Research Department **Bank of Israel**

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Discussion Paper No. 2012.07
May 2012

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Abstract

We employ a model-based approach in an ex-post evaluation of monetary policy decisions taken by the Bank of Israel during the years 2001-2010. Using ex-post information, we test, for each individual year, whether there could have been a Pareto improvement in inflation and output volatilities. This involves simulating counterfactual scenarios under alternative monetary policy shocks, where for each such simulation we compute the Root Mean Squares (RMS) of the inflation and output gaps during and following the evaluated year. We then examine the deviation of actual RMS from simulation-based frontiers. We also compare the actual RMS to a counterfactual RMS which would have been obtained for the case of no policy shocks. In other words, we test whether actual policy shocks were "efficient". The exercise reveals several distinct sets of years: years in which actual RMSs were close to the efficient frontier (2001 and 2009) and years in which they were far away (2003, 2004 and 2006); years in which monetary policy shocks led to an absolute improvement in economic outcomes (2004 and 2008) or an absolute worsening (2003, 2006); and years characterized by aggressive policy shocks (2002, 2008 and 2009), which were usually aimed at narrowing the output gap at the expense of more volatile inflation.

JEL classification: C54, E37, E52, E58

Keywords: Monetary Policy, Policy Evaluation, DSGE, Models and Applications, Israel

*The authors would like to thank Guy Segal, Roni Frish and participants in the Bank of Israel Research Department seminar for their valuable comments.

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הערכת המדיניות המוניטרית בדיעבד

איל ארגוב, אליעזר בורנשטיין, אלון בנימיני ועירית רוזנשטרום

תקציר

מטרת עבודה זו היא להעריך את המדיניות המוניטרית של בנק ישראל בשנים 2001–2010, בגישה מבוססת-מודל ובהינתן אינפורמציה הידועה בדיעבד. השאלה, שנבדקה לכל שנה בנפרד, היא אם המדיניות המוניטרית, כפי שהיא משתקפת בזעזועים הנגזרים לכלל המדיניות במודל, הביאה ל"שיפור פָּרֶטוֹ" במונחי השונויות של האינפלציה והתוצר. לשם כך ערכנו סימולציות המדמות את ההתפתחויות הכלכליות בהשפעתם של זעזועי מדיניות שונים מאלו שהיו בפועל (counterfactual simulations), ובכל סימולציה חישבנו את ממוצע הריבועים של סטיות האינפלציה ושל פערי התוצר. על סמך התוצאות נבנתה לכל אחת מהשנים עקומה המבטאת את "חזית היעילות", דהיינו את השילובים היעילים של ריבועי סטיות האינפלציה ופערי התוצר. לאחר מכן השווינו את הביצועים בפועל לחזית זו, ובדקנו אם זעזועי המדיניות קירבו את התוצאות בפועל ל"חזית היעילות" או הרחיקו אותן ממנה; במילים אחרות – אם המדיניות היתה "יעילה". מהתוצאות עולה כי ישנן שנים שבהן הביצועים בפועל היו קרובים לחזית היעילות (2001 ו-2009) ושנים שבהן הם היו רחוקים ממנה (2003, 2004 ו-2006). עוד עולה כי ישנן שנים שבהן זעזועי המדיניות המוניטרית הביאו לשיפור ביצועי המשק (2004 ו-2008), ושנים שבהן הם הביאו להרעה (2003 ו-2006). ולבסוף – ישנן שנים שהתאפיינו בזעזועי מדיניות חזקים (2002, 2008 ו-2009), אשר בדרך כלל גם התאפיינו בהעדפה של צמצום פער התוצר במחיר של שונות גבוהה יחסית באינפלציה.

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1 Introduction

Most inflation-targeting central banks set nominal interest rates on a regular basis, normally making eight to twelve interest rate decisions per year. It has been widely recognized that the process of setting monetary policy should be highly forward looking. Svensson (1997) refers to the process as "inflation *forecast* targeting". But to what extent do central banks evaluate their decisions in retrospect and what would be a possible measure for evaluating whether policy decisions have been efficient?

The main purpose of this paper is to offer a framework for evaluating past policy decisions. To the best of our knowledge, there has been little work done on principles and frameworks for ex-post evaluation of monetary policy decisions. The vast literature on optimal policy *rules* focuses on the general functioning of decision makers, i.e. evaluating the policy rule, rather than the actual decisions.[1] One of the exceptions is Svensson (2012) who proposes a framework for evaluating a specific policy decision. This involves calculating the expected Root Mean Squares (RMSs) of the inflation and output gaps ex ante, as they were projected when the interest rate decision was being made. Expected RMSs are also calculated for alternative future interest rate paths using a DSGE model and then compared to the baseline case. The exercise may demonstrate the tradeoff between stabilizing inflation and stabilizing output, or the analysis may show that the expected RMSs of both inflation and output could have both been reduced and therefore that the policy decisions were ex-ante inefficient.

The approach taken here differs from that of Svensson (2012) in two main ways: First, the approach can be applied in the evaluation of a set of policy decisions, say over a period of a year, and not just of a forecasted path at one specific point in time. Second, and more importantly, we employe an ex-post approach that evaluates past monetary policy decisions based on information available today and which was not necessarily available to the decision

[1] Using the terminology of DSGE models, the latter includes not only the systematic part of the rule but also policy "shocks", i.e. deviations from the rule.

makers at the time of the decision. One could argue that this makes the ex-post approach irrelevant. Nevertheless, we believe that it is of interest to examine what would have been the counterfactual outcomes under alternative decisions, the best economic results that policy makers could have delivered and the measures that should have been taken to achieve those results. Moreover, a single reference model clearly cannot forecast certain developments that may be predictable using other tools. Hence, the present model treats such developments as unexpected shocks (known only ex-post and not ex-ante), whereas in reality they could have been predicted and taken into account by decision makers. Put differently, ex-post evaluation may, to some extent, point to conclusions relevant to ex-ante policy conduct.

Our proposed framework compares the actual RMSs of two objective variables, i.e. the inflation and output gaps, to those of alternative counterfactual interest rate paths, calculated using a DSGE model. The hypothetical paths are obtained by varying the model's monetary policy shock. One particular benchmark alternative path is the case of zero policy shocks, i.e. strictly following the interest rate rule. We also search for the efficient frontier, i.e. the combinations for which the RMSs of both objective variables cannot both be improved. We regard the active policy actions (i.e. the non-systematic component of policy) as "efficient" when actual RMSs are closer to the frontier than those of the zero-policy-shock path.

The main underlying assumption of this framework is that over short horizons active policy making involves choosing deviations from an interest rate rule, i.e. manipulating the monetary policy shocks, rather than changing the policy rule per se. This assumption stems from our understanding that monetary policy rules cannot, and should not, be changed frequently. Among the reasons for this, is that central banks normally do not publish their policy rule and certainly not on a quarterly basis. If anything, central banks only publish an expected policy *path* and therefore it would not be realistic to consider counterfactual outcomes for alternative policy *rules*. Since frequently changing the policy rule is not practical and since the public uses the supposed rule to form their expectations with regard to future economic developments, we interpret active monetary policy to be the choice of short-run deviations from the rule, i.e. monetary policy "shocks". The driving forces behind such shocks may be changes in the loss function's weights (such as, a change in the relative importance assigned to stabilizing inflation or output) or considerations that are not systematically incorporated into the rule (for example, precautionary reactions to risk). There are of course alternative interpretations of deviations from an interest rate rule that are not consistent with our framework, such as real-time measurement errors in the variables entering the rule, exogenous pressures on policy makers and errors resulting from a non-structural rule.

The analysis includes a diagrammatic representation of the results, which uses two types of presentations: (1) a scatter plot of the actual, counterfactual and frontier RMSs and (2) the interest rate paths that generate the frontier RMSs, along with the actual path. To demonstrate the framework, we use the Bank of Israel's medium-scale DSGE model (MOISE)[2] to conduct monetary policy evaluations for each of the years 2001-2010. During this decade, inflation in Israel fluctuated around the center of the target band though there were large positive and negative deviations. For most of the period, the (model-based) output gap was negative (two percent on average), which in retrospect, may mean that there was considerable room for intervention, i.e. policy shocks, that would have improved economic outcomes.

The rest of the paper is organized as follows. Section 2 provides a brief description of MOISE. Section 3 discusses the estimation of the model. Section 4 describes the framework for policy evaluation. Section 5 demonstrates the use of the framework by evaluating monetary policy in Israel during the last decade. Finally, section 6 offers some concluding remarks.

[2] See Argov et al. (2012).

2 The model

We use the Bank of Israel's medium-scale DSGE model described in Argov et al. (2012), which follows along the lines of the ECB's New Area Wide Model and the Riksbank's RAMSES model (see Christoffel et al. (2008) and Adolfson et al. (2007), respectively).[3] The economic agents in the model are households, firms of several types in the production sector, a fiscal authority and an inflation-targeting central bank whose policy tool is the nominal interest rate. The production sector includes monopolistic producers of intermediate goods (who employ labor and capital as inputs for production), competitive producers of final goods, importers and exporters. In what follows, we will only present some of the key equations describing the structure of the economy. For a complete description of the model, see Argov et al. (2012).

2.1 Households

The model's economy consists of a continuum of households, indexed by $h \in [0, 1]$. Households derive a lifetime utility from the discounted flow of private consumption (with external habit formation) and leisure:

$$E_t \sum_{k=0}^{\infty} \left[\beta^k \left(\varepsilon_{t+k}^C \ln \left(C_{h,t+k} - \kappa C_{t+k-1} \right) - \frac{1}{1+\zeta} \left(N_{h,t+k} \right)^{1+\zeta} \right) \right], \tag{1}$$

where E_t is the mathematical expectations operator, $C_{h,t}$ denotes the consumption composite consumed by household h in period t and $N_{h,t}$ denotes working hours. The parameter β is the time-discount factor and ζ is the inverse of the Frisch elasticity of labor supply. Households are subject to external habit persistence, which is measured by the parameter κ. Households' preferences are subject to a consumption demand shock, ε_t^C.[4]

[3] Other similar central bank models include Brubakk et al. (2006) for Norway, Murchison and Rennison (2006) for Canada, Beneš et al. (2009) for New Zealand and Seneca (2010) for Iceland.

[4] In general, we will assume that shocks follow a log AR(1) process. For example, $\log(\varepsilon_t^C) = \rho^C \log(\varepsilon_{t-1}^C) + \eta_t^C$, where η_t^C is a white noise process.

The period-by-period budget constraint faced by household h is given by:

$$\begin{aligned} & \left(1+w_{\tau^C}\tau_t^C\right) P_{C,t}C_{h,t} + P_{I,t}I_{h,t} + P_{I,t}\Delta INV_t \\ & + \left(\varepsilon_t^{RP}\varepsilon_t^{DRP}R_t\right)^{-1} B_{h,t+1} + \left(\varepsilon_t^{RP}\Gamma_{B^*,t}R_t^*\right)^{-1} S_t B_{h,t+1}^* + \Xi_t + \Upsilon_{h,t} \\ = & \left(1-\tau_t^N-\tau_t^{W_h}\right) W_{h,t}N_{h,t} + \left(1-\tau_t^K\right) R_{K,t}K_{h,t} \\ & + \tau_t^K \delta P_{I,t}K_{h,t} + \left(1-\tau_t^D\right) D_{h,t} - T_t + B_{h,t} + S_t B_{h,t}^*. \end{aligned} \tag{2}$$

The first term, $\left(1+w_{\tau^C}\tau_t^C\right) P_{C,t}C_{h,t}$, denotes nominal expenditure on consumption. τ_t^C is the rate of value added tax (VAT), $w_{\tau^C} \in (0,1)$ is the share of goods that is subject to VAT and $P_{C,t}$ is the price of the consumption good. The term $P_{I,t}I_{h,t}$ is the expenditure on fixed capital investment and $P_{I,t}\Delta INV_t$ is the expenditure associated with the change in inventories. The latter is exogenously determined so that inventories, as a share of GDP ($\Delta inv_t = \frac{\Delta INV_t}{Y_t}$), follows an AR(1) process.

In the second row of the budget constraint (2), $B_{h,t}$ and $B_{h,t}^*$ denote bond holdings at the beginning of period t, denominated in domestic and foreign currencies, respectively. The market price of the local currency bond, $\left(\varepsilon_t^{RP}\varepsilon_t^{DRP}R_t\right)^{-1}$, is driven by the short-term gross nominal interest rate set by the central bank, R_t, and by two premium shocks which drive a wedge between the market return on bonds and the risk-free central bank rate. The first shock, ε_t^{RP}, which also drives the price of foreign currency bonds,[5] is introduced so as to generate a correlated shift in demand for both consumption and investment. The second shock, ε_t^{DRP}, drives the price of the domestic-currency bond only.[6]

Turning to foreign-currency-denominated bonds, the variable S_t denotes the nominal exchange rate and the variable R_t^* is the foreign risk-free nominal interest rate. We assume

[5] Hence, it is labeled as a 'symmetric' shock and can be thought of as a reduced form of some financial intermediation premium.

[6] Such a highly inertial shock drives the real forward rates for longer terms (hence this shock may be thought of as a shock to the "natural" interest rate). In turn, we will later assume that these forward rates serve as an anchor in the central bank's policy rule (see the interest-rate rule specified by equation 25 below). Thus, the nominal interest rate eventually adjusts so as to offset the effect of the shock on the market rate, and therefore the effect of the shock on consumption and investment persists only in the short to medium run.

an external financial intermediation premium associated with these bonds, given by:

$$\Gamma_{B^*} = \varepsilon_t^{RP^*} \exp\left[-\gamma_{B^*} s_{B^*,t+1} - \gamma_S E_t \left(\frac{S_{t+1}}{S_t}\frac{\bar{\Pi}^*_{t+1}}{\bar{\Pi}_{t+1}}\frac{S_t}{S_{t-1}}\frac{\bar{\Pi}^*_t}{\bar{\Pi}_t} - 1\right)\right], \tag{3}$$

where $s_{B^*,t+1} \equiv \left(S_t B^*_{t+1}\right) / \left(P_{Y,t} Y_t\right)$ is economy-wide net foreign assets as a share of nominal GDP.[7] Thus we assume an endogenous premium that depends on the economy-wide net foreign asset position and the expected nominal depreciation. The former insures a stable non-stochastic steady state while the latter allows for some sluggishness in the dynamics of the real exchange rate. Finally, $\varepsilon_t^{RP^*}$ is an exogenous shock to the external premium.

Closing the expenditure side, the variable Ξ_t denotes lump-sum transfers and the variable $\Upsilon_{h,t}$ is household h's holding of state-contingent securities that provide insurance against household-specific wage-income risk.

Household labor income, based on an hourly nominal wage of $W_{h,t}$, is subject to two taxes: a direct income tax τ_t^N and a social security tax $\tau_t^{W_h}$. We assume households are monopolistic suppliers of differentiated labor services, $N_{h,t}$. Nominal hourly wages are staggered using the Calvo (1983) setup, where $(1-\xi_W) \in (0,1)$ is the probability of receiving an exogenous and idiosyncratic signal that is followed by wage re-optimization. In the absence of such a signal, which occurs with probability ξ_W, the h'th household updates its hourly wage according to the following indexation scheme:

$$W_{h,t} = g_z \Pi^{\dagger}_{C,t} W_{h,t-1}, \tag{4}$$

where $\Pi^{\dagger}_{C,t} \equiv \left(\Pi_{C,t-1}\right)^{\chi_W} \left(\bar{\Pi}_t\right)^{(1-\chi_W)}$, with $\Pi_{C,t} \equiv P_{C,t}/P_{C,t-1}$, and $\bar{\Pi}_t$ is the (gross) inflation target. The parameter g_z denotes the long-run (gross) growth rate of labor productivity. The parameter χ_W measures the degree of inflation indexation in the wage setting.

There is also a flow of capital income, where the variable $R_{K,t}$ denotes the nominal price of capital services and $K_{h,t}$ denotes the capital stock owned by household h. The net tax

[7] The dynamics of the economy-wide net foreign assets are driven by the trade balance and the assumed exogenous foreign transfers. Hence: $\left(R_t^*\right)^{-1} B^*_{t+1} = B^*_t + \frac{P_{X,t} S_t X_t - P_{IM,t} IM_t + FTR_t}{S_t}$. See Argov et al. (2012) for a more detailed explanation.

rate on capital is τ_t^K.[8] The physical capital stock evolves as follows:

$$K_{h,t+1} = (1-\delta) K_{h,t} + \varepsilon_t^I \left[1 - \Gamma_I\left(\widetilde{I}_{h,t}\right)\right] I_{h,t}, \tag{5}$$

where ε_t^I is an investment-specific technology shock *á la* Greenwood et al. (1997). The variable $\Gamma_I\left(\widetilde{I}_{h,t}\right)$ is an investment adjustment cost associated with deviations of investment growth rates from the long-run productivity growth rate, g_z :

$$\Gamma_I\left(\widetilde{I}_{h,t}\right) = \frac{\gamma_I}{2}\left(\widetilde{I}_{h,t} - g_z^{\left(1+\omega_{\Gamma_I}\right)}\right)^2, \tag{6}$$

where

$$\widetilde{I}_{h,t} \equiv \frac{I_{h,t}}{I_{h,t-1}}\left(\frac{I_{h,t-1}}{I_{h,t-2}}\right)^{\omega_{\Gamma_I}}.$$

Based on its share of ownership in the monopolistic firms, household h earns a flow of dividends, $D_{h,t}$, which is subject to the tax rate on dividend income, τ_t^D. Finally, the variable T_t denotes lump sum taxes.

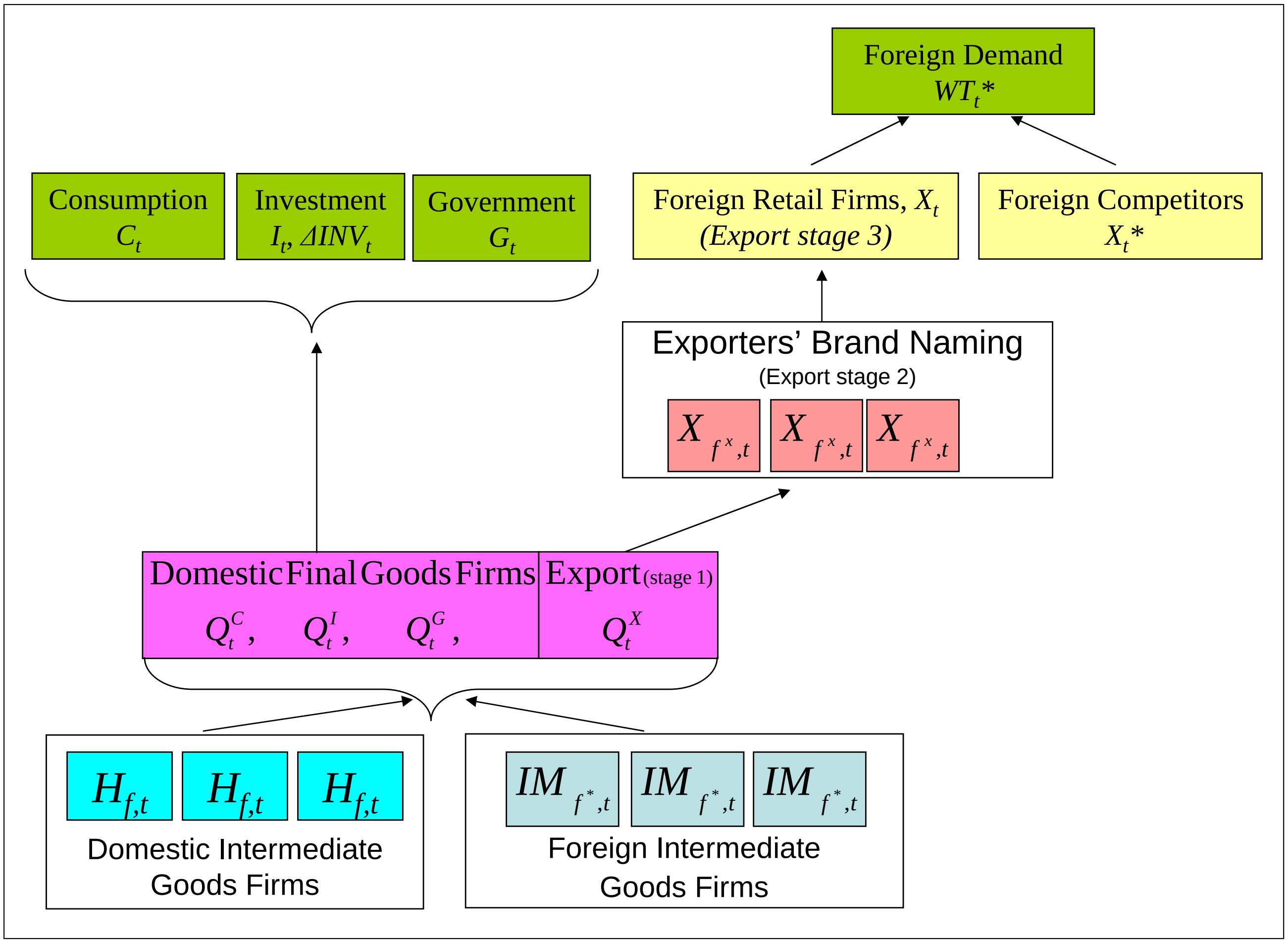
2.2 Firms

Figure 1 illustrates the structure of the production sector. The sector includes five types of firms:

- Monopolistically competitive domestic firms that produce differentiated intermediate-goods, $H_{f,t}$ where $f \in [0,1]$.
- Monopolistically competitive foreign firms that produce differentiated intermediate goods, $IM_{f^*,t}$ where $f^* \in [0,1]$, which are imported to the domestic economy.
- Perfectly competitive firms produce final goods for consumption, investment, government consumption and export (Q_t^C, Q_t^I, Q_t^G, and Q_t^X, respectively). The production

[8] Note that Argov et al. (2012) allow for variable capital utilization. However, in the estimation procedure this mechanisem is turned off.

Figure 1: The Structure of the Production Sector



inputs of these firms are composites of differentiated intermediate goods, both domestically produced ($H_{f,t}$) and imported ($IM_{f*,t}$).

- Monopolistically competitive exporters buy the final homogenous domestic export good (Q_t^X) and differentiate (brand name) it. The new differentiated good, $X_{f^X,t}$ where $f^x \in [0,1]$, is then sold to foreign retail firms.

- Foreign retail firms combine the differentiated export goods ($X_{f^X,t}$) into an homogenous exported good (X_t).

We assume that all monopolistically competitive firms are subject to Calvo (1983)-style price rigidity in terms of the *local* currency. The structure of the exporting sector is designed so as to introduce imported inputs in the production of exports and, at the same time, to allow for consumer-currency price rigidity (in exports). We will now turn to a detailed description of each firm type individually.

Domestic intermediate-good firms

A continuum of domestic firms, indexed by $f \in [0,1]$, produce differentiated intermediate goods, $H^s_{f,t}$. The production technology combines capital and differentiated labor services hired from the households ($K^s_{f,t}$ and $N_{f,t}$, respectively):

$$H^s_{f,t} = \max\left[\varepsilon_t \left(K^s_{f,t}\right)^{\alpha} \left(z_t N_{f,t}\right)^{1-\alpha} - \psi z_t,\ 0\right]. \tag{7}$$

Here ε_t is a transitory technology shock and z_t is a difference-stationary labor-augmenting productivity shock that determines the balanced growth path of all real variables (both are symmetric across firms). The gross growth rate of the labor productivity shock, $g_{z,t} \equiv z_t / z_{t-1}$, follows an AR(1) process.

The variable $K^s_{f,t}$ is the (homogenous) capital services rented under perfect competition. Labor services employed by the $f'th$ firm, $N_{f,t}$, is a Dixit and Stiglitz (1977) Constant Elasticity of Substitution (CES) composite of household-specific labor inputs, $N^h_{f,t}$:

$$N_{f,t} = \left(\int_0^1 \left(N^h_{f,t}\right)^{\frac{1}{\varphi^W_t}} dh\right)^{\varphi^W_t}. \tag{8}$$

Here we have defined the exogenous CES between differentiated labor services to be $\varphi^W_t / \left(\varphi^W_t - 1\right) > 1$, where $\varphi^W_t > 1$ may be interpreted as an exogenous wage markup shock.[9]

Finally, the production technology (7) includes a fixed-cost term, ψz_t, where the parameter ψ is calibrated to ensure zero profits in the steady state.

[9] All markups in the model follow AR(1) processes with a steady state value greater than one.

Firm f's total variable cost in production is given by :

$$TVC_t = R_{K,t}K^S_{f,t} + R^F_t\left(1+\tau^{W_f}_t\right)W_tN_{f,t}, \tag{9}$$

where $\tau^{W_f}_t$ is the social security tax rate levied on the firms. We allow for a working capital channel, $R^F_t = 1 + \nu^F(R_t - 1)$, where each firm must borrow a fraction ν^F of its wage bill ahead of production at an interest rate of R_t.

We assume sluggish price adjustment in the domestic intermediate good sector, using the Calvo (1983) setup. Thus, as in the staggered-wages setup presented in section 2.1, the probability that a firm doesn't receive an exogenous and idiosyncratic re-optimization signal is ξ_H, in which case the firm adjusts its price according to the following indexation scheme:

$$P_{H,f,t} = \Pi^{\chi_H}_{H,t-1}\overline{\Pi}^{1-\chi_H}_t P_{H,f,t-1}, \tag{10}$$

where $\Pi_{H,t} \equiv P_{H,t}/P_{H,t-1}$ and $\overline{\Pi}_t$ is the gross time-varying inflation objective. The parameter χ_H thus controls for the degree of indexation to past aggregate domestic inflation.

Foreign intermediate good firms

A continuum of foreign firms, indexed by $f^* \in [0,1]$, produce differentiated intermediate goods, $IM_{f^*,t}$, which are imported to the domestic economy. We assume consumer-currency pricing subject to the following nominal marginal cost:

$$MC^*_t = S_t\left(\overline{\Pi}^*_Y P^*_{OIL,t-1}\right)^{\omega^*}\left(P^*_{Y,t}\right)^{1-\omega^*}. \tag{11}$$

Except for the nominal effective exchange rate, S_t, all variables in (11) are expressed in terms of producer currency: $\overline{\Pi}^*_Y$ is the gross inflation rate of the foreign economy in the steady state, $P^*_{OIL,t}$ is the global price of oil and $P^*_{Y,t}$ is the global price of foreign intermediate goods. We assume an explicit role for the global price of oil, with the parameter ω^* representing the share of oil in the import basket.

Once differentiated, the imported intermediate goods are supplied as inputs to the final good firm in monopolistically competitive markets. As in the case of the domestically-produced intermediate goods, we employ the Calvo (1983) setup for the consumer-currency pricing of imported goods. However, this time the probability of not receiving the idiosyncratic re-optimization signal is denoted by ξ^*, in which case the firm adjusts its price according to the following indexation scheme:

$$P_{IM,f^*,t} = \Pi_{IM,t-1}^{\chi^*} \overline{\Pi}_t^{1-\chi^*} P_{IM,f^*,t-1}, \tag{12}$$

with $\Pi_{IM,t} \equiv P_{IM,t}/P_{IM,t-1}$. The parameter χ^* reflects the degree of indexation to past aggregate inflation of imported goods.

Domestic final good firms

Domestic firms producing final goods are divided into four categories: producers of consumption goods Q_t^C, producers of investment goods Q_t^I, producers of government-consumption goods Q_t^G and producers of exported goods Q_t^X.[10] This section describes the competitive producers in the first category, which can be carried over to the other categories.[11,12]

The final consumption good is a CES composite of domestically-produced and imported aggregates of intermediate goods (H_t^C and IM_t^C, respectively):

$$Q_t^C = \left(\nu_{C,t}^{\frac{1}{\mu_C}} \left[H_t^C \right]^{1-\frac{1}{\mu_C}} + (1-\nu_{C,t})^{\frac{1}{\mu_C}} \left[IM_t^C \right]^{1-\frac{1}{\mu_C}} \right)^{\frac{\mu_C}{\mu_C - 1}}. \tag{13}$$

The parameter μ_C is the CES between domestic and imported goods and the (time-varying) parameter $\nu_{C,t}$ measures the degree of home bias ($1-\nu_C$ will be the steady-state import-intensity in the Q_t^C sector).

[10]In equlibrium: $Q_t^C = C_t$, $Q_t^I = I_t + \Delta INV_t$ and $Q_t^G = G_t$. As for Q_t^X; see section 2.2.
[11]Up to a different parameterization.
[12]At the end of the section, we elaborate on some additional steps in the production and marketing of the exported goods.

The aggregates of the domestically-produced and imported intermediate goods are, respectively:

$$H_t^C = \left(\int_0^1 \left(H_{f,t}^C \right)^{\frac{1}{\varphi_t^H}} df \right)^{\varphi_t^H}, \tag{14}$$

and

$$IM_t^C = \left(\int_0^1 \left(IM_{f^*,t}^C \right)^{\frac{1}{\varphi_t^*}} df^* \right)^{\varphi_t^*}. \tag{15}$$

Thus, the optimal markups of the intermediate goods producers, φ_t^H and φ_t^*, are time-varying.

Since final good firms operate under perfect competition, they simply charge their marginal cost, so that:

$$P_{C,t} = \left\{ \nu_{C,t} \left[P_{H,t} \right]^{1-\mu_C} + (1-\nu_{C,t}) \left[P_{IM,t} \right]^{1-\mu_C} \right\}^{\frac{1}{1-\mu_C}}. \tag{16}$$

This section has described the firms producing the final consumption good, Q_t^C. The equations can be carried over to the other sectors (Q_t^I, Q_t^G and Q_t^X) by simply replacing the index C in equations (13) to (16) with I, G or X. The only exception is the price of exported goods, which will be denoted by $P_{DX,t}$, since the notation $P_{X,t}$ is being reserved to denote the (foreign-currency) price charged by exporters who buy Q_t^X, brand name it and sell it to foreign retail firms. This will be discussed in the remainder of this section.

Exporters

Final goods, as described in the previous subsection, are supplied under perfect competition. Monopolistic competition, which is essential for nominal frictions to exist, characterizes the intermediate good sector. These nominal frictions, however, induce *domestic* price rigidity. In order to enable price rigidity in terms of the foreign currency as well—that is, price rigidity of exported goods—we further segment the exporting sector into additional intermediate stages, thus allowing for frictions unique to exports. The focus of the present subsection is on the so-called exporters (see figure 1) indexed by $f^x \in [0, 1]$. These exporters buy homogenous exported goods, Q_t^X, at a marginal cost of $P_{DX,t}$ and brand name them using the following simple production function, so as to supply a differentiated good, $X_{f^x,t}$:

$$X_{f^X,t} = Q_{f^X,t}^X - \psi^X z_t. \tag{17}$$

In other words, brand naming is subject to a fixed cost, $\psi^X z_t$, as in the case of monopolistic producers of domestic intermediate goods.

We again use the Calvo (1983) setup for price rigidities. Thus, there is a constant probability, ξ_X, that exporters will not get to reoptimize prices, in which case they adjust their foreign-currency price, $P_{X,f^X,t}$, according to the following indexation scheme:

$$P_{X,f^X,t} = (\Pi_{X,t-1})^{\chi_X} \left(\overline{\Pi}_t^*\right)^{(1-\chi_X)} P_{X,f^X,t-1}, \tag{18}$$

where $\Pi_{X,t} \equiv P_{X,t}/P_{X,t-1}$ is (foreign currency) inflation in the exporting sector and $\overline{\Pi}_t^*$ is the gross potentially time-varying foreign inflation objective.

Foreign retail firms

Foreign retail firms purchase the differentiated export goods, $X_{f^X,t}$ where $f^X \in [0, 1]$, and combine them into an homogenous exported good, X_t (see figure 1). The homogenous exported good is, in turn, a CES aggregate of the differentiated goods:

$$X_t = \left(\int_0^1 \left(X_{f^X,t}\right)^{\frac{1}{\varphi_t^X}} df^X \right)^{\varphi_t^X}. \tag{19}$$

Since there are infinitely many foreign retailers who sell a homogenous good, the price of the good is equal to their marginal cost of production, namely $P_{X,t}$. The homogenous export good is combined with other countries' exports goods to form a CES aggregate of world trade, WT_t^*. Thus, the demand for Israeli exports is analogous to the demand for imported and domestic intermediate goods in the production of the final goods. The demand faced by foreign retailers marketing Israeli exports is, therefore, given by:

$$X_t = \nu_t^* \left(\frac{P_{X,t}}{P_{X,t}^{c,*} \Gamma_X^{\dagger} \left(X_t / WT_t^*; \varepsilon_t^X \right)} \right)^{-\mu^*} \frac{WT_t^*}{1 - \Gamma_X \left(X_t / WT_t^*; \varepsilon_t^X \right)}, \tag{20}$$

where $P_{X,t}^{c,*}$ is the price aggregate of world trade, the parameter μ^* is the price elasticity of exports and the exogenous process ν_t^* is a country-specific export-demand shock. The variable

$$\Gamma_X \left(X_t / WT_t^*; \varepsilon_t^X \right) \equiv \frac{\gamma^*}{2} \left[\left(\varepsilon_t^X \right)^{-\frac{1}{\gamma^*}} \frac{X_t / WT_t^*}{X_{t-1} / WT_{t-1}^*} - 1 \right]^2 \tag{21}$$

is an adjustment cost associated with variations in the composition of world trade, such that

$$\Gamma_X^{\dagger} \left(X_t / WT_t^*; \varepsilon_t^X \right) \equiv 1 - \Gamma_X \left(X_t / WT_t^*; \varepsilon_t^X \right) - \Gamma_X' \left(X_t / WT_t^*; \varepsilon_t^X \right) X_t. \tag{22}$$

2.3 Public authorities

2.3.1 The fiscal authority

The fiscal authority purchases homogenous final goods (G_t), issues bonds (B_t) and imposes taxes, both distortionary and lump sum.

We assume exogenous processes for government expenditures and tax rates. Thus, we assume an AR(1) process for government spending :

$$g_t = (1 - \rho_G)\, g + \rho_G g_{t-1} + \eta_t^G, \tag{23}$$

where government spending is stationarized by productivity so that $g_t \equiv G_t / z_t$. We essentially assume a random walk process for the VAT rate:

$$\tau_t^C = (1 - 0.99)\, \tau^C + 0.99 \tau_{t-1}^C + \eta_t^{\tau^C}. \tag{24}$$

The other tax rates—τ_t^N, $\tau_t^{W_h}$, τ^{W_f}, τ_t^K and τ_t^D—are assumed to be constant.

2.3.2 The Central bank

The central bank sets the nominal interest rate, R_t, using an inflation-expectation-based rule. We follow the literature that generalizes a Taylor (1993) type rule. This is done by making some standard modifications as in Christoffel et al. (2008) and Adolfson et al. (2007), which involve adding the forward interest rate, the *four-quarter* inflation rate and the nominal depreciation. In terms of log-linear deviations from the deterministic steady state, the policy rule takes the following form:

$$\begin{aligned} \hat{r}_t &= (1-\phi_R)\left[\widehat{rr}_t^{fwd} + \widehat{\overline{\pi}}_t + \phi_\Pi\left(\hat{\pi}_t^{CB} - \widehat{\overline{\pi}}_t\right) + \phi_y \hat{y}_t^{GAP} + \phi_{\Delta S}\Delta S_t\right] \\ &\quad + \phi_R \hat{r}_{t-1} + \eta_t^R. \end{aligned} \tag{25}$$

Thus, policy reacts to deviations of (expected) inflation from the inflation target $\left(\hat{\pi}_t^{CB} - \widehat{\overline{\pi}}_t\right)$, the output gap $\left(\hat{y}_t^{GAP}\right)$ and nominal depreciation $\left(\Delta S_t \equiv \Delta\hat{s}_t + \hat{\pi}_{Y,t} - \hat{\pi}_{Y,t}^*\right)$. The equation includes a policy shock, η_t^R, which is assumed to follow a white noise process.

The variable $\widehat{rr}_t^{fwd}$ is the forward real interest rate, i.e. the average of the real rates expected to prevail 5 to 10 years ahead:

$$\widehat{rr}_t^{fwd} = \frac{1}{20}E_t\left[\widehat{ri}_{t+21} + \widehat{ri}_{t+22} + \cdots + \widehat{ri}_{t+39} + \widehat{ri}_{t+40}\right], \tag{26}$$

where $\widehat{ri}_t \equiv \widehat{r}_t - E_t\widehat{\pi}_{C,t+1}$ is the (log-linearized) real interest rate. $\widehat{rr}_t^{fwd}$ is governed by ε_t^{DRP}, the domestic and highly inertial risk premium shock.[13]

To account for the disinflation process characterizing the first half of the sample period, we introduce a time-varying inflation target, $\widehat{\overline{\pi}}_t$, which essentially follows a random walk process:

$$\widehat{\overline{\pi}}_t = 0.99\widehat{\overline{\pi}}_{t-1} + \eta_t^{\overline{\Pi}}. \tag{27}$$

In view of the empirical as well as theoretical findings in Argov and Elkayam (2010), policy was made to react directly to nominal depreciation and to respond to both historical

[13] See section (2.1).

and expected inflation. Thus, the inflation to which the central bank reacts is defined as:

$$\hat{\pi}_t^{CB} = E_t \left[\hat{\pi}_{C,t-2} + \hat{\pi}_{C,t-1} + \hat{\pi}_{C,t} + \hat{\pi}_{C,t+1}\right]. \tag{28}$$

We define the output gap as the deviation of output from a technology-driven trend $\left(\hat{y}_t^{GAP} \equiv \log \frac{Y_t}{Z_t \varepsilon_t} - \log y\right)$. Notice that this trend includes both technology shocks: permanent (Z_t) and transitory (ε_t). In the context of the production function (7), this definition of the output gap essentially accounts for deviations of production inputs (capital and labor) from some (unobserved) trend. In this sense, our output gap measure might be interpreted as reflecting demand pressures and rigidities such as "time-to-build", rather than the more common measures that use only the permanent component as the trend. We are also aware that our trend component is not a flexible-price or competitive output measure which are recommended monetary policy targets in certain New Keynesian models. Apart from the complexities involved in calculating these theoretical measures, actually using them in policy evaluation makes the results highly dependent on model assumptions.

2.4 Market-clearing conditions

Let $P_{Y,t}Y_t$ be nominal GDP, i.e. the aggregate added value of the domestic economy. Since only non-competitive firms produce added value, we obtain:

$$P_{Y,t}Y_t = P_{H,t}H_t^s + S_t P_{X,t} X_t - P_{DX,t} Q_t^X. \tag{29}$$

Using the zero-profit conditions for competitive final good firms, and accounting for the market-clearing conditions for intermediate and final goods, we obtain an aggregate nominal resource constraint:

$$\begin{aligned} P_{Y,t}Y_t &= P_{C,t}C_t + P_{I,t}\left(I_t + \Delta INV_t\right) + P_{G,t}G_t + S_t P_{X,t} X_t \\ &\quad - P_{IM,t}\left(IM_t^C + IM_t^I + IM_t^G + IM_t^X\right). \end{aligned} \tag{30}$$

We define real output as that produced by the domestic intermediate good firm using the economy's production inputs, i.e. labor and capital:[14]

$$Y_t = H_t^s \ . \tag{31}$$

2.5 The foreign economy

The domestic economy is influenced by global conditions through channels represented by five foreign variables: the interest rate (R_t^*), intermediate good prices ($P_{Y,t}^*$), oil prices ($P_{OIL,t}^*$), export competitors' prices ($P_{X,t}^{c,*}$) and world trade (WT_t^*).

We opted for a simple closed-economy New Keynesian style model for the foreign economy, which is presented in its log-linearized form. Small hatted letters denote log deviations from a deterministic steady state and *epsilons* denote exogenous shocks.

For foreign output, $\hat{y}_t^*$, we specify a hybrid (both forward- and backward-looking) investment-saving equation:

$$\hat{y}_t^* = c_{y^*,+} E_t\left[\hat{y}_{t+1}^*\right] + (1 - c_{y^*,+})_t\, \hat{y}_{t-1}^* - c_{y^*,r} \cdot 4 \cdot \left(\hat{r}_t^* - E_t\left[\hat{\pi}_{Y,t+1}^*\right] - \widehat{rr}_t^{*,fwd}\right) + \varepsilon_t^{Y^*}. \tag{32}$$

This is a fairly standard specification, except for our use of $\widehat{rr}_t^{*,fwd}$ as a proxy for the foreign, so-called natural, interest rate. We use the observable forward nominal interest rate to identify it within the data. In view of this variable's in-sample pattern, as well as that of short-run nominal interest rates worldwide, we assume it approximately follows a random walk process:

$$\widehat{rr}_t^{*,fwd} = 0.99 \cdot \widehat{rr}_{t-1}^{*,fwd} + \varepsilon_t^{*,fwd}. \tag{33}$$

In order to bridge between global output ($\hat{y}_t^*$), which is specified by (32), and world trade ($\widehat{wt}_t^*$), which drives domestic exports in equation (20), we assume the following process:

$$\widehat{wt}_t^* = c_{wt,y}\hat{y}_t^* + c_{wt,y\_lag}\hat{y}_{t-1}^* + c_{wt,-}\widehat{wt}_{t-1}^* + \varepsilon_t^{WT^*}. \tag{34}$$

[14] Note that in the definition we employ for real output, the exporters' markup is excluded, although it is included in the definition of nominal output (29).

World inflation, $\hat{\pi}^*_{Y,t}$, is subject to a hybrid New Keynesian Phillips curve:

$$\begin{aligned} 4 \cdot \hat{\pi}^*_{Y,t} &= c_{\pi^*,+} \cdot 4 \cdot E_t \left[\hat{\pi}^*_{Y,t+1}\right] + (1 - c_{\pi^*,+}) \cdot 4 \cdot \hat{\pi}^*_{Y,t-1} \\ &\quad + c_{\pi^*,y} \frac{\hat{y}^*_t + \hat{y}^*_{t-1}}{2} + c_{\pi^*,OIL} \hat{p}^*_{OIL,t} + c_{\pi^*,\Delta OIL} \left(\hat{p}^*_{OIL,t} - \hat{p}^*_{OIL,t-2}\right) + \varepsilon^{\Pi^*}_t, \end{aligned} \tag{35}$$

where the relative price of oil, $p^*_{OIL,t} \equiv P^*_{OIL,t}/P^*_{Y,t}$, follows an AR(2) process:

$$\hat{p}^*_{OIL,t} = c_{oil,-} \hat{p}^*_{OIL,t-1} + c_{oil,\Delta} \left(\hat{p}^*_{OIL,t-1} - \hat{p}^*_{OIL,t-2}\right) + \varepsilon^{OIL}_t. \tag{36}$$

The foreign model is closed by an extended Taylor (1993)-type rule:

$$\begin{aligned} 4 \cdot \hat{r}^*_t &= (1 - c_{r^*,-}) \left[4 \cdot \left(\widehat{rr}^{*,fwd}_t + \widehat{\overline{\pi}}^*_t\right) \right. \\ &\quad + c_{r^*,\pi} 4 \cdot \left(\frac{\hat{\pi}^*_{Y,t-1} + \hat{\pi}^*_{Y,t} + \hat{\pi}^*_{Y,t+1} + \hat{\pi}^*_{Y,t+2} + \hat{\pi}^*_{Y,t+3}}{5} - \widehat{\overline{\pi}}^*_t \right) \\ &\quad \left. + c_{r^*,y} \hat{y}^*_t \right] + c_{r^*,-} \cdot 4 \cdot \hat{r}^*_{t-1} + \varepsilon^{R^*}_t. \end{aligned} \tag{37}$$

Finally, we assume away variations in the relative prices of the exporters' competitors, so that $p^{c,*}_{X,t} \equiv P^{c,*}_{X,t}/P^*_{Y,t} = 1$.

3 Model estimation

3.1 Data, filtering and calibrated parameters

The model was estimated using standard full-information likelihood-based Bayesian methods[15] on 24 macroeconomic time series for Israel. Most variables are expressed in terms of their log difference, $\Delta X_t \equiv \log \left(\frac{X_t}{X_{t-1}}\right)$. The exceptions are the interest rates, the VAT rate and the current account which is expressed in terms of its share in nominal GDP. Hours worked, employment and real domestic variables (GDP and its components) are expressed

[15] See An and Schorfheide (2007).

in per capita terms. Most of the time series had to be adjusted for seasonality, with the exception of interest rates, the exchange rate, tax rates and the price of oil. Nominal variables, which includes inflation rates, exchange rate depreciation, nominal wage inflation and interest rates were detrended using the inflation target. Following is the entire set of observable variables:

- GDP (ΔY_t)
- Private consumption (ΔC_t)
- Fixed capital investment (ΔI_t)
- Government consumption (ΔG_t)
- Exports (ΔX_t)
- Imports (ΔIM_t)
- GDP deflator ($\Delta P^M_{Y,t}$)
- Export deflator ($\Delta P^{NIS}_{X,t} = \Delta \left(S_t P_{X,t}\right)$)
- Current account ($s_{CA,t} = CA_t / P^M_{Y,t} Y_t$)
- CPI ($\Delta P_{C,t}$)
- Inflation target (annualized) ($4 \cdot \overline{\pi}_t$)
- Nominal exchange rate (ΔS_t)
- Nominal hourly wage (ΔW_t)
- Hours worked (ΔN_t)
- Employment (ΔEM_t)
- BoI key rate (r^{OB}_t)
- 5-10 year *fwd* real rate ($rr^{fwd,OB}_t$)
- VAT rate (τ^C_t)
- G4 nominal interest rate ($r^{*,OB}_t$)
- G4 CPI ($\Delta P^*_{Y,t}$)
- G4 GDP (ΔY^*_t)
- OECD imports (ΔWT^*_t)
- 5-10 year *fwd* G4 nominal rate ($r^{*,fwd,OB}_t$)
- Oil price ($\Delta P^*_{OIL,t}$)

In the theoretical model, the quantity of labor is measured by per capita hours worked, N_t. In order to also use employment data (EM_t), we add a semi-theoretical equation connecting hours worked to employment:

$$\widehat{EM}_t = \frac{\beta}{1+\beta\chi_{EM}} E_t\left[\widehat{EM}_{t+1}\right] + \frac{\chi_{EM}}{1+\beta\chi_{EM}}\widehat{EM}_{t-1} + \frac{(1-\beta\xi_{EM})(1-\xi_{EM})}{\xi_{EM}(1+\beta\chi_{EM})}\left(\widehat{N}_t - \widehat{EM}_t\right) + \varepsilon_t^{EM}, \tag{38}$$

where a hat over a variable denotes log deviation from steady state. The shock, ε_t^{EM}, is neither structural, nor does it have any feedback to the rest of the model.

The sample period is 1992:Q1 to 2009:Q4, with the first 12 quarters used only for initialization of the Kalman filter algorithm. Since this period is characterized by a number of structural transitions and discontinuities, real variables grew at different rates than overall output. However, the model—which is characterized by balanced growth paths determined by the productivity growth rate, g_z—is unable to account for this phenomenon. To deal with imbalanced growth rates in the data, we employ a model-consistent filtering approach, along the lines of the "additive hybrid models" described by Schorfheide (2011) and Canova (2009).[16] In this approach, imbalanced growth paths are extracted simultaneously with the estimation of the model's parameters and shocks. In other words, the raw data is smoothed within the model so as to remove the components that are viewed neither as cyclical nor as balanced trends. Thus, the Kalman smoother algorithm is used to remove only those parts of the data that cannot be well explained by the theoretical model's cyclical behavior. Thus, observation equations were added, which connect the structural model to the data using dynamic "observation errors" that reflect unbalanced growth processes.

In addition, since the observed interest rates, both domestic and foreign, do not appear to satisfy stationarity, it proved useful to treat them similarly to the trending variables. Thus, there are also two equations connecting the forward interest rates (domestic and foreign), together with some unobserved time-varying term premiums, to their observed (market-based) counterparts. Further details of this filtering block can be found in Argov et al. (2012).

[16] The employment equation (38) is also a form of such an "additive hybrid model".

In general, parameters that govern the steady-state solution of the model were calibrated so that the steady state would be consistent with presumed long-run great ratios, input weights in production or (imbalanced) growth rates. For the calibration of some parameter values (for example, steady-state markups), we followed what is common practice in the literature. Table 1 presents the calibration of the structural parameters.

Table 1: Calibrated Parameters

Parameter		Value	Parameter		Value
Discount factor	β	0.995	Wage markup	φ^W	1.3
Inverse of labor EoS	ζ	2.0	Dom. price markup	φ^H	1.3
Capital share in prod.	α	0.33	Imp. price markup	φ^*	1.3
LR productivity growth	g_z	1.0025	Exp. price markup	φ^X	1.1
Depreciation rate	δ	0.02	Home bias - C	ν^C	0.65
EoS in consumption	μ^C	1.1	Home bias - I	ν^I	0.60
EoS in investment	μ^I	1.1	Home bias - G	ν^G	0.95
EoS in government	μ^G	0.2	Home bias - X	ν^X	0.68
EoS in exports	μ^X	1.1	Gov. to GDP	s_G	0.26
Foreign EoS	μ^*	1.5	Consumption tax	τ^C	0.16
X's competitors price	p_X^C	1.0	Capital tax	τ^K	0.50
Relative technology	$\widetilde{z}$	1.0	Labor income tax	τ^N	0.28
X's weight in IM^*	ν^*	0.005	Payroll tax - h	τ^{W_h}	0.09
Working capital weight	ν^F	0.2	Payroll tax - f	τ^{W_f}	0.07
Foreign transfers to GDP	s_{FTR}	0.03	Gov. transfers to GDP	s_{TR}	0.15
LR inflation rate	$\overline{\Pi}$	1.005	Δ Inventories in GDP	Δinv	0.01
Share of taxed goods	w_{τ^C}	0.78			

3.2 Estimation results

The choice of priors and the results of the Bayesian estimation of the structural parameters and autoregressive coefficients are reported in table 2 and the results for the observation equation parameters, the standard deviations of the shocks and the parameters of the foreign economy model are presented in tables 3 and 4 of appendix A. In each table, the middle panel presents the prior's shape, mean and standard deviation, while the right hand panel presents statistics for the posterior distribution. The mode was retrieved by standard optimization algorithms while the standard deviation is approximated by the inverse of the Hessian matrix. The mean, as well as the 5th and 95th percentiles of the posterior distribution were calculated by generating 4 chains of 700,000 draws (half of which were burnt out) from the posterior distribution using the Metropolis-Hasting algorithm.

Most of the parameters of the monetary policy rule are well-identified by the data. The data provides firm support for interest rate smoothing with a posterior mean for ϕ_R of 0.83, which is typical of extended Taylor-type rules. The prior (of 0.2) for the output gap reaction coefficient (ϕ_y) receives some support from the data (as reflected by a posterior distribution that is somewhat narrower than the prior), while the posterior mean of the exchange rate reaction parameter ($\phi_{\Delta S}$) is somewhat lower than our prior (0.12 as compared to 0.2). Unfortunately, the data is ambiguous with regard to the inflation reaction parameter (ϕ_Π), such that the prior distribution (with a mean of 2.5) is approximately retrieved by the posterior. Nevertheless, our estimate largely conforms with those obtained for other countries, as well as with previous estimates obtained for Israel.

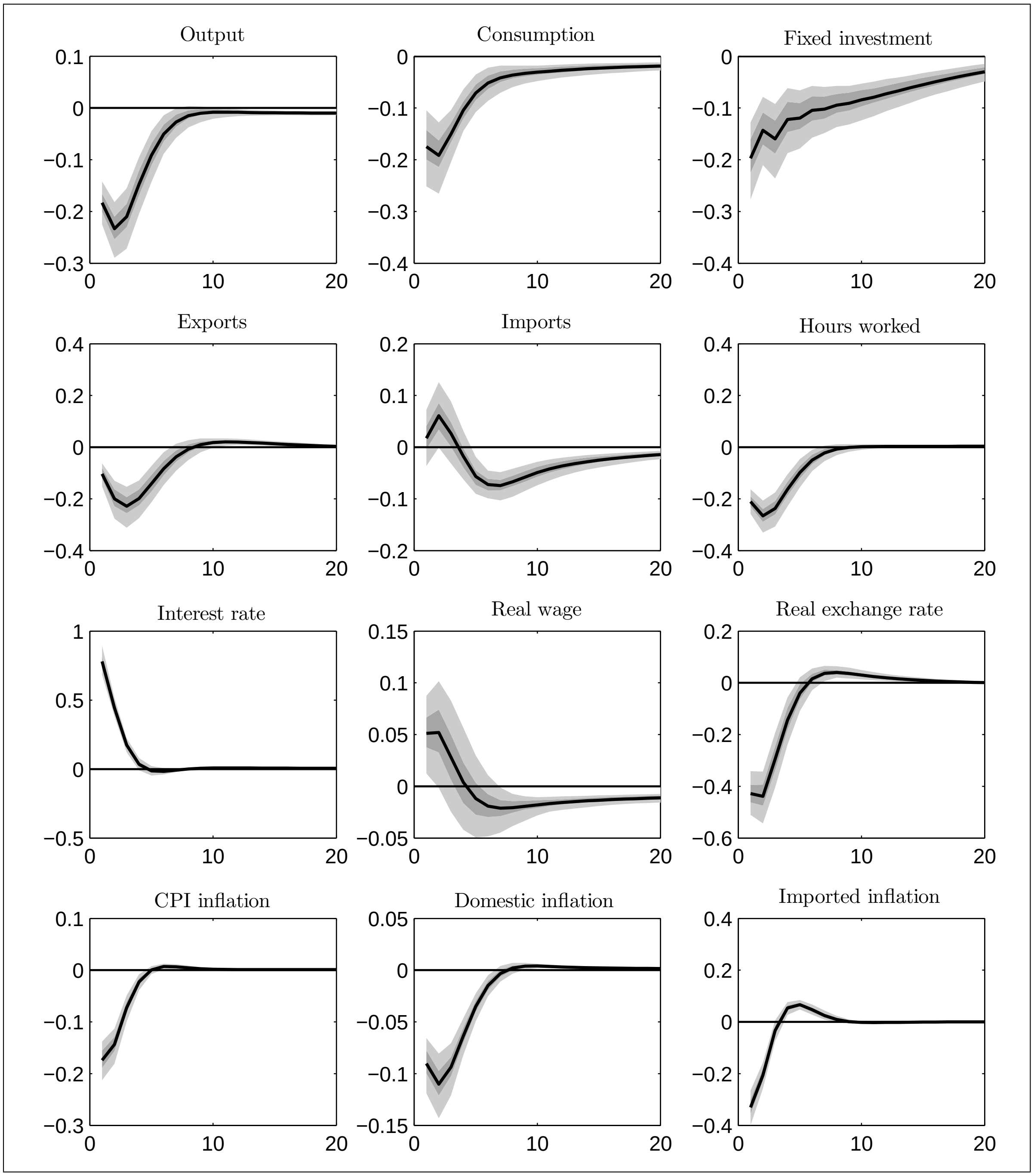
Figure 2 presents the impulse response function (IRF) for several key variables following a monetary policy shock (η^R). We focus on this shock since it will be used in the next section to simulate counterfactual scenarios of the economy. The graph presents the mean of the response and the 70- and 90-percent highest probability intervals calculated from the posterior distribution. All real variables are expressed as percentage deviations from the steady state of the model; the inflation measures are expressed as percentage-point deviations; and the interest rates are expressed as annualized percentage-point deviation.

As can be seen from the graph, an innovation to the interest rate rule (25) of one standard deviation triggers an immediate rise of the interest rate of 0.75 percentage points. As a result of the model's nominal frictions (such as price and wage stickiness), the real interest rate rises as well, leading to a reduction in domestic demand (consumption and investment), which lasts about two years. The rise in the interest rate also results in

Table 2: Prior and Posterior Distributions of the Main Structural Parameters

Parameter		Prior distribution			Posterior distribution				
		type	mean	std	mode	std	mean	5%	95%
Habit formation	κ	beta	0.70	0.15	0.616	0.064	0.706	0.568	0.861
Indexation parameters									
Employment	χ_E	beta	0.40	0.10	0.494	0.102	0.485	0.316	0.648
Dom. prices	χ_H	beta	0.40	0.10	0.365	0.097	0.355	0.201	0.504
Import prices	χ_{IM}	beta	0.40	0.10	0.300	0.089	0.322	0.179	0.462
Wages	χ_W	beta	0.40	0.10	0.377	0.100	0.377	0.217	0.531
Exports	χ_X	beta	0.40	0.10	0.281	0.085	0.294	0.158	0.429
Calvo parameters									
Employment	ξ_E	beta	0.60	0.10	0.614	0.040	0.646	0.552	0.743
Dom. prices	ξ_H	beta	0.60	0.10	0.606	0.053	0.648	0.552	0.746
Import prices	ξ_{IM}	beta	0.60	0.10	0.428	0.048	0.443	0.361	0.526
Wages	ξ_W	beta	0.60	0.10	0.456	0.057	0.543	0.421	0.664
Exports	ξ_X	beta	0.60	0.10	0.588	0.047	0.596	0.510	0.679
Adj. cost inv.	γ_I	gamma	2.00	1.00	2.816	0.709	3.305	1.919	4.680
Adj. cost inv. lag	ω_{Γ_I}	beta	0.50	0.15	0.554	0.082	0.536	0.394	0.681
Adj. cost export	γ^*	gamma	1.20	0.50	0.295	0.125	0.645	0.154	1.176
FX premium - B*	γ_B	gamma	0.01	0.01	0.012	0.003	0.012	0.006	0.017
FX premium - S	γ_S	beta	0.45	0.20	0.325	0.077	0.358	0.229	0.487
Oil import share	ω^*	beta	0.15	0.05	0.118	0.024	0.133	0.086	0.177
Monetary Policy									
Smoothing	ϕ_R	beta	0.70	0.10	0.814	0.035	0.833	0.780	0.887
Resp. to inflation	ϕ_Π	gamma	2.50	0.50	2.538	0.400	2.656	1.942	3.361
Resp. to output	ϕ_y	gamma	0.20	0.10	0.204	0.057	0.205	0.100	0.311
Resp. to depreciation	$\phi_{\Delta S}$	gamma	0.20	0.10	0.090	0.043	0.124	0.037	0.206
Autoregressive coeff.									
Transitory techn.	ρ	beta	0.70	0.15	0.920	0.039	0.859	0.760	0.959
Permanent techn.	ρ_{g_z}	beta	0.70	0.15	0.693	0.161	0.668	0.454	0.900
Symmetric prem.	ρ_{RP}	beta	0.70	0.15	0.767	0.065	0.737	0.575	0.877
External prem.	ρ_{RP^*}	beta	0.70	0.15	0.582	0.105	0.550	0.375	0.727
Consumption	ρ_C	beta	0.70	0.15	0.782	0.241	0.584	0.275	0.938
Inv. techn.	ρ_I	beta	0.70	0.15	0.906	0.035	0.732	0.482	0.944
Inventory inv.	$\rho_{\Delta INV}$	beta	0.70	0.15	0.708	0.109	0.678	0.513	0.852
Government	ρ_G	beta	0.70	0.15	0.679	0.218	0.672	0.416	0.935
Export share	ρ_{ν^*}	beta	0.70	0.15	0.839	0.094	0.664	0.377	0.921
Home bias	ρ_ν	beta	0.70	0.15	0.802	0.091	0.770	0.627	0.915
Domestic markup	ρ_{φ^H}	beta	0.30	0.15	0.196	0.131	0.241	0.039	0.429
Import markup	ρ_{φ^*}	beta	0.30	0.15	0.203	0.135	0.258	0.048	0.461
Wage markup	ρ_{φ^W}	beta	0.30	0.15	0.109	0.079	0.187	0.025	0.343
Export markup	ρ_{φ^X}	beta	0.30	0.15	0.102	0.078	0.142	0.017	0.261
Foreign transfers	ρ_{FTR}	beta	0.70	0.15	0.431	0.183	0.441	0.201	0.681

Figure 2: Impulse Response to an Interest Rate Shock



Note: Shock of one standard deviation. Solid line – mean of impulse response. Gray area – 70 and 90 percent highest interval of impulse response. Real variables – percentage deviation from steady state. Inflation – percentage point deviation from steady state. Interest rate – annualized percentage point deviation from steady state.

an appreciation of the domestic currency. Consequently, monopolistic exporters gradually raise their foreign currency prices, thereby reducing the demand for their products and as a result exports fall to 0.2 percent below steady state. Import demand is affected by two opposite forces: on the one hand, the reduction in domestic demand reduces the demand for imported intermediate goods while, on the other hand, the domestic appreciation generates an expenditure-switching effect. The graph suggests that, for the most part, the expenditure-switching effect dominates in the short run. As for output, both forces—namely, the contraction of domestic demand and the expenditure-switching effect—operate in the same direction to contract domestic activity and therefore output falls by approximately 0.2 percent. Note that output reaches its lowest point only after two quarters and gradually converges back to its trend within two years. Inflation falls on impact and the accumulated effect one year after the shock is about 0.4 percentage points. Interestingly, the drop in inflation results both from the direct effect of the appreciation on imported inflation and from lower marginal costs (wages and capital rental rates). Note that marginal cost falls as a result not only of the economic contraction, but also the appreciation's effect on wage demands. Taking into account the intensity of the effect on each component of inflation and the weight of each component in consumption, domestic and imported inflation make similar contributions to the reduction in CPI inflation.

It is interesting to compare our model's impulse responses to those reported for similar models of other economies, such as Christoffel et al. (2008) and Adolfson et al. (2007) for the euro area, Adolfson et al. (2008) for Sweden and Beneš et al. (2009) for New Zealand. Four general observations can be made: (1) The size of the shock in our model is typically larger by a scale of 1.5 to 3 (reflecting a larger estimated standard deviation of the interest rate shock). (2) While the effect on output in our model is typically smaller, mainly due to the lower sensitivity of investment, the effect on inflation is larger due to a faster exchange rate pass-through (along with higher import intensity). (3) The reaction of output in our model is faster and less hump-shaped, with the strongest effect on output being typically three to four quarters following the shock in the other economies, as compared to only two quarters in our model. (4) Finally, the effect of the shock has a shorter duration in our model (two years as compared to five years in other economies).

4 A framework for monetary policy evaluation

4.1 Overview

The proposed framework is intended to evaluate the efficiency of monetary policy decisions during a specific year. A monetary policy decision will be considered efficient if the RMSs of the inflation and output gaps could not have both been reduced at the same time. In addition, the framework can be used to determine whether the deviation from the policy rule—i.e., the monetary policy shocks—resulted in outcomes closer to or farther away from the efficient frontier (combinations of inflation and output gaps RMSs that cannot both be reduced) and whether they were aimed at reducing the RMS of the inflation gap or of the output gap.

The idea of the framework is to generate a large number of counterfactual simulations of the economy, based on the estimated DSGE model presented above. Each simulation uses an alternative interest rate path, which results in counterfactual macroeconomic outcomes for the relevant year, and alternative forecasted developments in the subsequent year. The various interest rate paths are generated by random draws of the monetary policy shocks. For each counterfactual simulation, we calculate the RMS of the inflation gap and of the output gap during the evaluated year and of the expected gaps in the following year, which is intended to internalize the effect of the monetary policy decisions on economic developments expected in subsequent periods. We then compare those RMSs to the baseline outcomes generated from the actual interest rate path for the evaluated year. The frontier, which is the set of efficient policy paths, consists of all the simulations that generate RMSs for the inflation and output gaps that are not subject to a further Pareto improvement.

It is worth mentioning a few fundamental assumptions underlying the proposed framework. First, as already discussed, the approach is of an ex-post nature. Efficient policy paths may reflect policy actions taken prior to unexpected shocks that are only observed in retrospect. In other words, we are not asking whether policy was efficient in an ex-ante sense, given the information available at the time the action was taken. Second, we assume that for short horizons of say one year monetary policy does not involve choosing an optimal interest rate rule but rather, choosing the ad hoc deviations from a systematic rule, or in other words, deciding on the size of interest rate shocks. This assumption rests on the principle that monetary policy rules cannot, and should not, be changed frequently. Among other reasons for this, central banks do not publish their systematic policy rules and certainly not on a quarterly basis. If anything, central banks only publish expected policy *paths* and therefore it would be meaningless to consider the counterfactual outcomes of alternative monetary policy *rules*.

An additional underlying assumption of the proposed framework is that welfare depends mainly on the accumulated absolute values of the inflation and output gaps, as defined in section 2.3.2. However, there is also a welfare loss associated with interest rate variability. Put differently, we only consider policy paths for which interest rate volatility does not significantly exceed the actual level that year or the average volatility over the sample period. While the previously mentioned assumptions are fundamental to the proposed framework, this additional assumption is not crucial and it is left to the researcher to decide whether to adopt it for a specific country or year.

4.2 A formal description of the methodology

The first step involves specifying a model, as described in sections 2 and 3. It is of course possible to employ other models on the conditions that it is solved to extract historical shocks which replicate actual outcomes during the sample and that monetary policy is characterized explicitly using a rule that includes an exogenous shock (as in equation 25).

This is followed by the following five steps:

Step I: Choose the year of evaluation and calculate the welfare loss

The period of evaluation isn't necessarily restricted to be a year. Nonetheless, we choose to work with calendar years for several reasons: (1) it is a natural reference period; (2) it is short enough so that monetary policy can be thought of as choosing deviations from some rule and not as choosing different rules; and (3) it is long enough for policy to have an effect on target variables, as is evident from the impulse response presented in figure 2.[17]

For the chosen year, calculate the variables assumed to be targeted by monetary policy. In our example, we assume that the central bank calculates welfare loss based on the RMS of the deviations of inflation from its target (inflation gap: $\pi^{GAP} = \pi - \bar{\pi}$) and deviations of output from a trend consistent with technological capacity (i.e. the output gap $\hat{y}^{GAP}$). Formally, calculate:

$$RMS(\pi^{GAP}) = \sqrt{\frac{1}{8}\left[\begin{array}{c}(\pi_{Q1} - \bar{\pi})^2 + \cdots + (\pi_{Q4} - \bar{\pi})^2 \\ + (E\pi_{Q4+1} - \bar{\pi})^2 + \cdots + (E\pi_{Q4+4} - \bar{\pi})^2\end{array}\right]} \tag{39}$$

and

$$RMS(\hat{y}^{GAP}) = \sqrt{\frac{1}{8}\left[\left(\hat{y}^{GAP}_{Q1}\right)^2 + \cdots + \left(\hat{y}^{GAP}_{Q4}\right)^2 + \left(E\hat{y}^{GAP}_{Q4+1}\right)^2 + \cdots + \left(E\hat{y}^{GAP}_{Q4+4}\right)^2\right]}. \tag{40}$$

In equations (39) and (40), E is the ex-ante forecast of a variable given information known in the last quarter of the evaluated year ($Q4$). The reason ex-ante forecasts are used for subsequent years, rather than ex-post realizations, is that we are trying to replicate the evaluations as if they were conducted at the end of the evaluated year and not in retrospect.

Step II: Extract the realized shocks

The Kalman filter is used to extract the historical shocks of the evaluated year: η_{Q1}, η_{Q2}, η_{Q3} and η_{Q4}, where the η's are vectors of all the model's i.i.d. shocks, including the

[17] Israel has a relatively rapid transmission mechanism. Therefore, in applying this framework to other economies one might choose to evaluate periods of 2-3 years.

monetary policy shock, η^R. The smoothed shocks should be such that simulating the model starting from the smoothed state in the last quarter of the previous year, while inflicting the economy with the extracted shocks, should replicate the observed variables of the evaluated year.

Step III: Run counterfactual simulation with zero MP shocks

Starting from the smoothed state in the last quarter of the previous year, a counterfactual simulation is run using the vector of extracted shocks from step II, except for the monetary policy shocks which are set to zero in every quarter of the evaluated year. All shocks for the periods subsequent to the evaluated year are set to zero as well. The result suggests what would have been the case had monetary policy makers not deviated from the estimated interest rate rule.

Following this simulation, the RMS of the objective variables is calculated, as in equations (39) and (40). Comparing the resulting counterfactual RMSs to the actual ones from step I shows the contribution of the policy's non-systematic component.

Step IV: Run counterfactual simulations with random monetary policy shocks

Five thousand four-period vectors of monetary policy shocks are drawn from the estimated distribution, $N\left(0, \sigma^{\eta^R}\right)$. For each draw, a counterfactual simulation is run with the vector of drawn monetary policy shocks and the remaining extracted shocks from step II. For each simulation, the RMS is calculated for the objective variables, as in equations (39) and (40).

Since we would also like to limit interest rate variability in the counterfactual simulations and avoid the possibility of entering negative territory for nominal interest rates, we only use simulations in which the interest rate path during the evaluated year, r_{sim}, satisfies the following requirements (to be explained below):

1. Limitation on the standard deviation of the simulated interest rate (σ^r_{sim}):

$$\sigma^r_{sim} < \begin{cases} \sigma^r_{smpl} & \text{if} \quad \sigma^r_{year} < \frac{1}{2} * \sigma^r_{smpl} \\ 2 * \sigma^r_{year} & \text{if} \quad \frac{1}{2} * \sigma^r_{smpl} < \sigma^r_{year} < \sigma^r_{smpl} \\ 2 * \sigma^r_{smpl} & \text{if} \quad \sigma^r_{smpl} < \sigma^r_{year} < 2 * \sigma^r_{smpl} \\ \sigma^r_{year} & \text{if} \quad 2 * \sigma^r_{smpl} < \sigma^r_{year} \end{cases} \tag{41}$$

where: σ^r_{sim} - S.D. of the simulated interest rate path.

σ^r_{year} - Actual S.D. of the interest rate path in the evaluated year.

σ^r_{smpl} - Average 4-period moving standard deviation of the interest rate during the entire evaluation sample (i.e. 2001-2010).

2. Limitation on the standard deviation of the interest rate changes ($\sigma^{\Delta r}_{sim}$):

$$\sigma^{\Delta r}_{sim} < \begin{cases} \sigma^{\Delta r}_{smpl} & \text{if} \quad \sigma^{\Delta r}_{year} < \frac{1}{2} * \sigma^{\Delta r}_{smpl} \\ 2 * \sigma^{\Delta r}_{year} & \text{if} \quad \frac{1}{2} * \sigma^{\Delta r}_{smpl} < \sigma^{\Delta r}_{year} < \sigma^{\Delta r}_{smpl} \\ 2 * \sigma^{\Delta r}_{smpl} & \text{if} \quad \sigma^{\Delta r}_{smpl} < \sigma^{\Delta r}_{year} < 2 * \sigma^{\Delta r}_{smpl} \\ \sigma^{\Delta r}_{year} & \text{if} \quad 2 * \sigma^{\Delta r}_{smpl} < \sigma^{\Delta r}_{year} \end{cases} \tag{42}$$

where: $\sigma^{\Delta r}_{sim}$ - S.D. of the simulated changes in the interest rate path.

$\sigma^{\Delta r}_{year}$ - Actual S.D. of the interest rate changes in the evaluated year.

$\sigma^{\Delta r}_{smpl}$ - Average 4-period moving standard deviation of the interest rate changes during the entire evaluation sample (2001-2010).

3. Limitation on the number of policy direction changes (ΔPD):[18]

$$\Delta PD_{sim} \leq \Delta PD_{year} + 1 \tag{43}$$

where:

ΔPD_{sim} - Number of policy direction changes in the simulated path.

ΔPD_{year} - Number of actual policy direction changes during the evaluated year.

To this end, any quarterly interest rate change smaller than 0.25 percentage points (on an annual basis) is treated as continuing the previous quarter's policy direction.

[18] From raising the interest rate to lowering it (or vise versa).

4. Limitation of an "effective" zero lower bound:

$$r_{sim} > 1/2 \quad \text{for all quarters of the simulation} \tag{44}$$

The first two limitations are intended to limit the amount of simulated interest rate volatility (both in its level and its changes). The general approach is to allow the simulated path to have up to *twice* the actual volatility in the evaluated year. In other words, we would like to consider paths with higher volatility than was actually observed, but not a great deal higher. This is expressed in the second line of equations (41) and (42): $\sigma^r_{sim} < 2 * \sigma^r_{year}$. However, we would also like to address two extreme cases. If the actual volatility in the evaluated year was relatively small (i.e. $\sigma^r_{year} < \frac{1}{2} * \sigma^r_{smpl}$), we would like to consider paths with volatility up to the sample average or in other words to ignore welfare losses from interest volatility up to the sample average. This is reflected in the first line of the equations. The second case addresses years during which the interest rate was relatively volatile ($\sigma^r_{smpl} < \sigma^r_{year}$), for which our approach would have allowed volatilities greater than twice the sample average. For this case, we limit the volatility to the greater between twice the average sample volatility and the evaluated year's volatility which is reflected in the third and fourth lines of equations (41) and (42).

The third limitation emerges from the implied tendency of policy makers to avoid frequent changes in the direction of policy. However, we do allow for one additional policy change relative to the actual number of policy changes that year. (A policy change in this context is a change in the *direction* of the interest rate.)

The fourth limitation addresses the zero lower bound of the nominal interest rate. During the course of the 2008-9 financial crisis, the Bank of Israel reduced rates down to 0.5%, while declaring that although the interest rate could be further reduced, any further reduction would have little effect. Our linear model does not have an inherent zero lower bound and therefore, 0.5% is treated as the "effective" lower zero bound Thus, simulations that are not consistent with this lower bound are discarded.

We should mention that a researcher has discretion in determining these limitations and can adjust the proposed framework to fit the circumstance of the country or the year being evaluated. We chose a set of restrictions that appear to be reasonable for all the years being evaluated.

Step V: Generate a diagrammatic representation of the results

We present the evaluation results using two types of diagrams: (a) a scatter diagram that presents the RMS of the objective variables, along with the feasible frontier; and (b) the interest rate paths of the simulations included in the frontier.

The first type of diagram (see, for example, panel A in figure 4) presents the RMS of the inflation gap (horizontal axis) and the output gap (vertical axis). The large dark red point is the actual RMS of the year (step I); the large light green point is the RMS from the zero-shock counterfactual simulation (step III); and the small points are the RMS from the random simulation (step IV). The diagram also presents the feasible frontier of the gap's RMS which connects all the points for which we cannot improve the RMS of both the output gap and the inflation gap. Note that the frontier is investigated using additional simulations, not necessarily drawn from the estimated distribution (which is not to say that they may violate one of the limitations mentioned above). This diagram leads to the following observations:

- The diagram indicates whether actual policy shocks led to outcomes that are closer to or farther away from the frontier, in comparison to the trivial situation of zero policy shocks, and whether they reduced the RMS of the inflation gap or the output gap.

- If the actual results are close to the frontier, the diagram can indicate whether they are on the side of a low inflation gap RMS or a low output gap RMS.

- The diagram can be used to determine whether the estimated shocks delivered results inside or outside the cluster cloud resulting from random draws. In some sense, this indicates whether the actual policy actions were "significantly" better than what would have been achieved by a random policy maker (who draws monetary policy shocks from an estimated normal distribution).

The second type of diagram (see, for example, panel B in figure 4) depicts the interest rate paths that generate the results along the frontier (the dashed lines). For comparison, we added the actual path (the solid red line) and the zero-policy-shock path (the solid green line with circle marker). This diagram indicates whether the actual path chosen in the evaluated year was above, below or within the mass of efficient paths.

Panel C of each diagram summarizes the limitations imposed on interest rate volatility. Panels D and E depict the variables included in the baseline scenario RMS computation i.e. actual outcomes of the inflation and output gaps, along with their ex-ante one-year-ahead forecasted path.

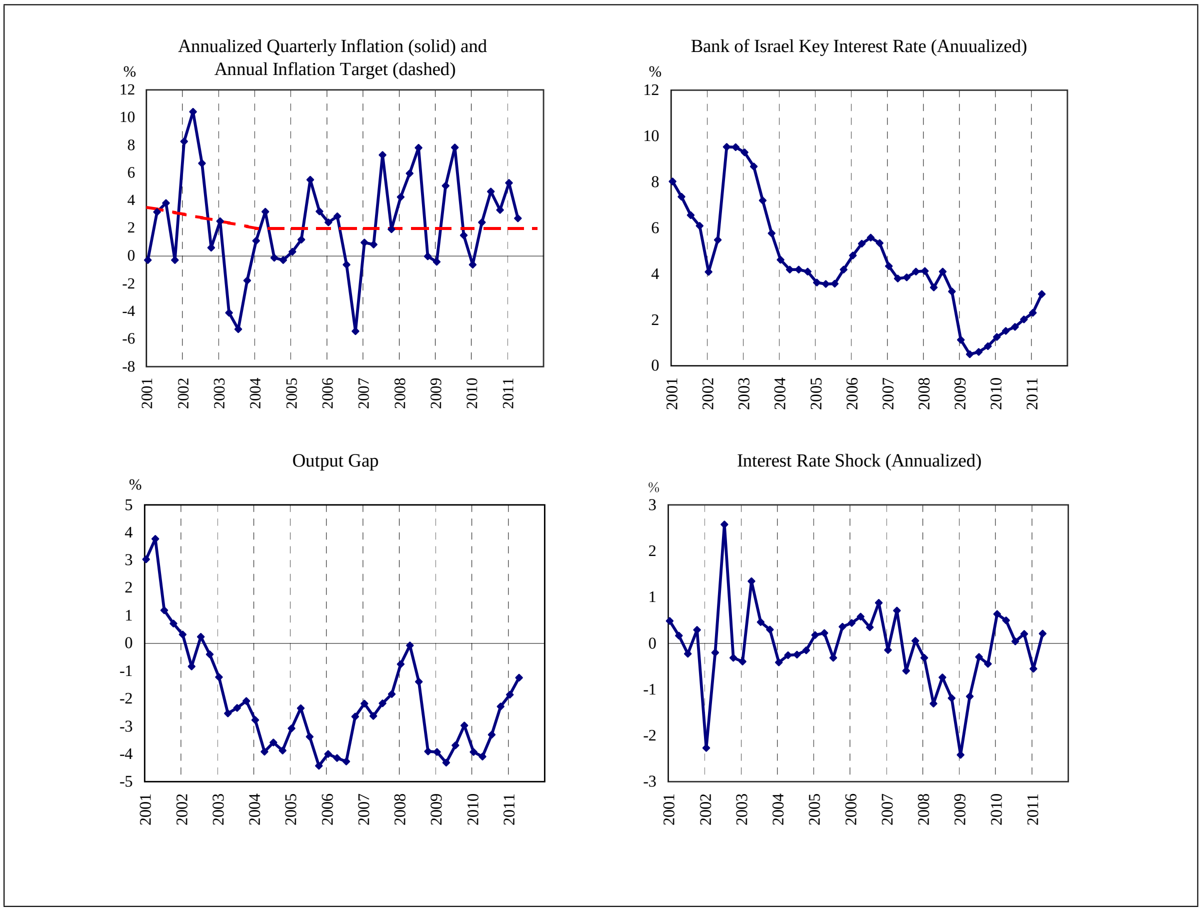
5 Ex-post evaluation of monetary policy

5.1 Historical perspective

Before implementing the framework for specific years using Israeli data, it is worthwhile to briefly survey the developments in the variables of interest during the sample period (2001-2010). Figure 3 depicts the quarterly inflation rate, the output gap, the nominal interest rate and the smoothed monetary policy shock, as derived from equation (25). Following are the observations:

Inflation fluctuated around the mid-point of the target-band, though with significant variance. Thus, inflation was above target in the years 2002, 2005, 2007, 2008 and 2009 and below target in the years 2003, 2004 and 2006. The output gap was negative for most of the evaluated years (2003-2010). The recessionary downward trend of the gap during 2001-2003 was due to a combination of three events: the second intifada which started in late 2000, the dot com crash in 2000-1 and macroeconomic policy's low level of credibility. The gap narrowed until mid-2008 when the global financial crisis began and started to improve again in mid-2010.

Figure 3: The Main Variables of Interest, 2001-2009



The interest rate path is characterized by a downward trend, in part due to the disinflation process (see top left hand panel in figure 3) and in part due to the reduction in long term real yields. However, for short horizons (up to one year) variance decompositions show that the monetary policy shock explains between 17% and 56% of the variation in the nominal interest rate (see Argov et al. (2012)). Inspecting the smoothed monetary policy shock (bottom right hand panel in figure 3) shows three outliers. (1) In early 2002, the interest rate was unexpectedly reduced by two percentage points (as part of an agreement with the government on expenditure cuts that wasn't adhered to); while in the second part of the year, on the background of rising inflation, there was a sharp increase in the interest rate, once again, through large policy shocks. (2) The years 2005-6 were characterized by small, but persistent positive policy shocks. This occurred in the aftermath of a large depreciation in 2005 which generated concern regarding a negative interest rate gap relative to the Fed rate. The result was low inflation and output that year. (3) The years 2008-9 were characterized by strong and persistent negative policy shocks in the wake of the financial crisis.

The framework was implemented for each of the years 2001-2010. Subsections (5.2)-(5.5) elaborate on a few characteristic years (presented in figures 4 to 7). Graphs for the remaining years can be found in appendix B.

5.2 Evaluation of 2003 - Inefficient policy shocks generated sub-optimal outcomes

The year 2003 followed a period of stagflation that ended with a sharp rise in the interest rate to 9 percent in mid-2002. As a result, inflation declined in 2003 and was even well below target during the second part of the year (see panel D of figure 4). In addition, slow growth led to the widening of the already negative output gap (see panel E of figure 4), which also contributed to low inflation. After realizing that inflation was too low in the second quarter of the year, the interest rate was reduced to approximately 6 percent by the end of the year. According to our model, these reductions were smaller than those dictated by the interest rate rule and therefore monetary policy shocks were in fact positive (see figure 3).

Figure 4 presents the policy evaluation for 2003. Panel A shows 2003 to be a year in which policy outcomes (represented by the dark red point) were distant from the frontier. Since the frontier is distant from the cluster cloud, any "normal" set of shocks would have led to outcomes that are also far from the frontier; however those actually chosen led to outcomes strongly dominated by the zero-shocks scenario (light green point), i.e. according to this framework the shocks chosen by policy makers were in the wrong direction. It is also evident from the diagram that the frontier is extremely small and that the cluster cloud is narrow and rising from left to right. thus, there seems to be no trade-off (or indifference) between policy paths. This is a result of the low level of inflation throughout most of the year and the negative output gap. In such circumstance, lower interest rate paths would necessarily reduce the RMS of both the inflation gap and the output gap at the same time, thus improving efficiency. Moreover, panel B of figure 4 indicates that the frontier interest rate paths are the lowest allowed by the imposed interest rate volatility limitations. It is also interesting to note that the ex-post frontier-consistent paths reach 5.5% by the end of the year, which is not much lower than the actual interest rate. The difference is a result of the interest rate not being reduced earlier.

The degree to which the conclusion of sub-optimality implies inefficient policy making mainly depends on whether the low inflation from the second quarter onwards could have been foreseen and whether the degree of interest rate smoothing was exaggerated. On the one hand, inflation was brought down by large nominal exchange rate appreciations, which are in general hard to predict; on the other hand, inflation expectations derived from the market were already below target in the second quarter of the year, indicating that the central bank might have started to react somewhat too late, even by ex-ante terms. As for the degree of smoothing, the somewhat traumatic experience of the sharp interest rate cut in 2002 was certainly on the minds of policy makers, though we have seen that the framework only indicates that the cuts should have been earlier, but not larger. Recall that this analysis is not intended to be a criticism of policy making in 2003. We are merely demonstrating that the framework may generate a picture of suboptimal policy that can trigger important real-time discussions on key policy making issues, such as the limitations on interest rate volatility and forecasting changes in the inflation rate.

5.3 Evaluation of 2004 - Efficient policy shocks generated absolute improvement

After the relatively dramatic macroeconomic events in 2002-3, the year 2004 brought some stability. Thus inflation was positive although somewhat lower than the target while the output gap was negative, though it stopped widening in the second quarter. By the second quarter of the year the interest rate had reached 4%, which was low relative to the model's long-run level. This was partly the result of negative policy shocks (see figure 3).

Figure 5 presents the policy evaluation for 2004. Panel B indicates that as in 2003, frontier policy paths were lower than the actual one (particularly in the second half of the year) indicating that the reduction of the interest rate should have continued throughout the year to approximately 3.0% by the last quarter. In contrast to 2003, panel A shows that policy shocks in 2004 brought about improvement in the RMS of both the output and inflation gaps relative to the zero-shock scenario. Hence, this is an example of a year in which active policy decisions were in the correct direction; however, from an ex-post point of view they should have been more aggressive.

5.4 Evaluation of 2009 - Aggressive policy shocks pushes to the frontier

The year 2009 reflects in particular the effect of the financial crisis on Israel. At the beginning of the year, output fell so that the output gap reached a negative peak. Monetary policy reacted quickly and aggressively by reducing the interest rate to the effective zero lower bound (0.5), partly through exceptionally large negative policy shocks. By the second half of the year, it was acknowledged Israel had weathered the global crisis relatively well. Thus, financial markets remained unstressed, output began to recover at an impressive pace and inflation was not radically brought down throughout most of the crisis (on the contrary, it remained well above the target). As a result, the Bank of Israel was the first central bank to begin raising the interest rate from the zero bound. Interest rate hikes were very gradual and less than would be dictated by the policy rule, i.e. monetary policy shocks were slightly negative (see figure 3).

Figure 6 presents the policy evaluation for 2009. It is evident from panel A that the actual policy shocks (the dark red point) aggressively pushed RMS outcomes closer to the frontier, relative to the zero-policy shocks scenario (the light green point), which is well outside the normally-distributed randomly drawn shocks that generated the cluster of small points.[19] Moreover, the adopted policy placed RMS outcomes to the far right of the frontier, indicating a clear preference for output stabilization over inflation stabilization.

In terms of the interest rate path, panel B shows that the actual path in the first and last quarters of 2009 is in the middle of the distribution, while in the second and third quarters it is at the lower bound (which is the zero lower bound). Interestingly, this implies that the typical efficient paths are composed of a sharp interest rate reduction at the beginning of the year (in the wake of low inflation and output), a large increase in the second and third quarters (due to the upturn in inflation) and a reduction at the end of the year (due to the moderation in inflation, along side a still negative output gap). In other words, while the data shows one change in policy direction, our framework's results are heavily dependent on the possibility of allowing for one additional change in searching for efficient paths.

5.5 Evaluation of 2010 - An inflation-oriented policy

The year 2010 was characterized by relatively high inflation as a result of increased housing prices and a negative though shrinking output gap in the aftermath of the global financial crisis. Monetary policy was characterized by interest rate hikes, which, though gradual, were generated by positive monetary policy shocks, mainly during the first half of the year (see figure 3).

Figure 7 presents the policy evaluation for 2010. It is evident from panel A that without the policy shocks (the light green point), outcomes would have been on the efficient frontier.

[19] To be precise, actual RMS outcomes do not fully dominate the zero-shock simulation since the inflation-gap RMS is higher.

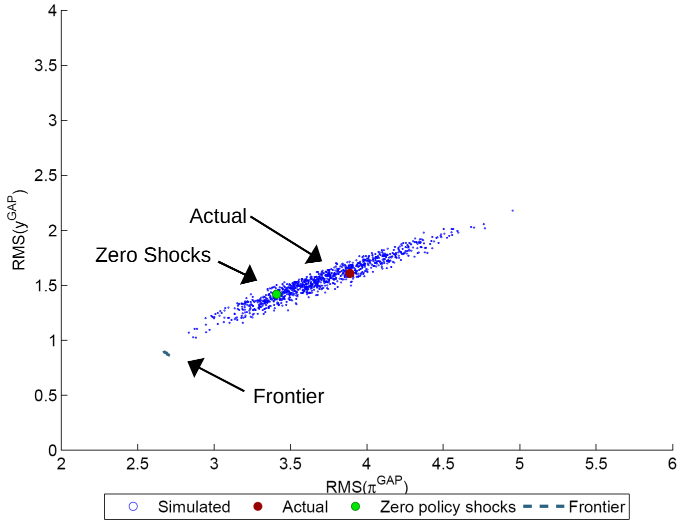
The positive policy shocks at the beginning of the year shifted outcomes somewhat away from the frontier, though not in a suboptimal manner since they reduced the RMS of the inflation gap (at the expense of a wider output gap). In fact, since the reduction in the inflation gap was approximately equal to the widening of the output gap (in terms of RMS), a policy maker with equal weights on output and inflation would have been indifferent between the outcomes.

In terms of the interest rate path, panel B of figure 7 shows that the actual path in the first quarter of 2010 is well above the entire distribution of the frontier paths (for this quarter), while in the rest of the quarters the path lies within the distribution. The framework interprets the first quarter's interest rate hike as being inefficient due to the combination of positive policy shocks with low inflation and a negative output gap (i.e. policy shocks increased the gaps rather than reducing them).

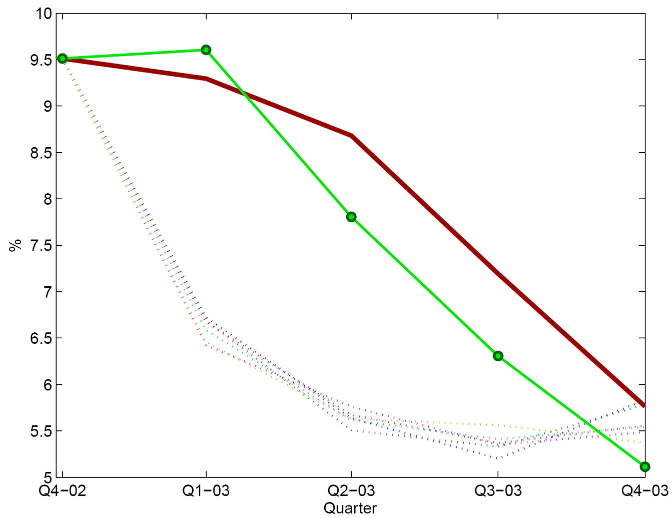
It is worthwhile to again mention the ex-post nature of this exercise. For instance, the Bank of Israel's Inflation Report for the first quarter of 2010 reveals that the low inflation rate in the first quarter was partly a result of indirect tax reductions (that policy makers might not want to react to) and temporary decreases in housing and energy prices that were unexpected at the time the policy decisions were made. Nevertheless, to the extent that the unexpected decreases were an important factor in policy decision making, the contribution of this ex-post evaluation may be in calling for a reexamination of the tools used to generate short-term forecasts of housing and energy prices and whether they are given sufficient attention (in triggering judgemental interventions in the forecasts).

Figure 4: Ex-post Monetary Policy Evaluation for 2003

A. Actual and Counterfactual Root Mean Square (RMS) of Output and Inflation Gaps



B. Interest Rate Path: Actual (dark red), Zero Shocks (light green with marker) and Frontier Paths (dashed)



C. Indicators of Interest Rate Volatility

	Sample	Evaluated Year	Limit
σ^r	0.73%	1.2%	1.50%
$\sigma^{\Delta r}$	0.67%	0.54%	1.10%
ΔPD		0	1

Figure 4: Ex-post Monetary Policy Evaluation for 2003 (cont.)

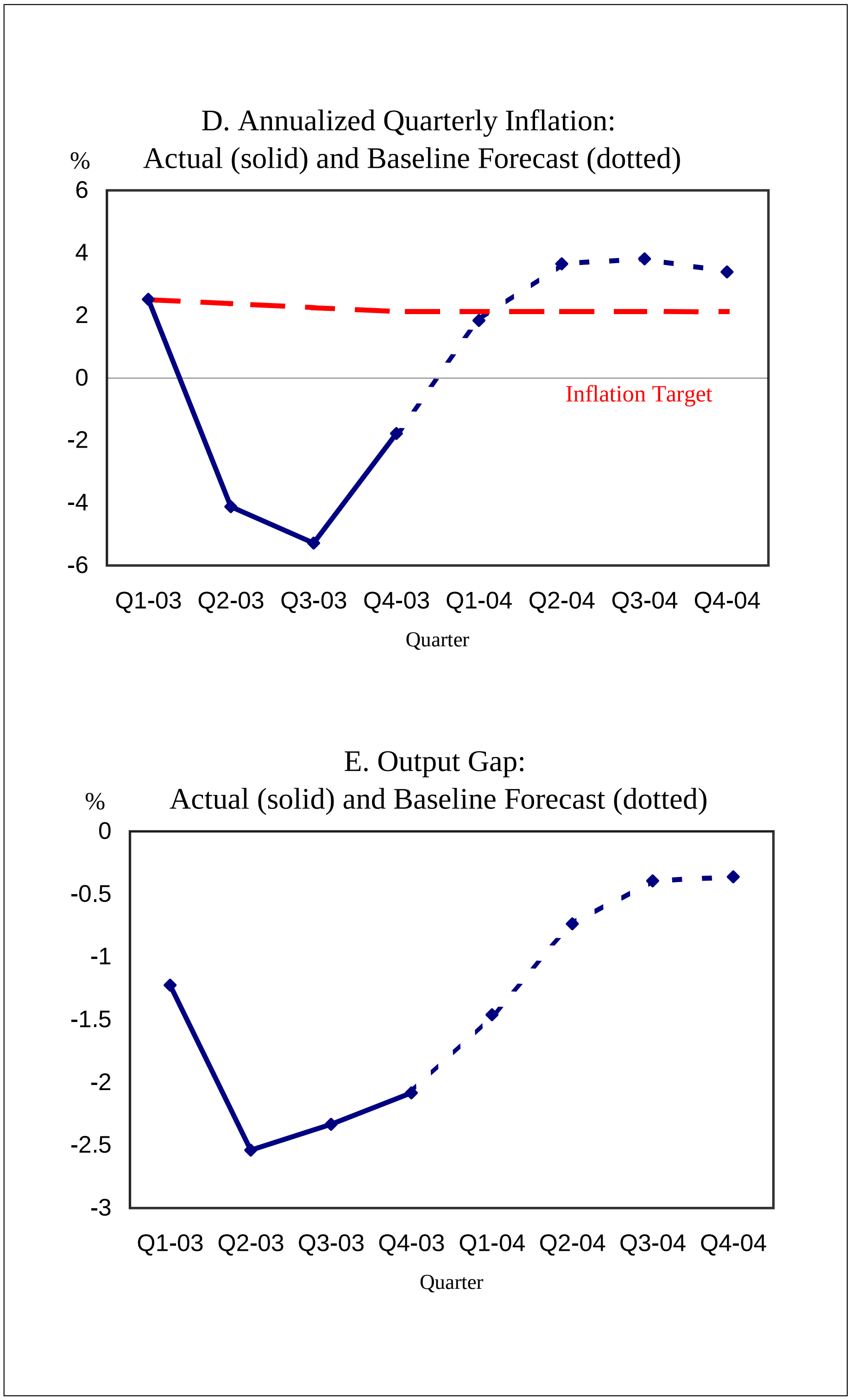
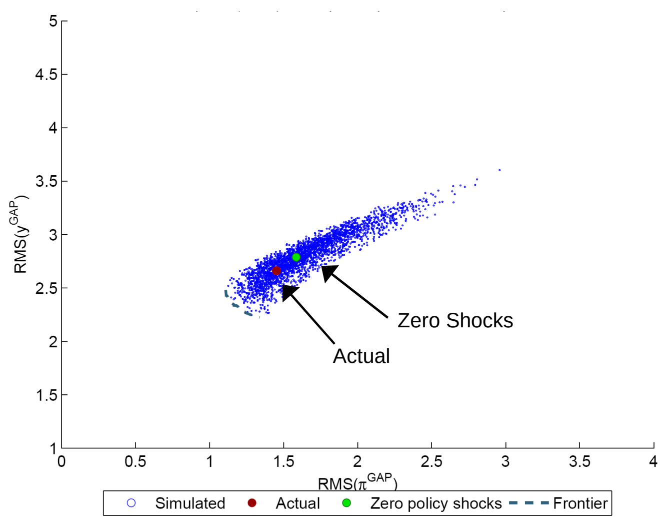
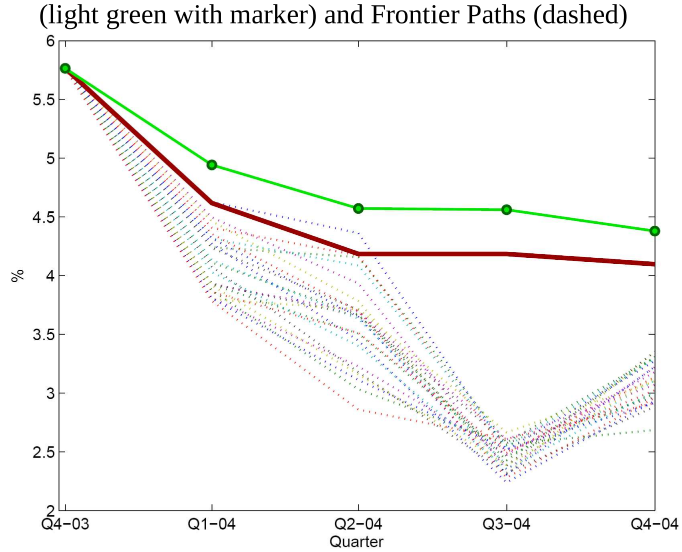


Figure 5: Ex-post Monetary Policy Evaluation for 2004

A. Actual and Counterfactual Root Mean Square (RMS) of Output and Inflation Gaps



B. Interest Rate Path: Actual (dark red), Zero Shocks (light green with marker) and Frontier Paths (dashed)



C. Indicators of Interest Rate Volatility

	Sample	Evaluated Year	Limit
σ^r	0.73%	0.58%	1.20%
$\sigma^{\Delta r}$	0.67%	0.40%	0.80%
ΔPD		0	1

Figure 5: Ex-post Monetary Policy Evaluation for 2004 (cont.)

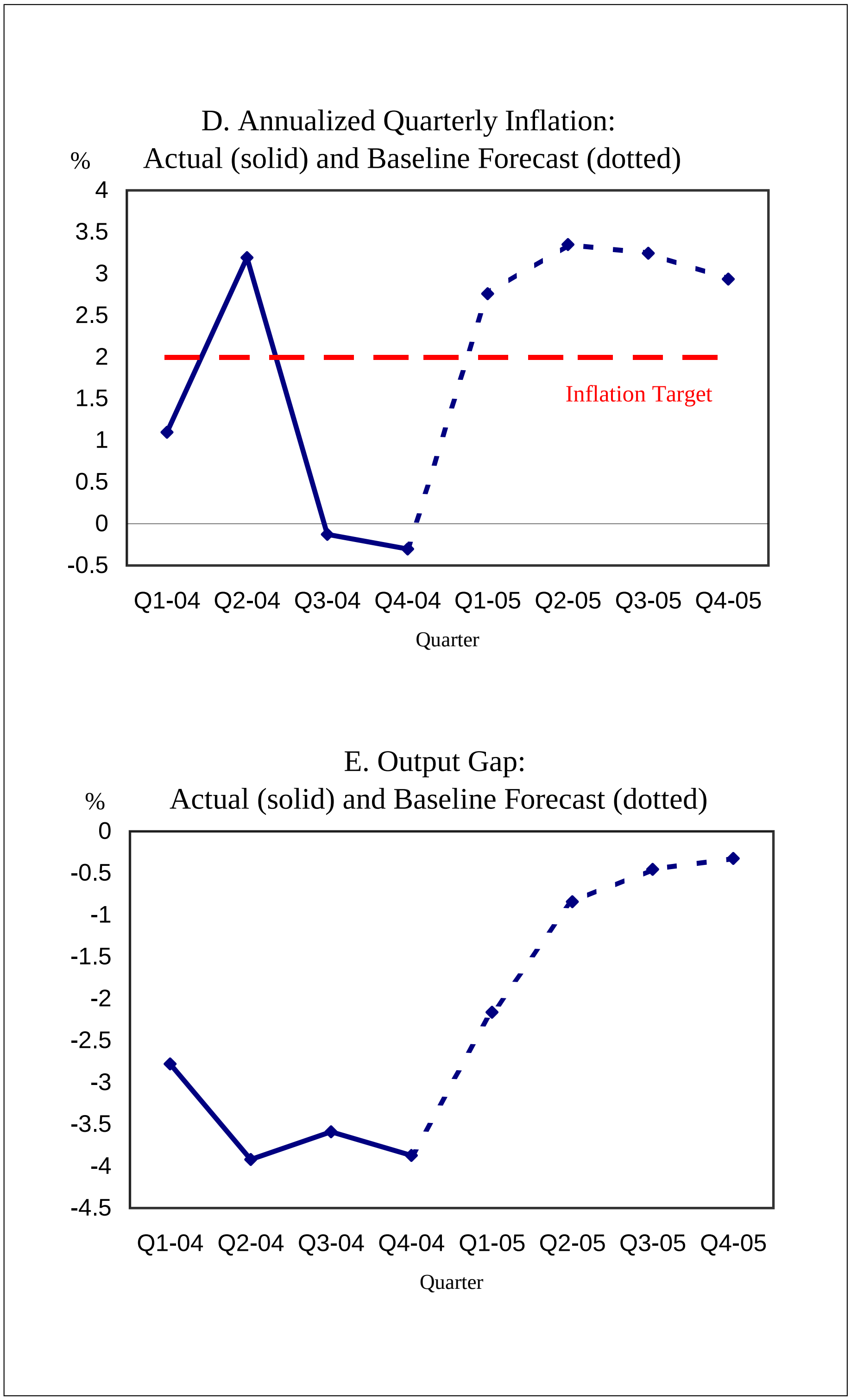
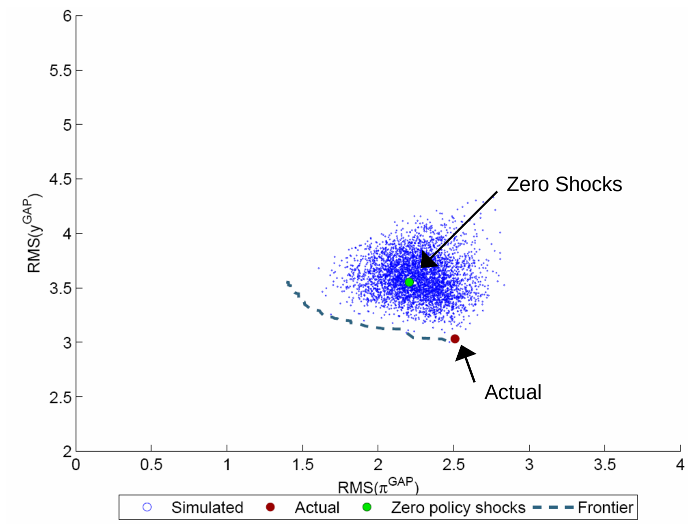
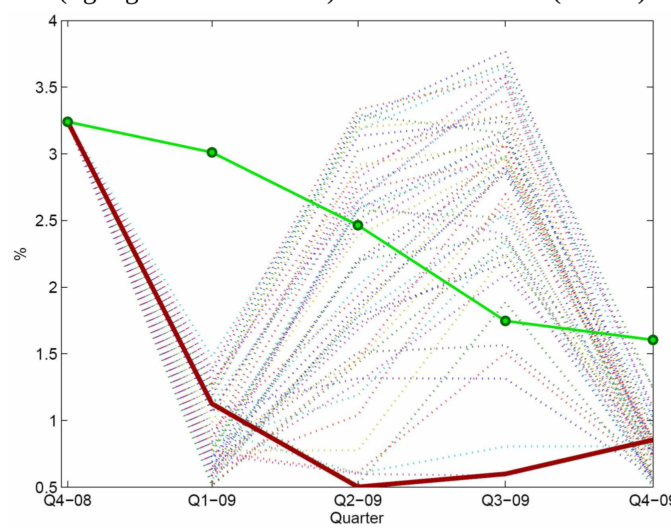


Figure 6: Ex-post Monetary Policy Evaluation for 2009

A. Actual and Counterfactual Root Mean Square (RMS) of Output and Inflation Gaps



B. Interest Rate Path: Actual (dark red), Zero Shocks (light green with marker) and Frontier Paths (dashed)



C. Indicators of Interest Rate Volatility

	Sample	Evaluated Year	Limit
σ^r	0.73%	1.00%	1.50%
$\sigma^{\Delta r}$	0.67%	0.94%	1.30%
ΔPD		1	2

Figure 6: Ex-post Monetary Policy Evaluation for 2009 (cont.)

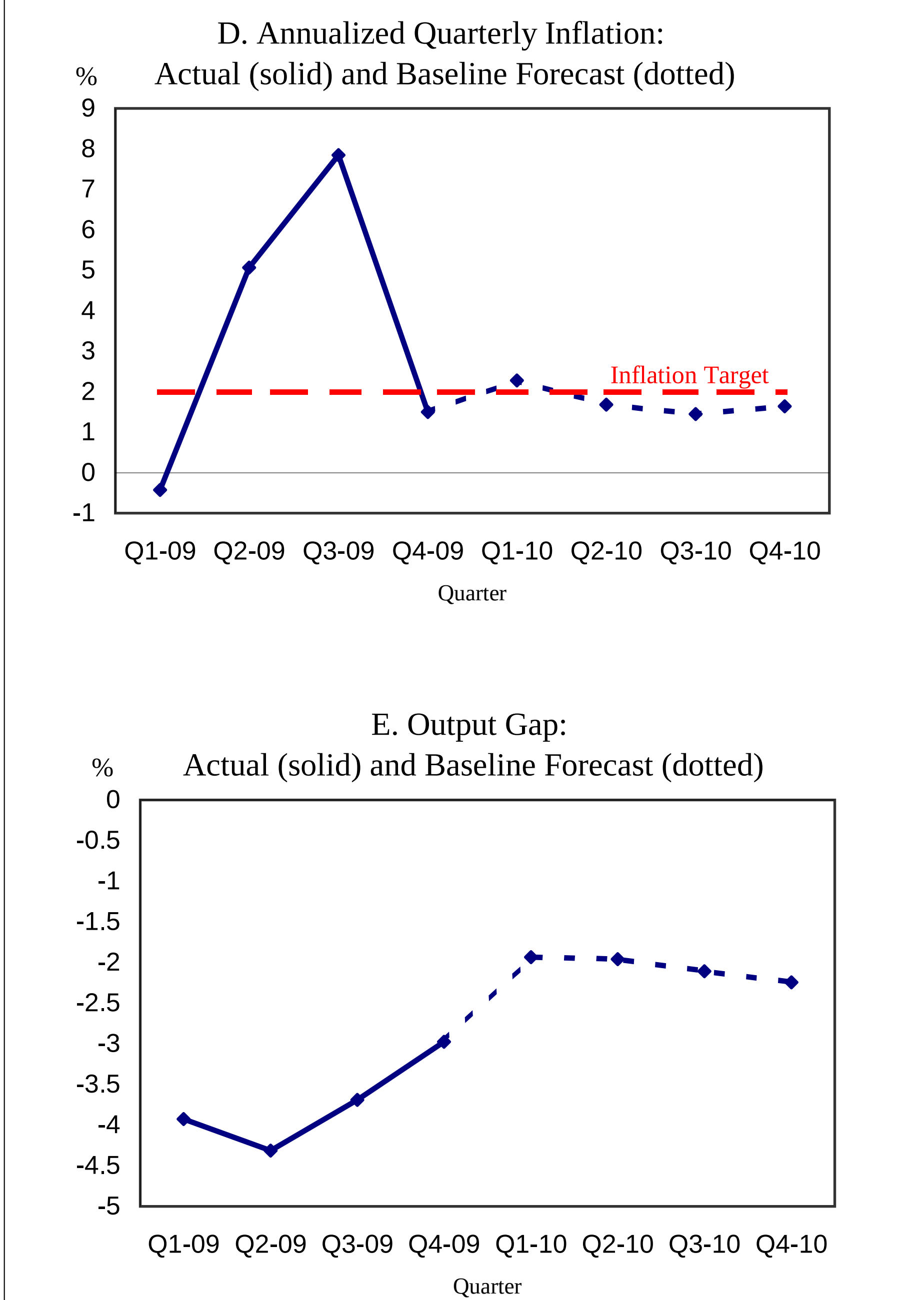
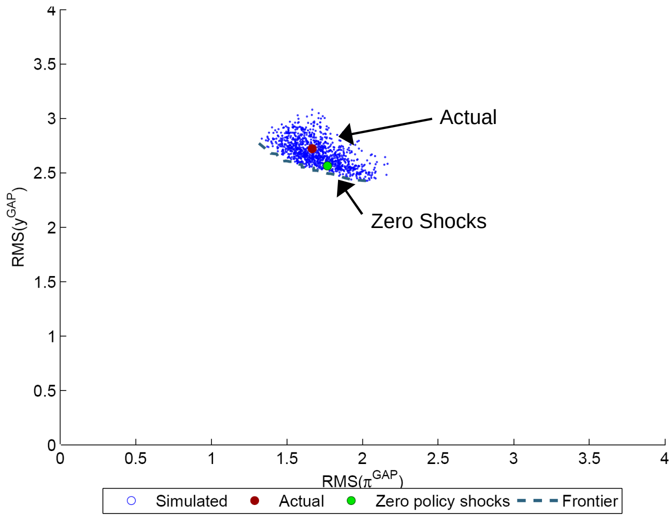
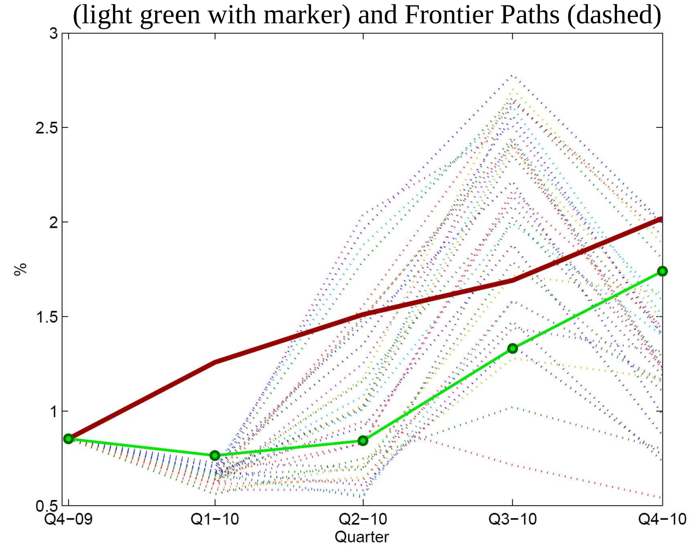


Figure 7: Ex-post Monetary Policy Evaluation for 2010

A. Actual and Counterfactual Root Mean Square (RMS) of Output and Inflation Gaps



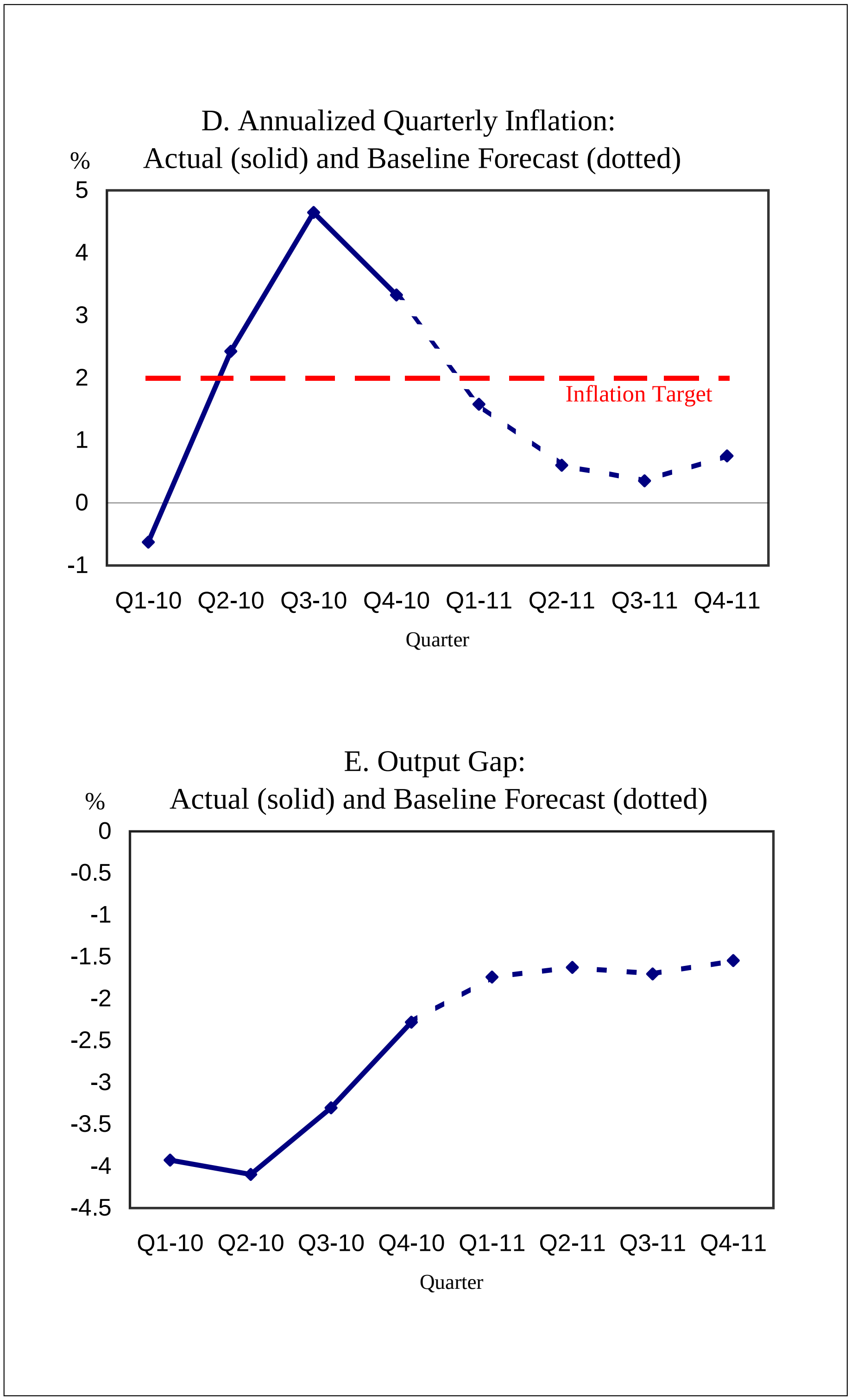
B. Interest Rate Path: Actual (dark red), Zero Shocks (light green with marker) and Frontier Paths (dashed)



C. Indicators of Interest Rate Volatility

	Sample	Evaluated Year	Limit
σ^r	0.73%	0.39%	0.79%
$\sigma^{\Delta r}$	0.67%	0.08%	0.67%
ΔPD		0	1

Figure 7: Ex-post Monetary Policy Evaluation for 2010 (cont.)



6 Concluding Remarks

A framework has been presented for conducting ex-post evaluations of monetary policy decisions. The framework compares actual Root Mean Squares (RMSs) of two objective variables (such as the inflation and output gaps) during a given period to counterfactual RMSs for alternative interest rate paths, which are calculated by varying the monetary policy shock (the interest rate equation's error term). A particular benchmark alternative is zero policy shocks, i.e. strictly following the interest rate rule. Policy decisions are considered to be efficient when actual RMSs are closer to the efficient frontier than those resulting from the zero-policy shock alternative.

In order to illustrate the use of the framework, it was applied to Israeli data for each one of the calendar years 2001-2010. The results allow us to group the years according to the following criteria: whether the RMS outcomes were close to the efficient frontier (2001 and 2009) or far away from it (2003, 2004 and 2006); whether the monetary policy shocks led to an absolute improvement in the inflation and output gaps (2004 and 2008) or an absolute worsening (2003 and 2006); and whether policy shocks were aggressive (2002, 2008 and 2009), which usually narrowed the output gap at the expense of inflation. Moreover, during years in which RMS outcomes were in the vicinity of the frontier, results were either in the middle part of the frontier or in the output-oriented part. In some sense, this points to the existence of a non-negligible weight on output stabilization in the Bank of Israel loss function. Aside from this general finding, it is difficult to draw additional general conclusions regarding monetary policy conduct.

The framework has some obvious merits: it can be applied to almost any model; it provides flexibility in choosing the two policy objective variables and in placing restrictions on alternative policy paths; and it doesn't necessitate that a position be taken with regard to the weights in the central bank's loss function. However, it has some drawbacks as well. Since shocks are often unpredictable, the ex-post approach cannot address the question of whether policy could have been more efficient in an ex-ante sense. Thus, policy makers are apparently judged for how they reacted in advance to unpredictable shocks. Hence, care should be taken in interpreting the results. One should also keep in mind that the results may be sensitive to the choice of objective variables. For example, the output gap can be defined as the deviation from a trend that is consistent with technological capacity or with flexible prices. Another possible weakness is that while imposing some limitations on interest rate variability seems adequate, it involves some judgment, thus making the results less objective. Finally, the framework views the interest rate equation error term as an active monetary policy shock, which is open to criticism. Admittedly, the error term may also represent real-time measurement errors in the variables that enter the rule, exogenous pressures on policy makers or errors resulting from a misspecified rule. These possible shortcomings should be kept in mind when employing the proposed framework and they call for the development of additional frameworks to evaluate policy decisions.

It is our view that the implementation of this type of evaluation on a regular basis, say once a year, may help central banks improve their understanding of past policy decisions. This may also assist central banks in communicating their decisions and the outcomes of those decisions and may help identify weak points in the analysis and discussions preceding policy decisions.

Appendices

Appendix A Estimation results for non-structural parameters

Table 3: Prior and Posterior Distributions of the Global Parameters

Parameter		Prior distribution type	mean	std	Posterior distribution mode	std	mean	5%	95%
Output equation									
Expectations	$c_{y^*,+}$	beta	0.50	0.10	0.227	0.048	0.225	0.146	0.302
Real rate	$c_{y^*,r}$	gamma	0.20	0.05	0.156	0.030	0.157	0.107	0.205
AR in shock	ρ_{Y^*}	beta	0.70	0.07	0.643	0.063	0.636	0.535	0.738
Inflation equation									
Expectations	$c_{\pi^*,+}$	beta	0.70	0.15	0.966	0.026	0.953	0.915	0.993
Output	$c_{\pi^*,y}$	gamma	0.10	0.03	0.071	0.017	0.076	0.046	0.105
Oil - level	$c_{\pi^*,OIL}$	gamma	0.05	0.03	0.025	0.007	0.028	0.015	0.041
Oil - change	$c_{\pi^*,\Delta OIL}$	gamma	0.05	0.03	0.016	0.005	0.017	0.008	0.026
AR in shock	ρ_{Π^*}	beta	0.70	0.15	0.247	0.084	0.261	0.125	0.391
Monetary policy equation									
Smoothing	$c_{r^*,-}$	beta	0.75	0.10	0.832	0.033	0.831	0.778	0.885
Resp. to inflation	$c_{r^*,\pi}$	gamma	2.50	0.50	2.087	0.429	2.211	1.487	2.908
Resp. to output	$c_{r^*,y}$	gamma	0.50	0.05	0.516	0.051	0.523	0.437	0.606
AR in shock	ρ_{R^*}	beta	0.25	0.05	0.302	0.053	0.301	0.215	0.385
World trade equation									
Output	$c_{wt,y}$	normal	2.50	0.50	2.336	0.371	2.331	1.719	2.961
Lagged output	$c_{wt,y-}$	normal	0.00	1.00	1.509	0.746	1.380	0.165	2.626
Lagged world trade	$c_{wt,-}$	normal	0.00	0.50	0.176	0.149	0.215	-0.029	0.468
Oil price inflation									
Lag	$c_{oil,-}$	beta	0.70	0.15	0.667	0.078	0.635	0.505	0.771
Lagged change	$c_{oil,\Delta}$	normal	0.00	0.50	-0.415	0.096	-0.411	-0.576	-0.250
Shocks' standard deviations									
Demand	S.D.(η^{Y^*})	inv. gamma	0.01	Inf	0.002	0.000	0.002	0.002	0.003
Supply	S.D.(η^{Π^*})	inv. gamma	0.01	Inf	0.007	0.001	0.007	0.006	0.009
Interest rate	S.D.(η^{R^*})	inv. gamma	0.00	Inf	0.002	0.000	0.002	0.002	0.003
World trade	S.D.(η^{WT^*})	inv. gamma	0.03	Inf	0.007	0.001	0.007	0.005	0.009
Oil price	S.D.(η^{OIL})	inv. gamma	0.10	Inf	0.124	0.012	0.124	0.101	0.146
LR rate	S.D.($\eta^{*,fwd}$)	inv. gamma	0.00	Inf	0.001	0.000	0.001	0.000	0.001

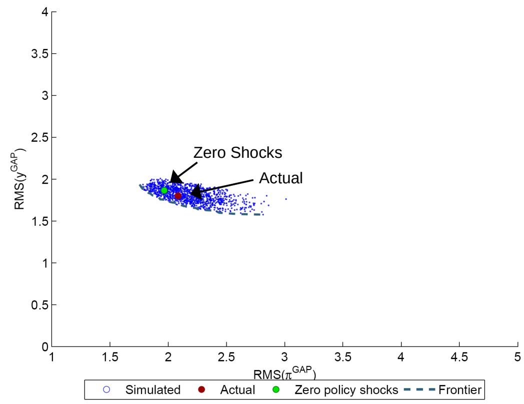
Table 4: Prior and Posterior Distributions of Observation Parameters and Shocks' S.D.

Parameter		Prior distribution type	Prior mean	Prior std	Posterior mode	Posterior std	Posterior mean	Posterior 5%	Posterior 95%
Observation parameters									
Obs. error output def.	$\rho_{OB,\Delta Y}$	normal	0.00	0.25	-0.185	0.136	-0.189	-0.421	0.032
Employment	$\rho_{OB,E}$	beta	0.70	0.15	0.907	0.044	0.837	0.718	0.959
Constant	tp	normal	0.01	0.01	0.012	0.004	0.011	0.004	0.018
Obs. error	$\rho_{OB,fwd}$	beta	0.70	0.15	0.740	0.169	0.716	0.510	0.938
Constant	tp^*	normal	0.02	0.01	0.018	0.004	0.018	0.011	0.025
Obs. error	ρ_{OB,fwd^*}	beta	0.70	0.15	0.832	0.104	0.791	0.631	0.958
Hours	ρ_{EX}^{N}	beta	0.70	0.15	0.933	0.038	0.792	0.569	0.979
Consumption	ρ_{EX}^{C}	beta	0.70	0.15	0.546	0.179	0.600	0.365	0.842
Investment	ρ_{EX}^{I}	beta	0.70	0.15	0.735	0.189	0.737	0.515	0.948
Export	ρ_{EX}^{X}	beta	0.70	0.15	0.602	0.169	0.580	0.332	0.824
Import	ρ_{EX}^{IM}	beta	0.70	0.15	0.675	0.160	0.615	0.377	0.855
Foreign GDP	$\rho_{EX}^{Y^*}$	beta	0.70	0.15	0.655	0.143	0.645	0.432	0.866
World trade	$\rho_{EX}^{WT^*}$	beta	0.70	0.15	0.849	0.077	0.800	0.654	0.950
Oil price	$\rho_{EX}^{P^*_{OIL}}$	beta	0.50	0.07	0.566	0.067	0.552	0.443	0.660
Shocks' standard deviations									
Obs. error output def.	S.D.$(\eta^{\Delta P_Y^M})$	inv. gamma	0.01	Inf	0.007	0.001	0.007	0.006	0.009
Employment	S.D.$(\eta^{OB,E})$	inv. gamma	0.01	Inf	0.003	0.000	0.003	0.002	0.003
Dom. term prem.	S.D.$(\eta^{fwd,OB})$	inv. gamma	0.01	Inf	0.002	0.001	0.002	0.002	0.003
Foreign term prem.	S.D.$(\eta^{*,fwd,OB})$	inv. gamma	0.01	Inf	0.002	0.000	0.002	0.001	0.002
Hours worked	S.D.(η_{EX}^{N})	inv. gamma	0.00	0.00	0.001	0.000	0.001	0.000	0.001
Consumption	S.D.(η_{EX}^{C})	inv. gamma	0.01	0.00	0.003	0.000	0.003	0.002	0.004
Investment	S.D.(η_{EX}^{I})	inv. gamma	0.01	0.00	0.004	0.001	0.004	0.003	0.006
Export	S.D.(η_{EX}^{X})	inv. gamma	0.01	0.00	0.003	0.001	0.003	0.002	0.005
Import	S.D.(η_{EX}^{IM})	inv. gamma	0.01	0.00	0.003	0.001	0.003	0.002	0.004
Wages	S.D.(η_{EX}^{W})	inv. gamma	0.01	0.00	0.010	0.002	0.011	0.007	0.016
Foreign GDP	S.D.$(\eta_{EX}^{Y^*})$	inv. gamma	0.01	0.00	0.003	0.000	0.003	0.002	0.003
World trade	S.D.$(\eta_{EX}^{WT^*})$	inv. gamma	0.01	0.00	0.004	0.001	0.004	0.003	0.006
Oil price	S.D.$(\eta_{EX}^{P^*_{OIL}})$	inv. gamma	0.03	0.01	0.032	0.007	0.038	0.023	0.052
Exchange rate	S.D.(η_{EX}^{S})	inv. gamma	0.01	0.01	0.013	0.002	0.014	0.010	0.018
Transitory techn.	S.D.(η)	inv. gamma	0.03	Inf	0.011	0.001	0.012	0.010	0.013
Permanent techn.	S.D.(η^{g_z})	inv. gamma	0.01	Inf	0.002	0.000	0.002	0.001	0.002
Symmetric prem.	S.D.(η^{RP})	inv. gamma	0.03	Inf	0.010	0.003	0.013	0.006	0.022
External prem.	S.D.(η^{RP^*})	inv. gamma	0.03	Inf	0.011	0.002	0.011	0.008	0.014
Dom. prem.	S.D.(η^{DRP})	inv. gamma	0.00	Inf	0.000	0.000	0.001	0.000	0.001
Consumption	S.D.(η^{C})	inv. gamma	0.03	Inf	0.012	0.006	0.035	0.007	0.067
Inv. Techn.	S.D.(η^{I})	inv. gamma	0.05	Inf	0.042	0.009	0.052	0.020	0.081
Inventory inv.	S.D.$(\eta^{\Delta INV})$	inv. gamma	0.01	Inf	0.013	0.001	0.013	0.011	0.015
Government	S.D.(η^{G})	inv. gamma	0.01	Inf	0.006	0.001	0.006	0.004	0.008
Export share	S.D.(η^{ν^*})	inv. gamma	0.05	Inf	0.042	0.007	0.058	0.035	0.082
Home bias	S.D.(η^{ν})	inv. gamma	0.01	Inf	0.008	0.001	0.008	0.007	0.010
Domestic markup	S.D.(η^{φ^H})	inv. gamma	0.05	Inf	0.028	0.009	0.038	0.016	0.059
Import markup	S.D.(η^{φ^*})	inv. gamma	0.03	Inf	0.026	0.007	0.029	0.015	0.043
Wage markup	S.D.(η^{φ^W})	inv. gamma	0.50	Inf	0.238	0.068	0.335	0.141	0.519
Export markup	S.D.(η^{φ^X})	inv. gamma	0.10	Inf	0.066	0.017	0.076	0.042	0.107
Foreign transfers	S.D.(η^{FTR})	inv. gamma	0.01	Inf	0.016	0.002	0.016	0.013	0.019
Interest rate	S.D.(η^{R})	inv. gamma	0.01	Inf	0.002	0.000	0.002	0.002	0.003
Inf. target	S.D.$(\eta^{\overline{\Pi}})$	inv. gamma	0.00	Inf	0.001	0.000	0.001	0.001	0.001
Consumption tax	S.D.(η^{τ^C})	inv. gamma	0.00	Inf	0.002	0.000	0.002	0.002	0.003

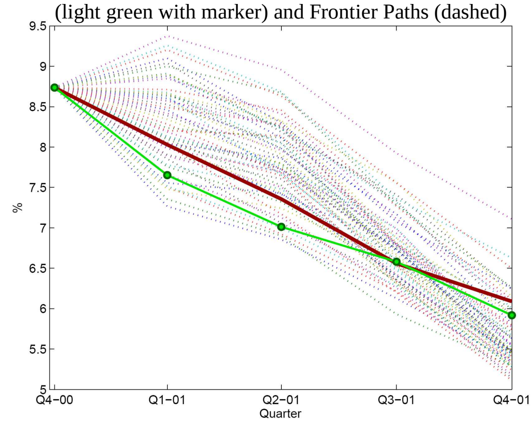
Appendix B Graphic evaluation of monetary policy

Figure 8: Ex-post Monetary Policy Evaluation for 2001

A. Actual and Counterfactual Root Mean Square (RMS) of Output and Inflation Gaps



B. Interest Rate Path: Actual (dark red), Zero Shocks (light green with marker) and Frontier Paths (dashed)



C. Indicators of Interest Rate Volatility

	Sample	Evaluated Year	Limit
σ^r	0.73%	0.78%	1.50%
$\sigma^{\Delta r}$	0.67%	0.12%	0.67%
ΔPD		0	1

Figure 8: Ex-post Monetary Policy Evaluation for 2001 (cont.)

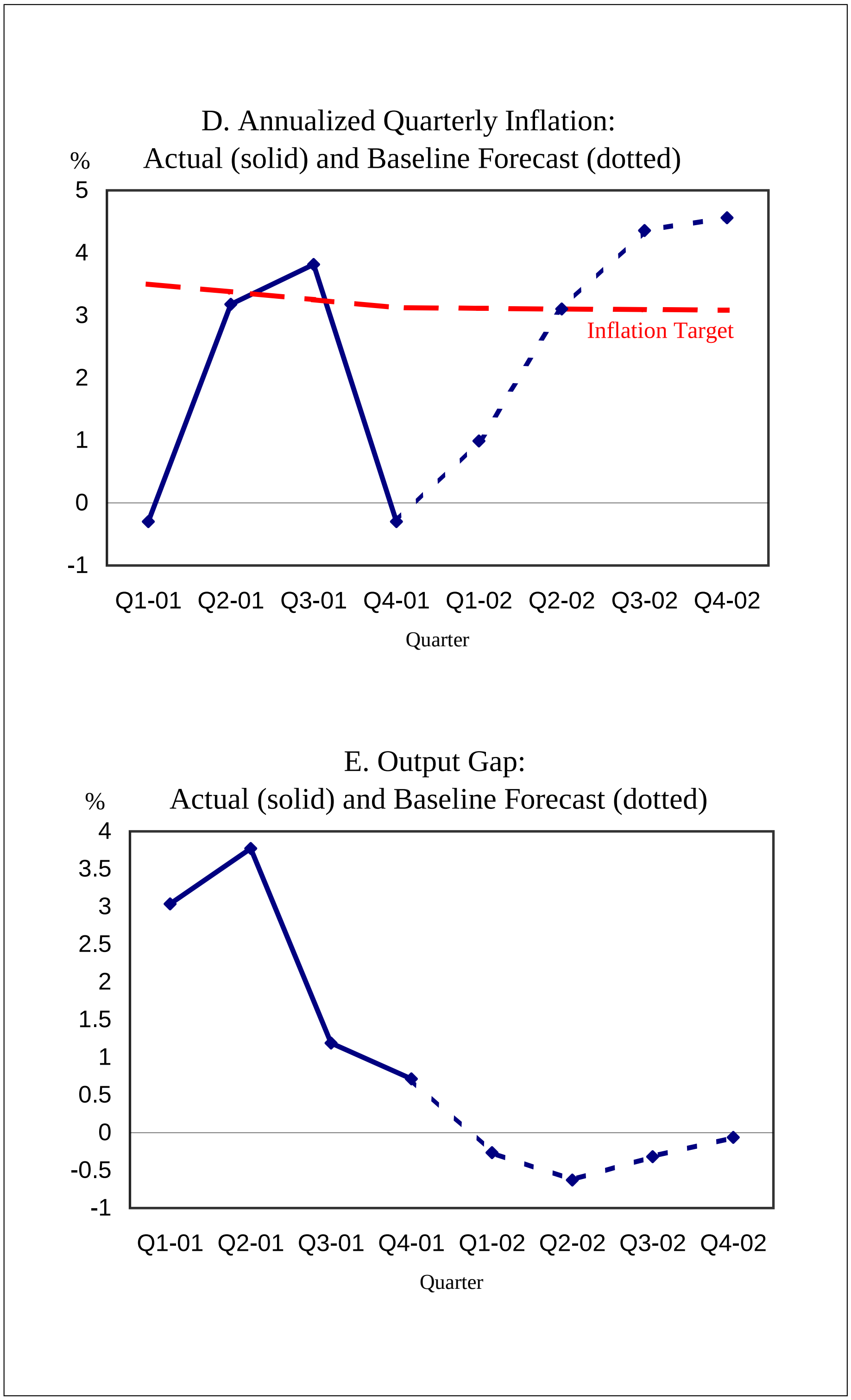
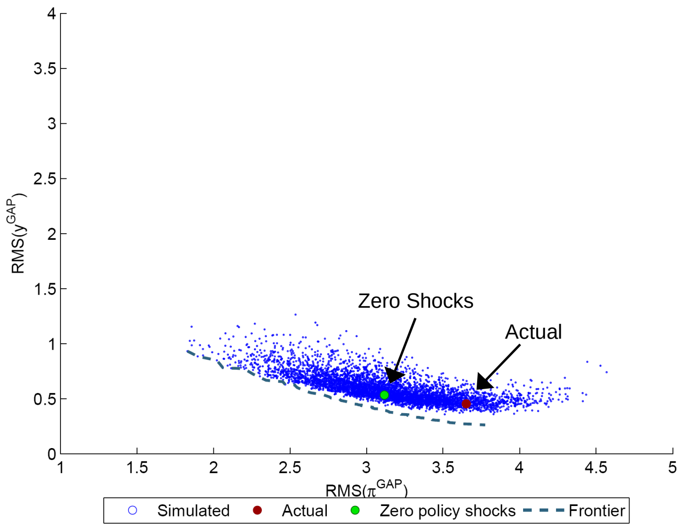
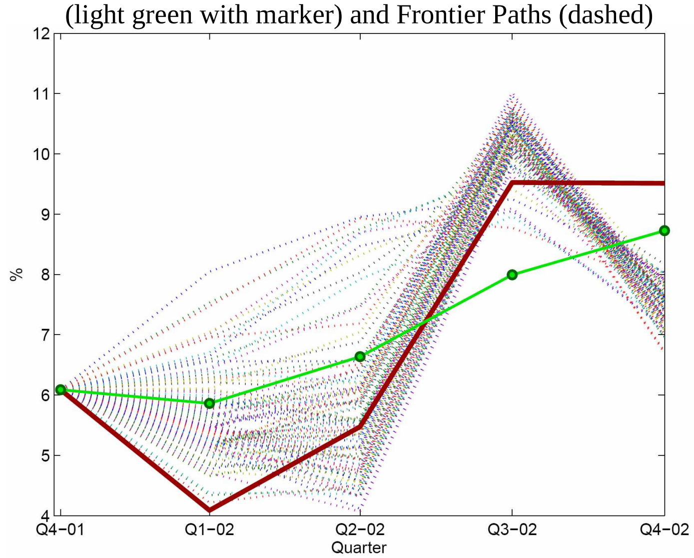


Figure 9: Ex-post Monetary Policy Evaluation for 2002

A. Actual and Counterfactual Root Mean Square (RMS) of Output and Inflation Gaps



B. Interest Rate Path: Actual (dark red), Zero Shocks (light green with marker) and Frontier Paths (dashed)



C. Indicators of Interest Rate Volatility

	Sample	Evaluated Year	Limit
σ^{r}	0.73%	2.30%	2.30%
$\sigma^{\Delta r}$	0.67%	2.20%	2.20%
ΔPD		1	2

Figure 9: Ex-post Monetary Policy Evaluation for 2002 (cont.)

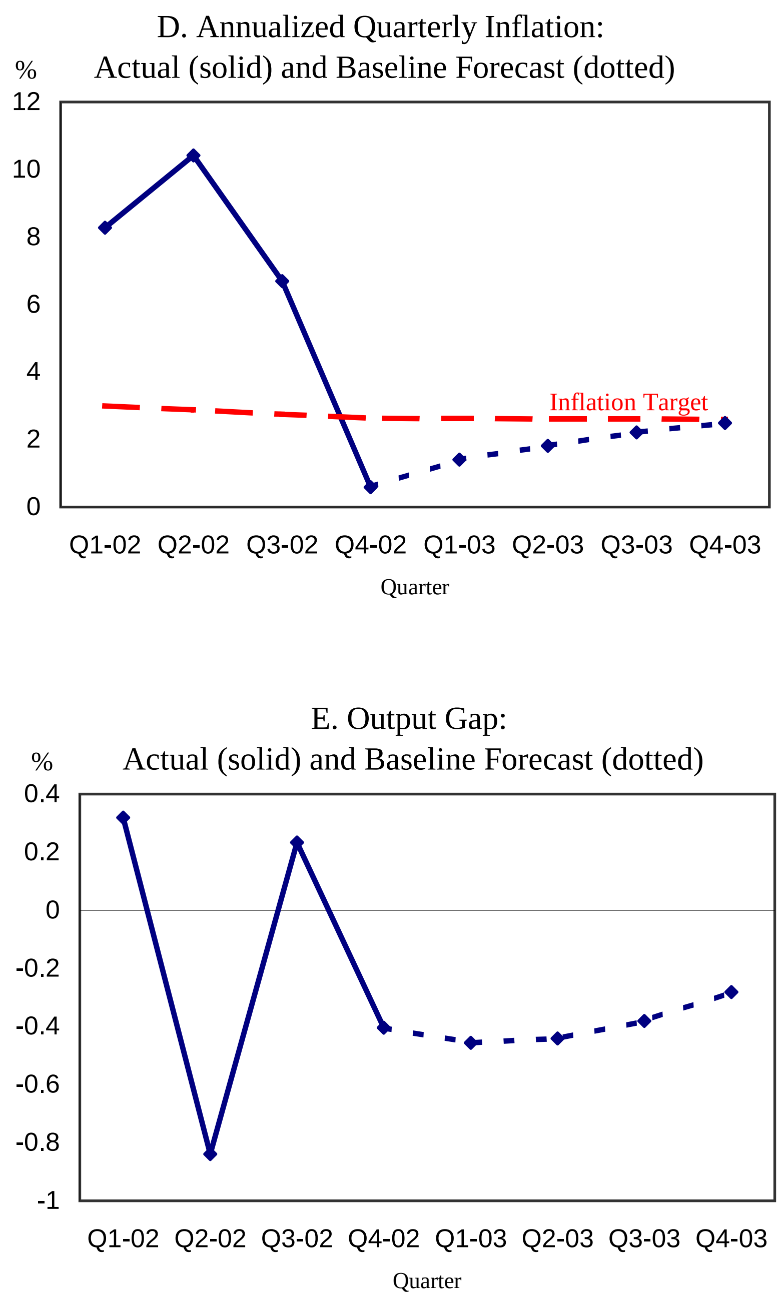
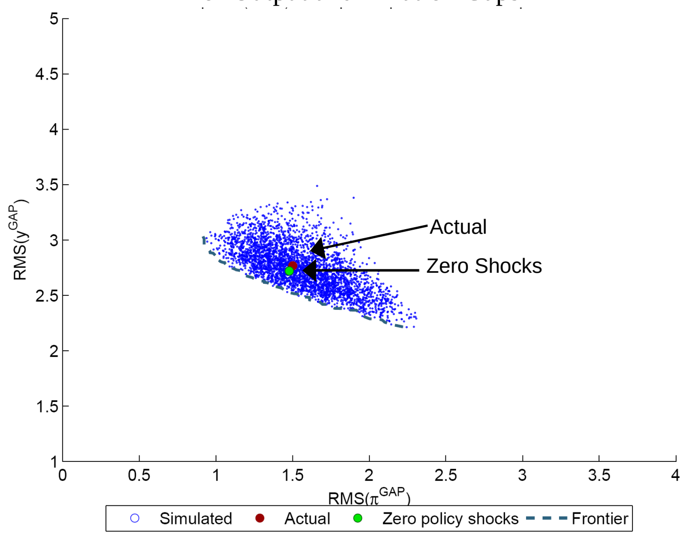
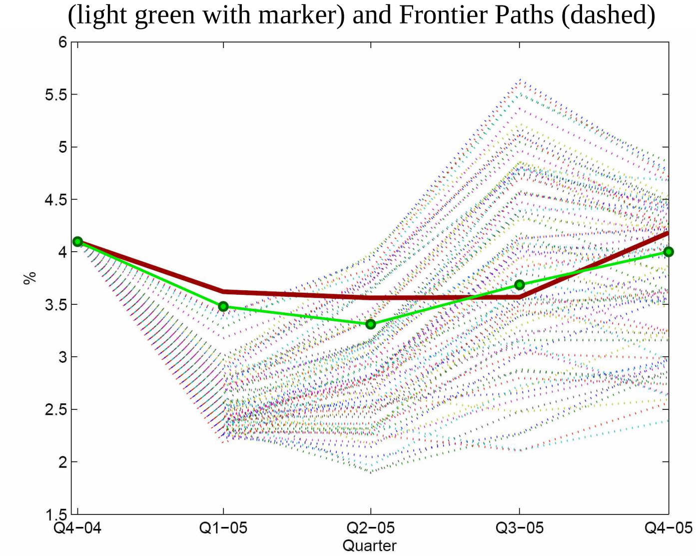


Figure 10: Ex-post Monetary Policy Evaluation for 2005

A. Actual and Counterfactual Root Mean Square (RMS) of Output and Inflation Gaps



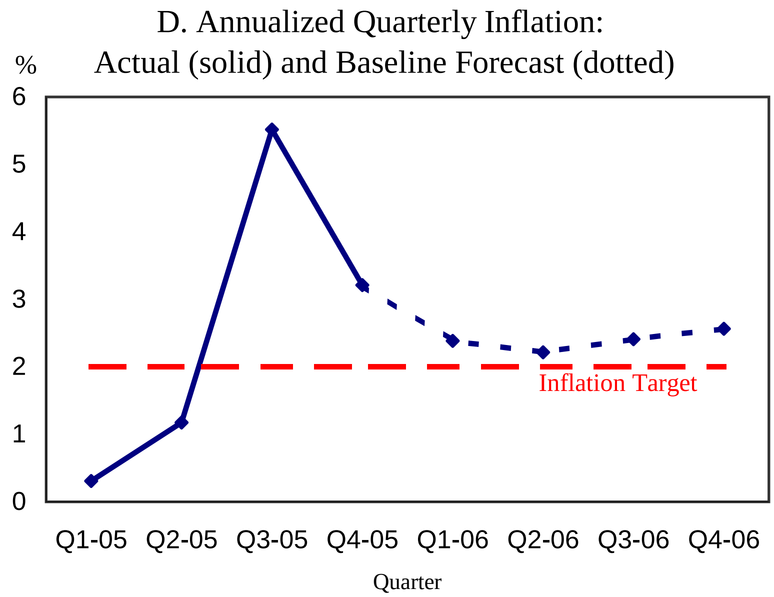
B. Interest Rate Path: Actual (dark red), Zero Shocks (light green with marker) and Frontier Paths (dashed)



C. Indicators of Interest Rate Volatility

	Sample	Evaluated Year	Limit
σ^{r}	0.73%	0.27%	0.73%
$\sigma^{\Delta r}$	0.67%	0.39%	0.78%
ΔPD		1	2

Figure 10: Ex-post Monetary Policy Evaluation for 2005 (cont.)



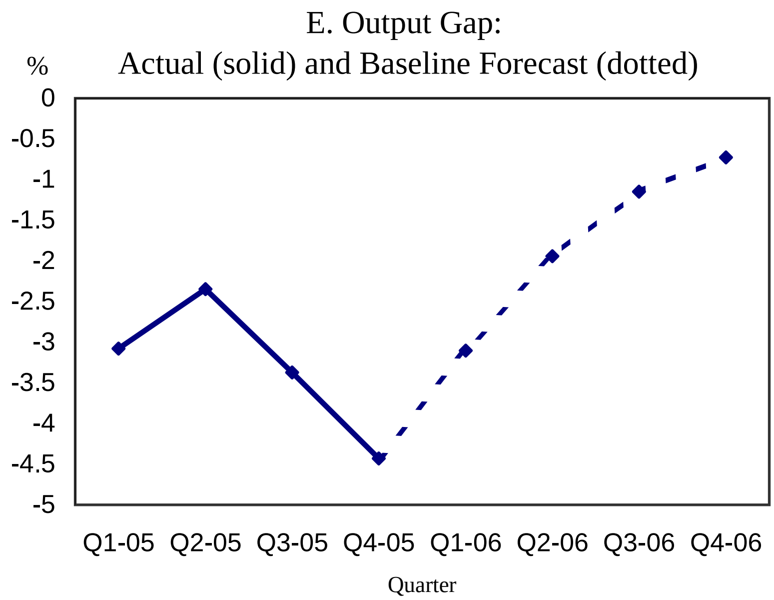
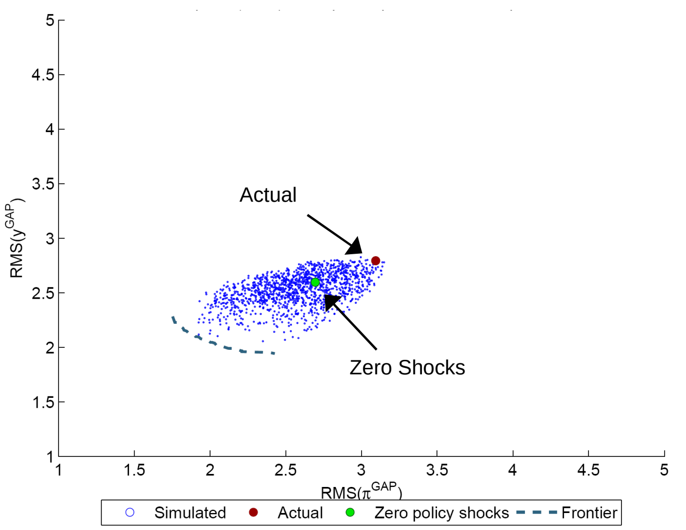
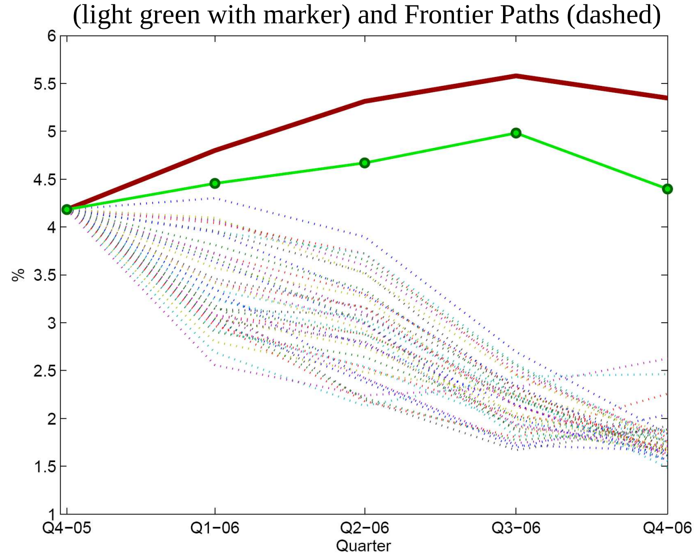


Figure 11: Ex-post Monetary Policy Evaluation for 2006

A. Actual and Counterfactual Root Mean Square (RMS) of Output and Inflation Gaps



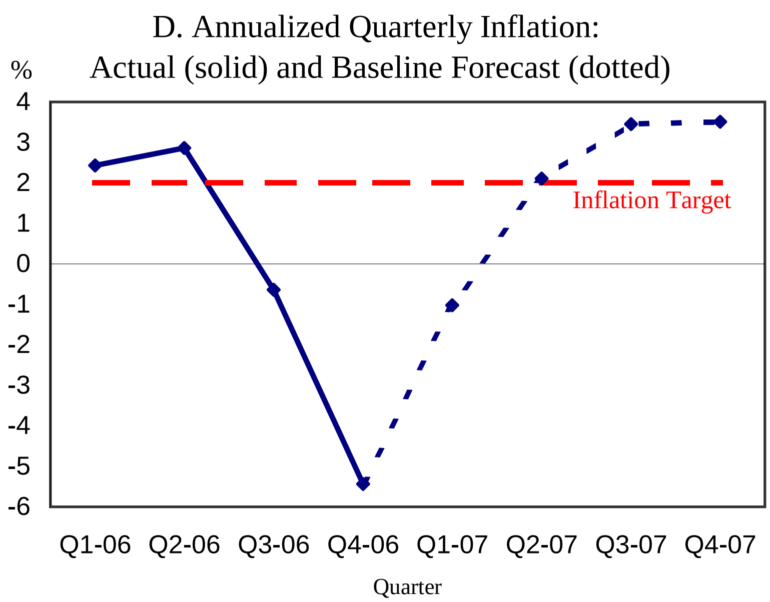
B. Interest Rate Path: Actual (dark red), Zero Shocks (light green with marker) and Frontier Paths (dashed)



C. Indicators of Interest Rate Volatility

	Sample	Evaluated Year	Limit
σ^r	0.73%	0.50%	1.00%
$\sigma^{\Delta r}$	0.67%	0.33%	0.67%
ΔPD		0	1

Figure 11: Ex-post Monetary Policy Evaluation for 2006 (cont.)



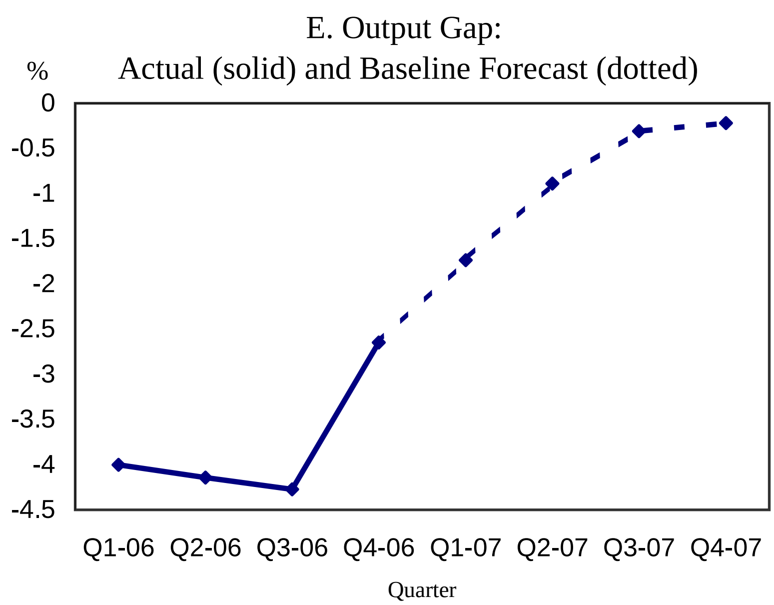
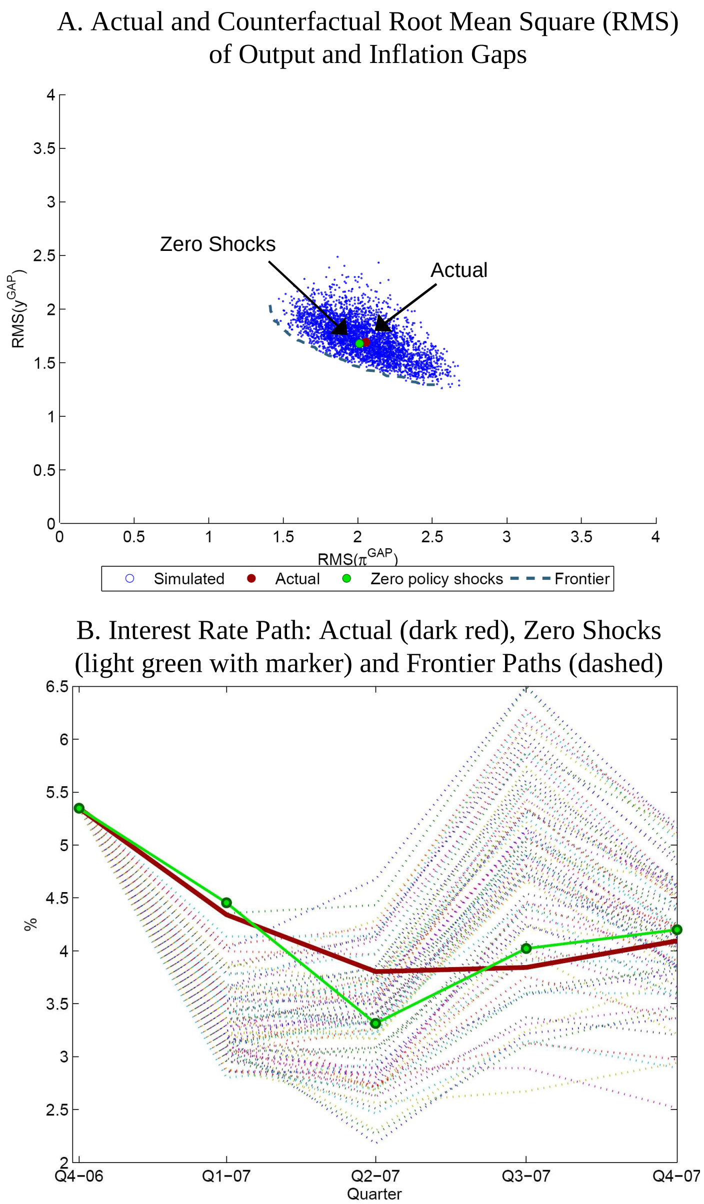


Figure 12: Ex-post Monetary Policy Evaluation for 2007



C. Indicators of Interest Rate Volatility

	Sample	Evaluated Year	Limit
σ^r	0.73%	0.56%	1.10%
$\sigma^{\Delta r}$	0.67%	0.49%	0.99%
ΔPD		1	2

Figure 12: Ex-post Monetary Policy Evaluation for 2007 (cont.)

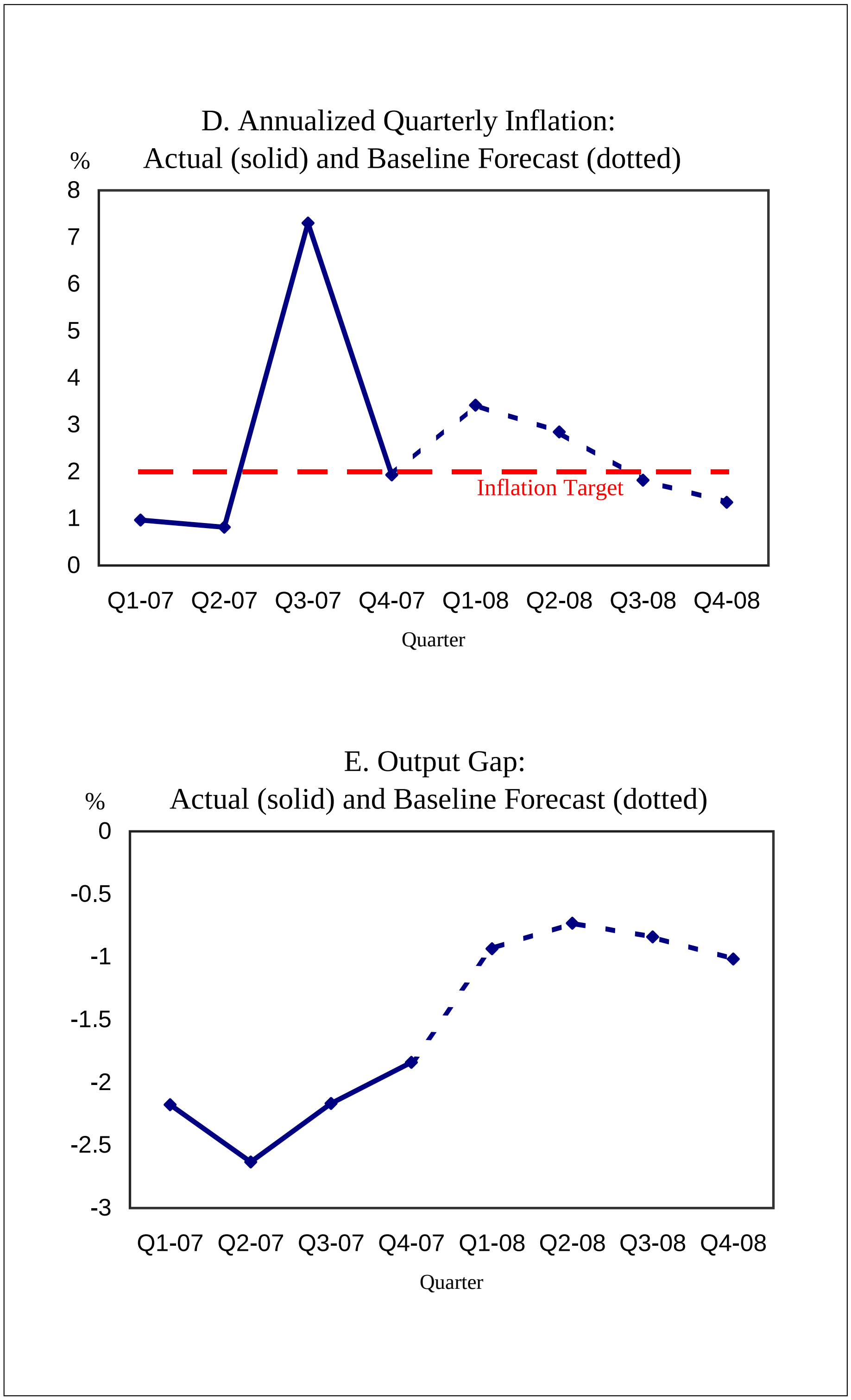
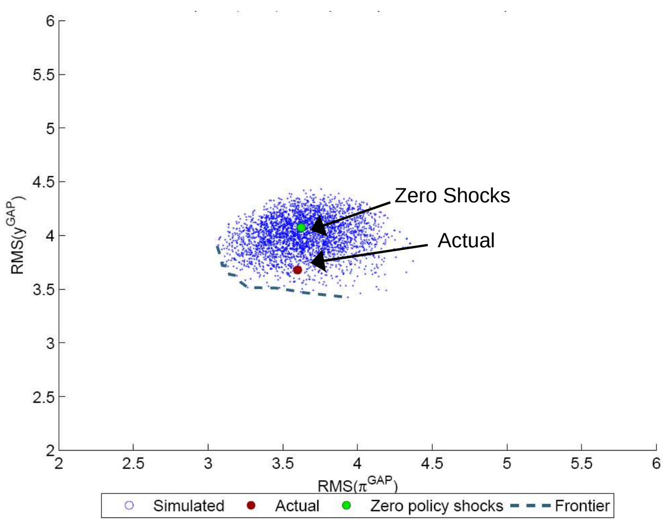
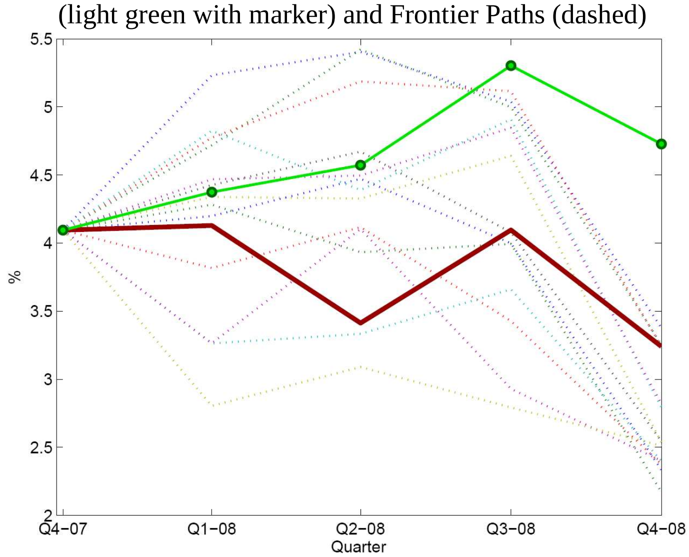


Figure 13: Ex-post Monetary Policy Evaluation for 2008

A. Actual and Counterfactual Root Mean Square (RMS) of Output and Inflation Gaps



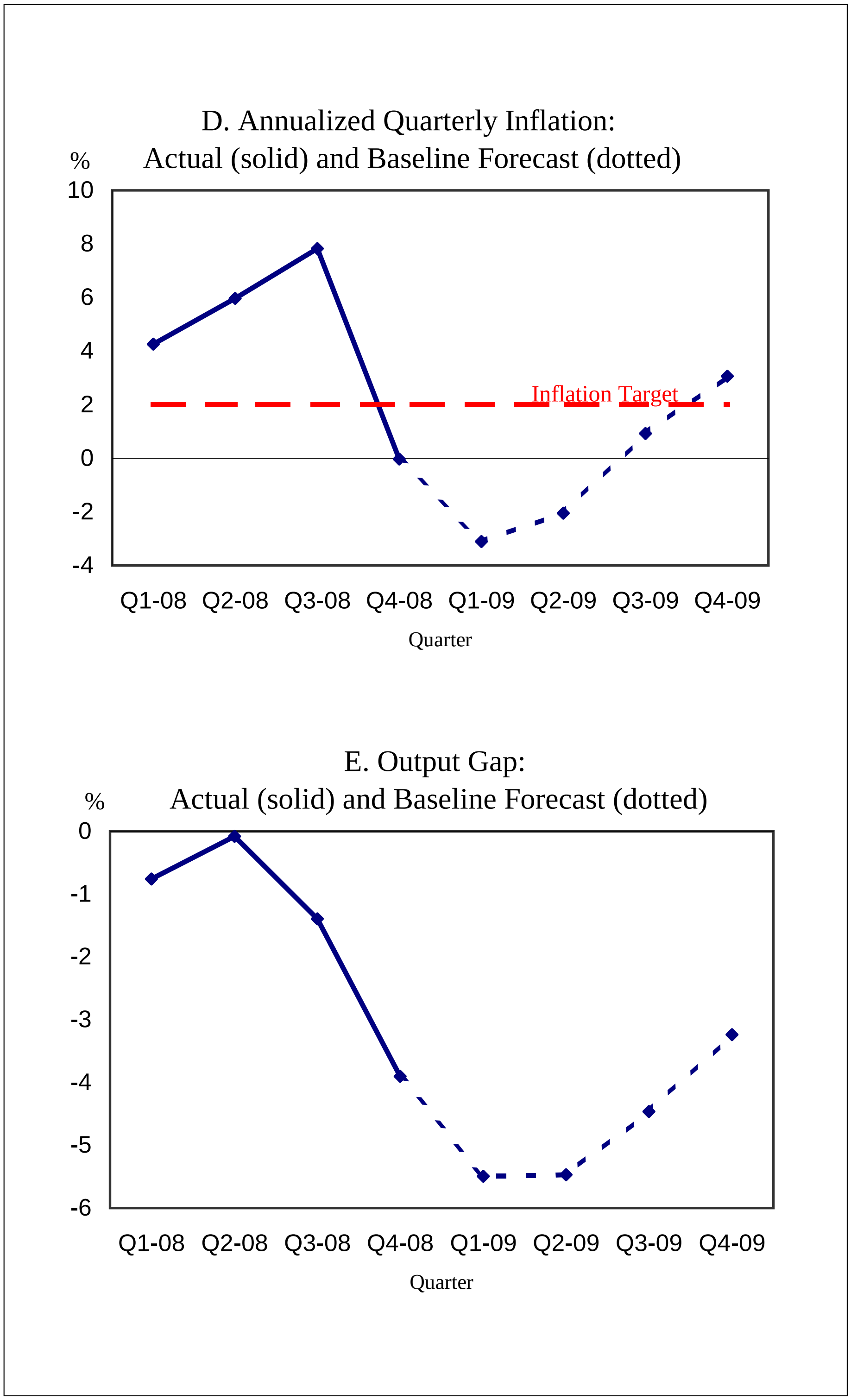
B. Interest Rate Path: Actual (dark red), Zero Shocks (light green with marker) and Frontier Paths (dashed)



C. Indicators of Interest Rate Volatility

	Sample	Evaluated Year	Limit
σ^r	0.73%	0.39%	0.77%
$\sigma^{\Delta r}$	0.67%	0.62%	1.20%
ΔPD		2	3

Figure 13: Ex-post Monetary Policy Evaluation for 2008 (cont.)



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