2007. We set $\rho^R = 0.85$ and $\kappa = 25$ to generate the strength of the interest rate and the exchange rate channels that conform to our understanding of the monetary transmission mechanism in Thailand.

Finally, the lag-one autocorrelation coefficients for the exogenous processes, (ρ^{R^*}, ρ^T), are set to 0.8.

4. Model Properties

In this section we examine model properties. Given the parameterized transition equations that characterize the model structure, and given the steady-state conditions implied by the balanced growth path that characterize the fixed terminal conditions, we can solve for transition dynamics toward the steady state after we perturb our model by introducing various kinds of shocks. In what follows, we first focus on the monetary policy transmission. Subsequently, we study the impulse responses to nonmonetary shocks to see what happen to our model economy and how the policy interest rate reacts in each case.

4.1. Monetary Policy Transmission

4.1.1. Interest Rate Shock This shock demonstrates the role of the monetary transmission mechanism in the economy. Consider a temporary one percentage point increase in the policy interest rate for one period, the impulse responses to which are depicted by the lines with markers in Figure 1. Given nominal rigidities, a higher nominal interest rate leads to a higher real interest rate, which lowers both consumption and investment. On the external side, following the increase in the interest rate, the exchange rate appreciates, reducing export receipts when denominated in the local currency and thus discouraging export production in the short run. In effect, both domestic and export firms cut back production. Once the temporary effects of changes in relative input prices dissipate, employment of inputs falls, thereby putting downward pressures on marginal costs. Consequently, the domestic price level starts to decrease and inflation falls.

In response to a decrease in inflation owing to the initial exogenous increase in the policy interest rate, the central bank lowers the interest rate subsequently, restoring consumption and investment to their pre-shock levels. Exports rise in line with an exchange depreciation (in fact exports overshoot briefly before reverting to its steady-state level). Given increased activities in domestic and export sectors, inflation eventually returns to its pre-shock level.

4.1.2. The Bank-Lending Channel By comparing the impulse responses of macro variables in a model with and without banks, as shown in Figure 1 respectively by the lines with and without markers, one can gauge the strength of the bank-lending channel. A large difference between the two impulse responses is usually associated with a strong bank-lending channel.

After the policy rate increases, consumption and investment decrease. With regard to investment, the presence of financial frictions that give rise to the role of banks causes contraction to be greater relative to the case where financial frictions are absent. This finding follows immediately from the fact that, with higher total wage bills owing to intermediation costs, domestic firms employ less labor as well as capital, the latter giving rise to a more softening in investment demand by households. The fall in domestic demand reduces the loan-to-deposit ratio, leading to further decline in production as fewer loans are available. Such a contraction in demand is in addition to the tightening effects from the higher intertemporal price that is the central mechanism in the traditional interest rate channel.

With regard to costs and prices, the marginal cost in the case where banks are present is higher relative to the case without banks. This is precisely due to the presence of the interests on loans. As a result, we see that, while inflation is temporarily below the steady state given a tightened monetary policy, inflation is higher in the case where the bank-lending channel operates relative to the case where such a channel is absent.

4.2. Responses to Nonmonetary Shocks

In what follows we return to our baseline model in which all monetary policy transmission channels operate. We examine below how our model economy responds to exogenous nonmonetary shocks.

4.2.1. Productivity Shock Consider a one percent temporary increase in productivity growth that results in a one percent permanent increase in the level of productivity as shown in Figure 2. On the production side, this positive productivity shock increases the level of production in both the domestic and export sectors by one percent in the long run. Note how the adjustment process toward the new steady state takes several quarters compared with the interest rate shock scenario. On the demand side, the higher labor productivity leads to a new steady-state real wage that is one percent above the pre-shock level. Such a permanent increase in real labor compensation affords households to increase demand for consumption and investment goods by one percent—thus matching an increase in production.

As the positive productivity shock enables firms to hire less labor for a given amount of output, it effectively reduces marginal costs. Domestic firms thus lower prices and consequently inflation falls. The central bank responds by cutting the interest rate temporarily to allow inflation to return to the target.

4.2.2. Price Shock Consider a temporary positive shock to the price set by firms, as shown in Figure 3, which causes a temporary rise in inflation. Monetary policy responds by raising the policy interest rate. On the external side, exports initially fall as the nominal exchange rate appreciates. A higher interest rate and a lower real wage dampen consumption and investment demand, causing a decline in domestic firms' production and factor employment, which lead to a fall in marginal cost, the domestic price, and inflation. The central bank then responds by reversing its stance—loosening monetary policy, resulting in a fall in the policy rate to the pre-shock level.

4.2.3. Exchange Rate Shock Consider a temporary increase in the country-specific risk premium, which can be interpreted as a temporary loss of investors' confidence in domestic assets, that causes the exchange rate to depreciate temporarily as shown in Figure 4. On the external front, as the exchange rate depreciates it induces a rise in export production. With regard to domestic production, the depreciation causes an increase in the imported intermediate good price that raises the domestic firms' marginal cost and the price they charge, leading to higher inflation. Monetary policy reacts by increasing the policy interest rate.

During the transition back to the steady state, the higher interest rate brought about by the central bank leads to a subsequent exchange rate appreciation, dampening exports to the pre-shock level. The higher real interest rate also leads to a decline in both consumption and investment. Domestic production, which is demand determined, softens, leading to a fall in the employment of factor inputs and the attendant reduction in marginal cost, the domestic price, and inflation. The central bank subsequently cuts the policy rate so as to bring inflation back to the steady state.

5. Model Evaluation

5.1. Methodology

This section provides an evaluation of the structural model outlined above. In what follows, we compare statistical moments implied by the model with those obtained from data. We are interested in volatility, persistence, and comovements in the data as represented by the standard deviations, autocorrelations, and cross correlations. These second moments implied by the model can be computed in a straightforward manner, as they usually are functions of the innovations' variances and other model parameters. On the other hand, second moments implied by the data can be calculated in a number of ways. One of the earliest accounts is to compute sample moments as in Kydland and Prescott (1982). Alternatively, we can retrieve population moments from the data by using bootstrap procedures as in Benes, de Castello Branco, and Vavra (2007), which is the methodology we adopt in the present paper. An advantage of this methodology is that, instead of just the point estimates of the second moments, we now have the whole distributions, and in effect we have considered the statistical uncertainty associated with sample estimates. This methodology thus enables us to gauge more meaningfully the closeness between model and empirical moments.

Benes, de Castello Branco, and Vavra's (2007) bootstrap procedure can be summarized as follows. First, to calculate the point estimate of the empirical population autocorrelation function, we fit a vector autoregression (VAR):

$$\mathbf{x}_t = A\mathbf{x}_{t-k} + \boldsymbol{\varepsilon}_t.$$

The population autocorrelation function is then a function of $var\left(\boldsymbol{\varepsilon}_t\right)$ and A. For example, for a first-order VAR, $x_t = ax_{t-1} + \varepsilon_t$, the variance of x_t is given by $\sigma_\varepsilon^2/(1-a^2)$. Second, we resample the vector $\mathbf{x}_t$ using a wild recursive bootstrap procedure *à la* Goncalve and Kilian (2002):

$$\hat{\mathbf{x}}_t^i = A\hat{\mathbf{x}}_{t-k}^i + \eta^i\boldsymbol{\varepsilon}_t.$$

where $\hat{\mathbf{x}}_t^i$ denotes the ith sampling of $\mathbf{x}_t$ that depends on an independently and identically distributed scalar, η^i, drawn from a standard normal distribution. Third, given $\hat{\mathbf{x}}_t^i$, we reestimate a VAR

$$\hat{\mathbf{x}}_t^i = \hat{A}^i\hat{\mathbf{x}}_{t-k}^i + \hat{\boldsymbol{\varepsilon}}_t^i.$$

For each ith resampling we now have $\hat{A}^i$ and $\hat{\boldsymbol{\varepsilon}}_t^i$ as respective counterparts to A and $\boldsymbol{\varepsilon}_t$ of the first step. Consequently, we can compute the autocorrelation function for the ith resampling, which is a function of $var\left(\hat{\boldsymbol{\varepsilon}}_t^i\right)$ and $\hat{A}^i$, leading to a distribution of the autocorrelation.

5.2. Results

In what follows we evaluate the model by showing how well it captures volatility, persistence, and comovements in the Thai data, which are obtained via the bootstrap procedure on an unrestricted VAR of order 2 based on data over 2000Q1–2008Q1. The macro variables we consider are the growth rates of consumption and investment, inflation, and the interest rate—all of which are stationary variables.

Figure 5 shows the relative standard deviations of macro variables. Lines with the circle and square markers respectively depict the relative standard deviations obtained from model prediction and from VAR estimation. The bars make up the distribution of the relative standard deviations obtained from the bootstrap procedure. The top panel shows the relative standard deviation of investment growth relative to that of consumption growth. We see that the model predicts quite well: it gives the relative standard deviation of approximately 3, roughly close to that predicted by VAR and within a reasonable region implied by the bootstrap distribution. In the bottom panel, the model gives the ratio of the standard deviation of inflation to that of consumption growth that fares reasonably well.

Figure 6 shows the autocorrelations. We see that the model predicts quite well for the consumption growth rate but less so for investment growth, and gives an unexpected sign for inflation.

Figure 7 shows the cross correlations. The cross correlations implied by the model between the consumption and investment growth rates and between the consumption growth rate and inflation are satisfactory and remarkably good in the case of investment growth and inflation.

6. Conclusions

When the staff at the Bank of Thailand decided to build a new model based on the dynamic stochastic general equilibrium framework, we envisioned several benefits that could be obtained during the modeling process. First, the new model will work as a complement to, and not a substitute for, the current macroeconometric model that has well supported the implementation of the inflation targeting framework. Second, the new model will provide several insights on the workings of the economy and a conducive framework for discussions by the staff and policymakers in a theoretically coherent manner in line with recent developments in the literature. Third, there will be more interaction among modelers, sector specialists, and other staff throughout the model building and developing processes, and the experience over the past two years has proved that knowledge sharing among the central bank staff has been a success.

The structural model detailed in the paper has several features that are typical of New Keynesian small open economy models. Optimizing agents make intertemporal decisions rationally subject to constraints in a coherent and well-defined framework, with nominal and real frictions incorporated in the model to generate realistic model dynamics. Parameters of the model are calibrated based on empirical findings that best characterize the Thai economy. We assess model properties by introducing various types of shocks to the model and examine the impulse responses which are found to be mostly consistent with previous findings based on alternative methodologies. We also assess statistical moments implied by the model and compare them with those obtained from the data, and find that certain moments are better matched with data than others.

A number of model development plans are currently under way. With regard to the structure of the model, we have considered enriching the financial sector by moving away from the competitive banking sector to better mimic the nature of the Thai banking system that is dominated by a small number of large commercial banks. Furthermore, in addition to the bank-lending channel of the monetary policy transmission mechanism as in Bernanke and Blinder (1988), works on the balance sheet channel *à la* Bernanke and Gertler (1995) are in progress. We also plan to revisit the fiscal rule in order to prepare for a larger role of fiscal policy in the model. In terms of parameterization, we have contemplated estimating formally the model using the Bayesian approach. In this way, we will have allowed the data to determine model parameters in a more consistent manner, while we can still incorporate our prior beliefs in the form of calibrated values.

While DSGE models are widely considered the workhorse model for policy analysis that is at the research frontier, it needs to be kept in mind that no single model can answer all types of questions correctly all the time. What is more important is a good understanding of the inner workings of the economy, which are essentially what every economic model tries to capture and every economist tries to appreciate.

7. Acknowledgements

The author wishes to thank seminar participants at the Bank of Thailand, Bank Indonesia, the Bank for International Settlements, and the Hong Kong Institute for Monetary Research—in particular, Martin Eichenbaum, Douglas Laxton, Titanun Mallikamas, Anella Munro, Chaipat Poonpatpibul, Sergio Rebelo, Amara Sriphayak, Regina Sawatronapak, Prasong Werakarnjanapongs, and Feng Zhu—for helpful suggestions on earlier versions of the model. The author is grateful to Jaromir Benes for sharing and providing technical advice on the use of IRIS, a software package used for building and solving the model, as well as kindly giving guidance on programming.

8. Appendix: Stylized Facts of the Thai Economy

This appendix summarizes findings in Tanboon (2007a) that identify salient features characterizing the long-run and business cycle properties of the Thai economy. We are interested in these features because most DSGE models are designed to mimic the economy in the long run and to capture monetary policy transmission channels over the business cycle.

8.1. Long-run properties

8.1.1. Long-term trend A balanced growth path refers to an equilibrium in which major economic aggregates grow at rates such that certain ratios of aggregate variables should be roughly constant over time. Most simple growth models are constructed assuming these properties. This is partly motivated by theoretical convenience but also by historical observations notably those by Kaldor (1957). Among his most important observations is that per capita output grows at a rate that is roughly constant. Figure 8, taken from Kongsamut, Rebelo, and Xie (2001), shows that the growth rate of the U.S. per capita output is remarkably stable over the past 100 years.

The finding in the case of Thailand is comparable with that of the U.S. Figure 9 shows the Thai per capita output from 1971 to 2006 measured in real terms at an annual frequency in the log scale. The solid and dotted lines depict the actual and smoothed values respectively, with smoothing done using the Hodrick–Prescott filter with the smoothing parameter equal to 100. Although there is a noticeable deviation from the long-term trend during the onset and the aftermath of the financial crisis in 1997, per capita output still exhibits a roughly constant growth rate. This finding is not unlike in the case of the U.S. in that despite large deviations during the Great Depression and the economic boom accompanying World War II, output per capita is found to grow at an approximately constant rate over the long term. With regard to GDP components, it is shown in Tanboon (2007a) that the growth rates of private consumption, exports, and imports are remarkably constant, whereas private investment grows at a constant rate only up to the onset of the financial crisis in 1997.

8.1.2. Shares in output One important implication of the economy on a balanced growth path is that shares of aggregate variables in output should be roughly constant over time. Figures 10–12 show that shares of total, private, and public consumption (respectively CR, CPR, CGOVR) in output are very much constant over the past 10 years. In contrast to consumption, the shares of investment and net exports seem to be more or less constant in the post-1997 period.

In sum, this subsection shows that the Thai economy appears to have been on a balanced growth path. Output per capita and most economic aggregates are found to have grown at a roughly constant rate over the past 50 years. Investment growth, which is relatively more sensitive to disturbances than other GDP components, has been constant up to slightly before 1997. More data may be necessary to determine whether investment will resume its previous trend, but given that the growth paths of other GDP components are unchanged, investment is likely to revert to its balanced growth path. In terms of proportion of output, although over the past 50 years or so shares of major economic aggregates in output tend to move around, the consumption share has been remarkably constant, while shares of investment and net exports are roughly so after the financial crisis. These findings on long-term growth and shares in output suggest that the Thai economy can be approximately characterized as balanced growth.

8.2. Business cycle properties

The purpose of this subsection is to examine fluctuations around the economy's long-run growth trend. We are interested in characterizing economic fluctuations because we want to understand which shocks are important for cyclical volatility, and more importantly how the propagation mechanisms of these shocks work. Understanding of business cycles is the first step toward designing a dynamic general equilibrium model.

8.2.1. Comovements in macroeconomic time series Consistent with findings on comovements in macro time series in other economies, for the Thai economy it is found that (1) consumption fluctuates less than other aggregate macro variables and tend to move closely with output; (2) investment swings most; and (3) exports and imports fluctuate more than consumption but less than investment. In particular, Table A.1 shows relative standard deviations and cross correlations between detrended series. The second column shows the standard deviation of each detrended series; the third column shows the standard deviation of each output component relative to output. Here, private consumption fluctuates with a similar degree as output, while private investment, exports, and imports fluctuate 4.4, 1.7, and 2.8 times than output. In the next columns $\rho(X_{t-k}, Y_t)$, $\rho(X_t, Y_t)$, and $\rho(X_{t+k}, Y_t)$ denote correlation between output today, Y_t, and the past, contemporaneous, and future output component X respectively. If $\rho(\cdot)$ attains the maximum value in absolute value equal to ρ^* at $t, t-k, t+k$, then X is said to move contemporaneously with, lead or lag output by k years respectively. If $\rho^* > (<)\ 0$, then X is said to be procyclical (countercyclical). The main findings can be summarized as follows. First, consumption, investment, and imports are procyclical and move contemporaneously with output. Second, exports are procyclical and lead output by two years. Third, headline and core inflation are procyclical and lag output by one year.

8.2.2. Persistence in macroeconomic time series Persistence is the extent to which shocks today have an effect on the future path of variables—in other words, how gradually shocks to macroeconomic variables dissipate over time. An intuitive measure of persistence of a variable is the rate at which its autocorrelation function decays to zero. Autocorrelation is a measure of how well a series matches a time-shifted version of itself. For example, a lag-one correlation of a series x_t tells us how much x_t correlates with x_{t-1}, and if it is high then we know that after one period x_t decays only slowly. In some cases, however, the effect of autocorrelation at smaller lags will influence the estimate of autocorrelation at longer lags. For instance, strong lag-one autocorrelation coefficients between x_t and x_{t-1} and between x_{t-1} and x_{t-2} implies a high degree of correlation between x_t and x_{t-2} even though no direct correlation exists. In this case, partial autocorrelation between x_t and x_{t-k} gives the extent of correlation with the effect of lags 1 to $k-1$ removed. Figures 13–14 show autocorrelation and partial autocorrelation of detrended output, from which we see a significant degree of persistence. Details on persistence of output components can be found in Tanboon (2007a); the key findings are that the first-order autocorrelation coefficients of detrended output, consumption, investment, and imports are found to be in the range of 0.6–0.7, while that of exports is around 0.3.

In sum, this subsection examines the business cycle properties of major aggregate variables characterizing the Thai economy over the past 50 years. The main findings are as follows. First, comovements in the Thai macroeconomic time series are quite similar to those found in other countries documented in the literature. Most importantly, consumption tends to move closely with output and investment fluctuates more than other aggregate variables. Second, there is a significant degree of persistence in macroeconomic time series.

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Table A.1: Cross Correlation between Real GDP and its Components

X	σ_X	σ_X/σ_Y	$\rho_{(X_{t-5},Y_t)}$	$\rho_{(X_{t-4},Y_t)}$	$\rho_{(X_{t-3},Y_t)}$	$\rho_{(X_{t-2},Y_t)}$	$\rho_{(X_{t-1},Y_t)}$	$\rho_{(X_t,Y_t)}$	$\rho_{(X_{t+1},Y_t)}$	$\rho_{(X_{t+2},Y_t)}$	$\rho_{(X_{t+3},Y_t)}$	$\rho_{(X_{t+4},Y_t)}$	$\rho_{(X_{t+5},Y_t)}$
Consumption	4.08	0.96	-0.38	-0.29	-0.03	0.18	0.52	0.82	0.71	0.39	0.12	-0.10	-0.24
Private	4.38	1.03	-0.32	-0.21	0.05	0.26	0.59	0.85	0.68	0.33	0.05	-0.15	-0.27
Public	5.63	1.32	-0.40	-0.47	-0.37	-0.28	-0.08	0.22	0.41	0.44	0.33	0.18	0.04
Investment	14.93	3.51	-0.31	-0.18	0.08	0.34	0.62	0.82	0.64	0.32	0.06	-0.13	-0.30
Private	18.85	4.43	-0.20	-0.05	0.21	0.40	0.60	0.71	0.48	0.14	-0.08	-0.18	-0.29
Public	18.85	4.43	-0.45	-0.46	-0.31	-0.07	0.25	0.56	0.59	0.55	0.37	0.11	-0.11
Export	7.32	1.72	0.01	0.17	0.34	0.48	0.45	0.42	0.26	-0.06	-0.10	-0.14	-0.16
Import	11.97	2.81	-0.19	-0.02	0.18	0.40	0.65	0.77	0.51	0.12	-0.08	-0.24	-0.30
CPI	2.15	0.50	-0.29	-0.45	-0.54	-0.57	-0.48	-0.21	0.21	0.52	0.61	0.53	0.33
Core CPI	1.95	0.46	-0.09	-0.31	-0.52	-0.63	-0.66	-0.55	-0.06	0.38	0.54	0.56	0.50
GDP (Y)	4.25	1.00	-0.31	-0.19	0.03	0.33	0.71	1.00	0.71	0.33	0.03	-0.19	-0.31

Sample Ranges: Real GDP: 1951–2006; Investment: 1952–2006; Consumption, Export, Import: 1957–2006; CPI: 1970–2006; Core CPI: 1985–2006

Fig. 1. Interest Rate Shock

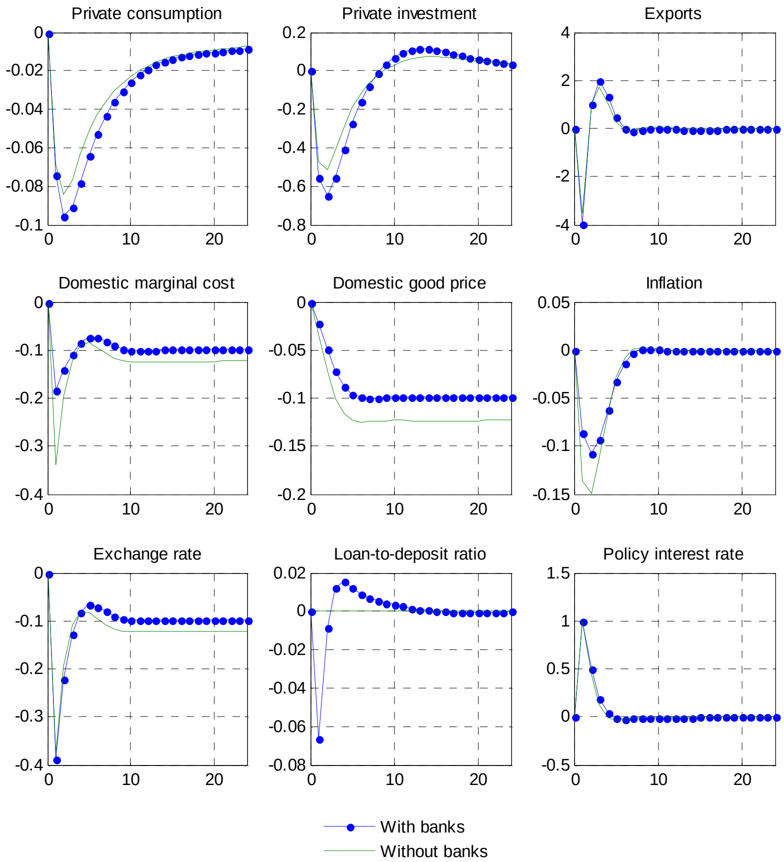


Fig. 2. Productivity Shock

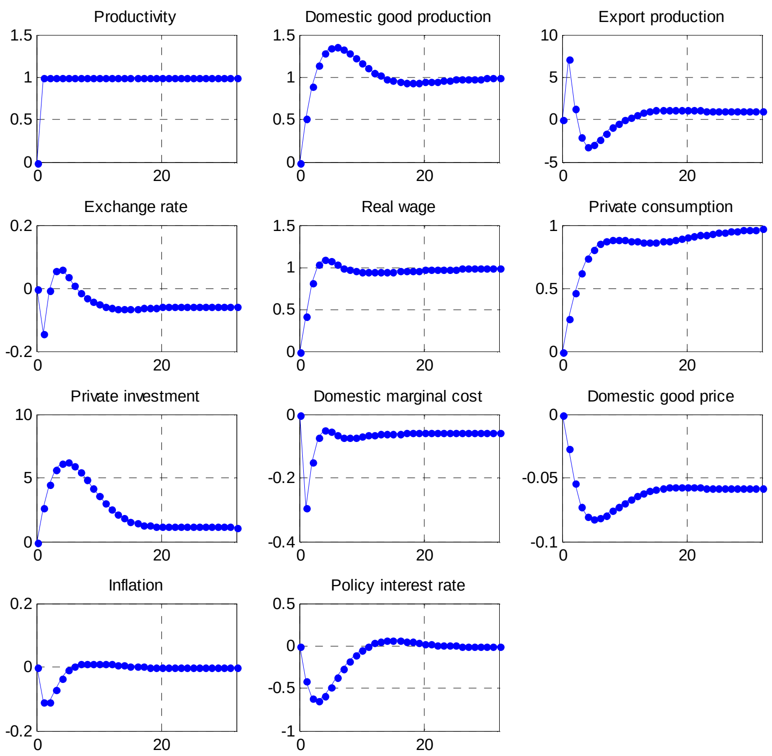


Fig. 3. Price Shock

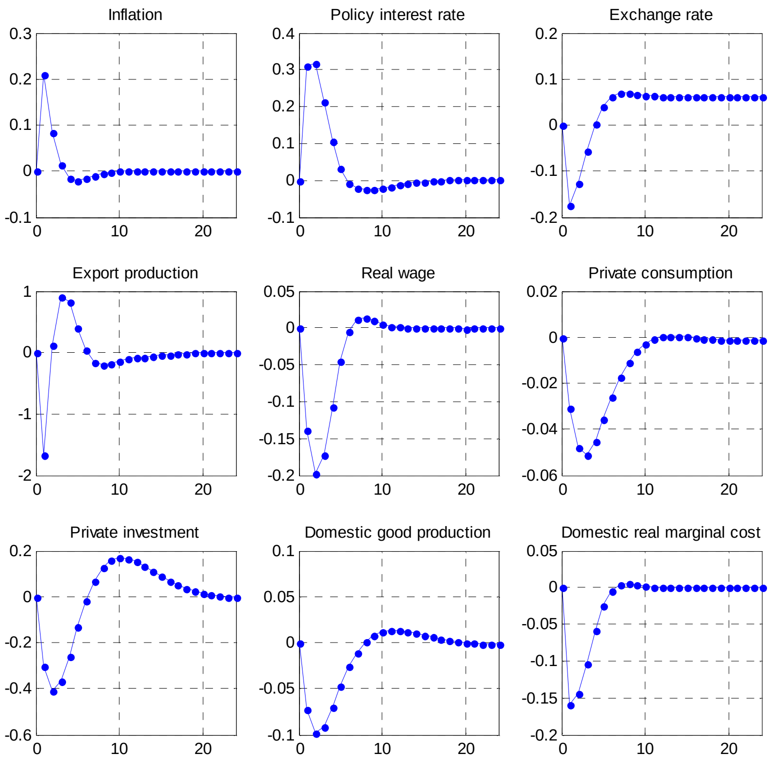


Fig. 4. Exchange Rate Shock

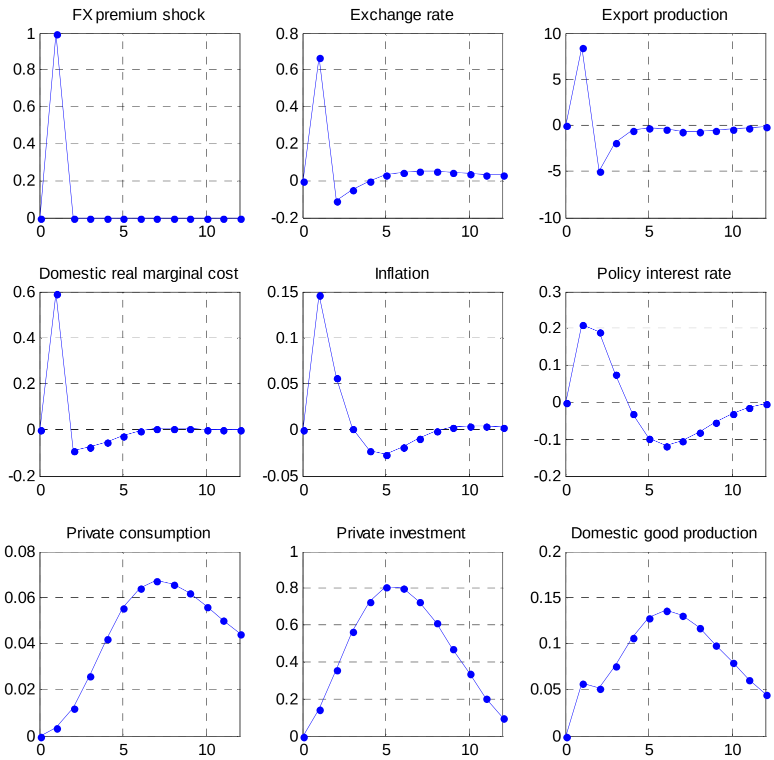


Fig. 5. Model-implied and Empirical Moments (1)

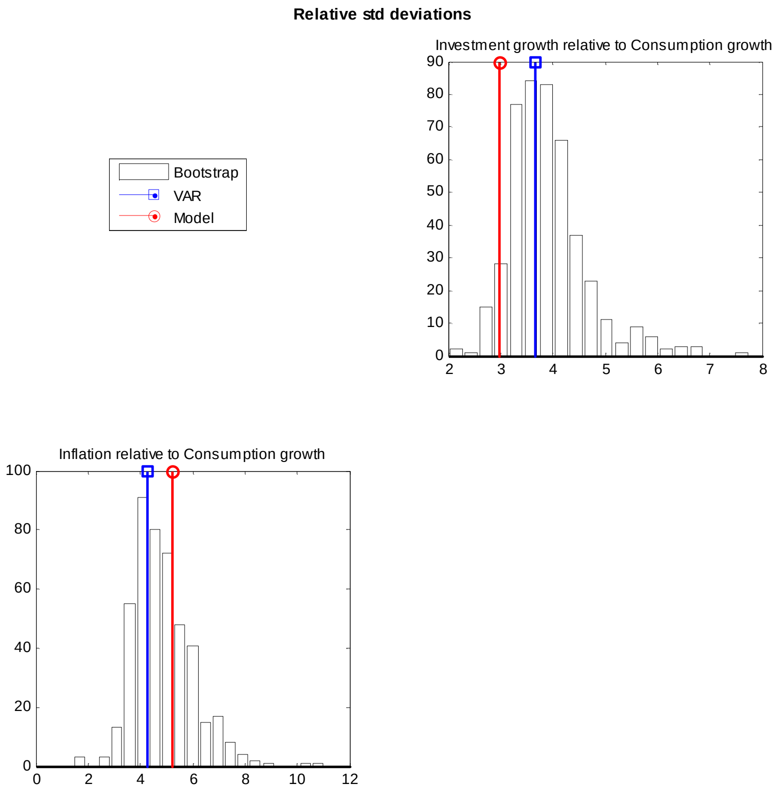


Fig. 6. Model-implied and Empirical Moments (2)

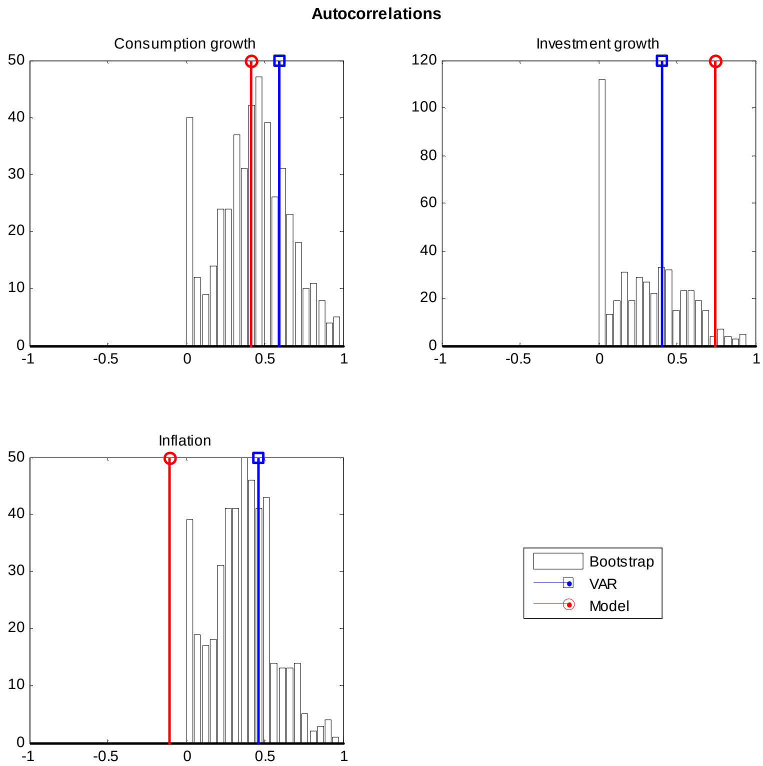


Fig. 7. Model-implied and Empirical Moments (3)

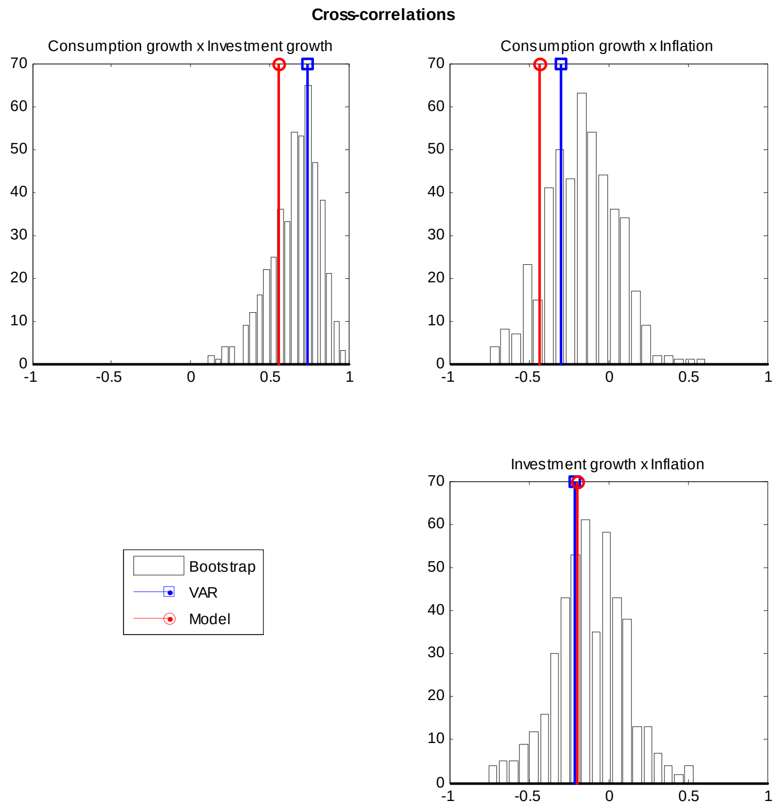
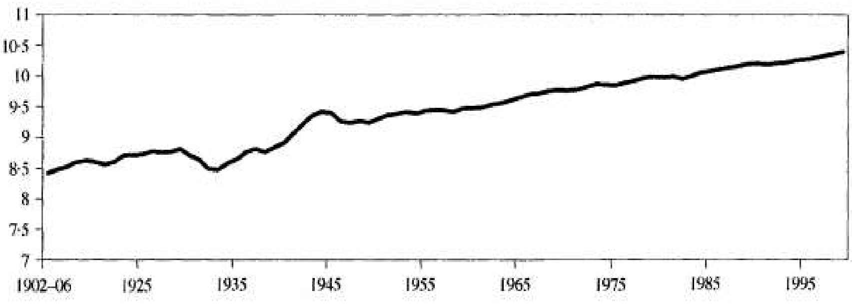


Fig. 8. U.S. per capita GDP, 1902–1999 (in logarithm)



Sources: Historical Statistics of the U.S.; Economic Report of the President; and U.S. Census Bureau.

Fig. 9. Thai output per capita, 1971–2006 (in logarithm)

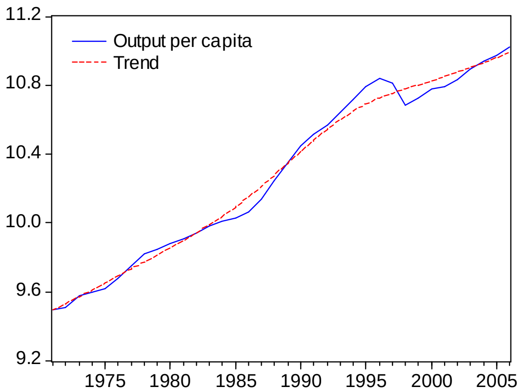


Fig. 10. Consumption Share in GDP

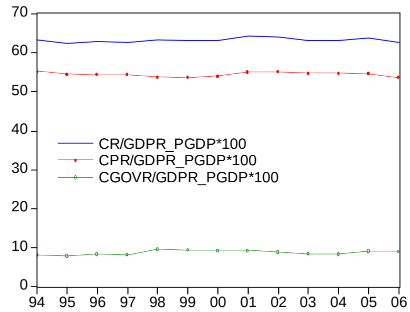


Fig. 11. Investment Share in GDP

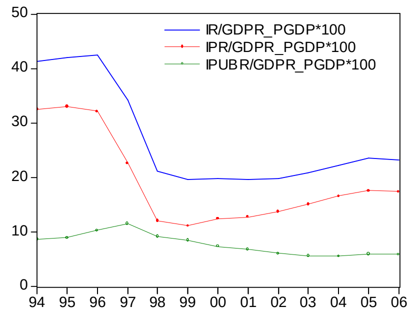


Fig. 12. Net Export Share in GDP

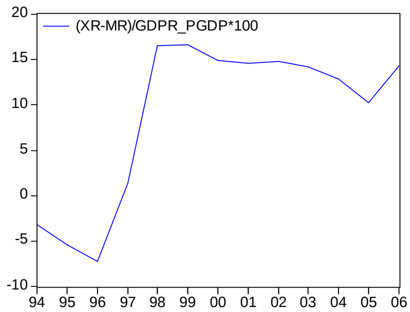


Fig. 13. Autocorrelation of detrended output

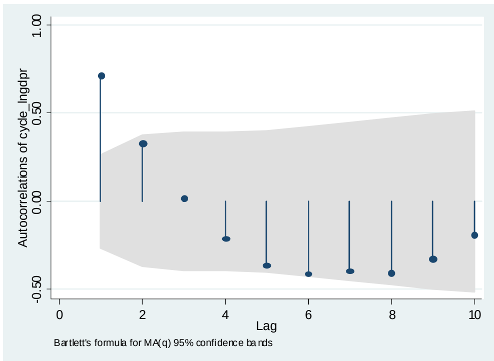


Fig. 14. Partial autocorrelation of detrended output