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Central Bank Objectives, Monetary Policy Rules, and Limited Information*

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Abstract

Since the Global Financial Crisis, a lively debate has emerged regarding the monetary policy rule the central bank of a small open economy (SOE) follows and should follow. By identifying the monetary policy rule that best fits historical data and minimizes central bank loss functions, this study contributes to this debate. We estimate a medium-scale micro-founded SOE model under various monetary policy rules using Israeli data from 1994 to 2019. Our results indicate that the model achieves a better fit to historical data when assuming inflation targeting (IT) compared to nominal income targeting (NGDP). Given central bank goals, shock uncertainty, and limited information, NGDP targeting rules may have been more desirable over the last three decades than IT rules.

יעדי הבנק המרכזי, כללי מדיניות מוניטרית ומידע מוגבל

יונתן בן שימול

תקציר

מאז המשבר הפיננסי העולמי, התפתח דיון סוער בנוגע לכלל המדיניות המוניטרית בו נוקט, וצריך לנקוט, בנק מרכזי של כלכלה קטנה ופתוחה. מחקר זה תורם לדיון המוזכר על ידי זיהוי כלל המדיניות המוניטרית המתאים ביותר לנתונים ההיסטוריים וממזער את פונקציות ההפסד של הבנק המרכזי. לשם כך, אנו אומדים מודל בקנה מידה בינוני המבוסס יסודות מיקרו למשק קטן ופתוח תחת כללי מדיניות מוניטרית שונים, תוך שימוש בנתוני המשק הישראלי בין השנים 1994 ל-2019. תוצאותינו מראות שתחת ההנחה של יעדי אינפלציה המודל מתאים טוב יותר לנתונים ההיסטוריים בהשוואה ליעד תוצר נומינלי. בהינתן מטרות הבנק המרכזי, אי-הוודאות לגבי זעזועים והמידע המוגבל שבפניו, ייתכן שכללי יעד תוצר נומינלי היו רצויים יותר במהלך שלושת העשורים האחרונים לעומת כללי יעד אינפלציה.

1 Introduction

The aftermath of the global financial crisis (GFC) prompted a spirited discourse among economists concerning the objectives and monetary policy rules central banks should adopt to stabilize economies.[1] The GFC witnessed a decline in nominal interest rates, leading to agents being ensnared in liquidity traps, where interest rates reached the lower bound without sufficiently stimulating economic activity (Svensson, 2003a). Post-GFC, nominal interest rates in Israel and several developed or emerging market economies frequently deviated from the paths predicted by standard (Taylor, 1993) or augmented Taylor-type rules (Kazinnik and Papell, 2021).

This study endeavors to evaluate the timing and implications of these deviations. To this end, we employ the MOdel for the ISraeli Economy (MOISE) model (Argov et al., 2012) with various monetary policy rules over the past three decades to identify the rule that best aligns with Israeli economic dynamics. Following previous ex-post evaluations of monetary policy decisions for Israel (Argov et al., 2015), we adopt an empirical perspective to assess alternative monetary policy rules for Israel from 1994 to 2019. Our findings indicate that an inflation targeting (IT) monetary policy rule, encompassing real output (RGDP) gap, exchange rate, and micro-founded natural interest rate targets, best fits Israeli economic dynamics over the last three decades. Despite Israel being a small open economy (SOE), our results show that IT and nominal income (NGDP) targeting rules not specifically targeting the exchange rate showcase commendable data fitting and alignment with central bank objectives. Considering central bank objectives and data constraints, our results highlight the superiority of NGDP level targeting across various shocks and loss functions, particularly under conditions of limited information.

Decades before the GFC, a consensus emerged around the importance of central banks adhering to well-defined policy rules (Ricardo, 1824; Lohmann, 1992), emphasizing both clear and appropriate monetary policy rules (Taylor, 1993) and flexible IT (Svensson, 1999a). However, criticisms have surfaced, suggesting that NGDP targeting might better serve central banks' objectives and mandates (McCallum and Nelson, 1999). Several reasons support the pursuit of IT policies, such as providing an anchor for public expectations (Bernanke and Mishkin, 1997) and facilitating long-term contracts due to their more frequent and easily measurable nature than output or nominal income (Svensson, 1999b). Public debates, exacerbated by the GFC, have questioned the relevance of the IT

[1] See Hendrickson (2012), Frankel (2014), Sumner (2014, 2015), Belongia and Ireland (2015), McCallum (2015), among others.

framework. Criticisms include central banks relying on IT, neglecting asset-price bubbles, and failing to respond adequately to supply and terms of trade shocks (Bhandari and Frankel, 2017).

Bernanke and Mishkin (1997) explore whether NGDP growth or level is a superior target to inflation, contending that the public's better understanding of inflation makes it a more viable target. However, others argue their quasi-equivalence under certain circumstances (Koenig, 1996). The challenges associated with measuring inflation and the output gap, which are difficult to comprehend for both households and economists, pose obstacles to the IT rule (Kiley, 2013). Despite these challenges, our study emphasizes that most agents think in nominal terms, especially when inflation is low, supporting the proposition that targeting NGDP (level or growth) enhances contract certainty. Nevertheless, the assumption of nominal reasoning weakens when inflation is high, leading to substantial real losses (Diamond et al., 1997).

The auto-correction mechanism of NGDP targeting also helps to moderate business cycle fluctuations. For example, policymakers gain flexibility by setting a target for NGDP growth of 5%, composed of RGDP growth and inflation. If RGDP growth falls to 2%, policymakers can let inflation raise to 3% to achieve the target, potentially stimulating economic activity through increased purchases. In contrast, conventional IT presents a challenge during supply shocks like oil price spikes, where stabilizing economic activity can worsen inflation and vice versa. NGDP targeting rules consider both inflation and economic activity, offering a possible solution by balancing these opposing influences on NGDP.

Our study compares IT and NGDP rules using the MOISE model, a medium-scale micro-founded SOE dynamic stochastic general equilibrium (DSGE) model calibrated and estimated using Bayesian techniques for the Israeli economy. This allows us to determine the targeting regime that best aligns with the Bank of Israel's monetary policy decisions and assess the effectiveness of these targeting rules in terms of central bank loss according to the available information set.

The MOISE model's micro-foundations, linking parameters and shocks to deeper structural parameters, offer a theoretical framework particularly valuable in cases with limited data. This linkage enhances the model's suitability for policy analysis, providing a measure of welfare through the utility of agents in the economy (Woodford, 2003). We model a spectrum of central bank loss functions aligned with monetary policy committee discussions and practical central bank objectives, offering insights into policy perspectives more relevant for policymakers in practice (Benchimol and Fourçans, 2019). Our results indicate that interest rate decisions in Israel followed an IT rule over the last three decades under full information. However, NGDP level rules emerge as the most desirable regime for interest rate decisions and Israeli economic dynamics. Specifically, NGDP level targeting rules combined with exchange rate and natural interest rate targets are most effective at minimizing central bank loss functions under limited information.

The remainder of this study is organized as follows. Section 2 succinctly describes the MOISE model and its monetary policy rule. Section 3 presents some empirical intuition about the MOISE and NGDP rules. Section 4 defines the models used in the empirical methodology (Section 5). Section 6 determines which monetary policy rule best fits historical data, and Section 7 discusses the estimated rule coefficients. Central bank loss measures are presented in Section 8, Section 9 draws some policy implications, and Section 10 concludes the study.

2 The MOISE model

The Bank of Israel developed the MOISE model to support monetary policy formulation and macroeconomic forecasting. Based on large-scale models used by central banks like the area-wide models of the European Central Bank (Fagan et al., 2005; Christoffel et al., 2008), MOISE is used for monetary policy analysis and economic out-of-sample forecasting of the Israeli economy.[2] MOISE incorporates modifications and extensions reflecting the unique characteristics of the Israeli economy to improve the model's fit with Israeli data (Argov et al., 2012).

The MOISE model features three types of economic agents: households that decide how much to consume, invest, work, and at what wage; monopolistically competitive (domestic, foreign, exporters) firms of several types in the production sector that hire and employ workers and capital, and decide how much to produce and at what price to sell their products; and a central bank that determines the nominal short-term interest rate. Additionally, the model features several real frictions, including habit formation in consumption and adjustment costs in investment.

The monetary policy rule used in the original MOISE model is inspired by Argov and Elkayam (2010). Argov et al. (2012) generalize a Taylor (1993) type rule, with standard modifications following monetary policy rules used in other large-scale SOE models (Adolfson et al., 2007; Christoffel et al., 2008). The nominal interest rate in the MOISE model follows an IT rule augmented with the forward interest rate, average forward-looking inflation rate (central bank inflation rate), and nominal depreciation targets. In terms of log-linear deviations

[2] The Bank of Israel's Research Department publishes staff forecasts four times a year.

from the deterministic steady-state, the policy rule used in the MOISE model is

$$\hat{r}_t = (1-\phi_R)\left[\widehat{rr}_t^{fwd} + \widehat{\bar{\pi}}_t + \phi_\Pi\left(\hat{\pi}_t^{CB} - \widehat{\bar{\pi}}_t\right) + \phi_y \hat{y}_t^{GAP} + \phi_{\Delta S}\Delta S_t\right] + \phi_R \hat{r}_{t-1} + \eta_t^R, \tag{1}$$

where monetary policy reacts to the forward 5-10 years expected real interest rate, $\widehat{rr}_t^{fwd}$, central bank targeted inflation measure, $\hat{\pi}_t^{CB}$ is the central bank inflation rate,[3] the time-varying inflation target[4] $\widehat{\bar{\pi}}_t$, the output gap, $\hat{y}_t^{GAP}$, and nominal depreciation growth (Adolfson et al., 2008; Argov and Elkayam, 2010), ΔS_t. The policy shock, η_t^R, follows a white noise process. ϕ_R, ϕ_Π, ϕ_y, and $\phi_{\Delta S}$ are the weights on the interest rate smoothing, the inflation gap, the output gap, and the nominal depreciation, respectively.

Empirical as well as theoretical findings motivate the direct response of interest rate policy to nominal depreciation and the response to both historical and expected inflation (Argov and Elkayam, 2010). Therefore, the central bank reacts to the following forward- and backward-looking average inflation measure in MOISE, given by

$$\hat{\pi}_t^{CB} = \frac{1}{4}\left(\hat{\pi}_{t-2}^C + \hat{\pi}_{t-1}^C + \hat{\pi}_t^C + \mathbb{E}_t\left[\hat{\pi}_{t+1}^C\right]\right), \tag{2}$$

where $\hat{\pi}_t^C$ is the domestic CPI inflation and $\mathbb{E}_t[.]$ is the rational expectation operator.[5]

The rest of the MOISE model is described in Argov et al. (2012). In this paper, we do not alter the structure or parameter calibration of the MOISE model, and focus solely on varying the monetary policy rule. To facilitate understanding, we use the same notations as in Argov et al. (2012).

Eq. 2 is used in Section 3. To focus on standard IT monetary policy rules, only rules considering contemporaneous IT are used in the rest of the paper (Section 4). Nevertheless, even if this average IT feature is included in the monetary policy rules, our results hold.[6]

3 Empirical Intuition

This section provides some stylized facts and intuition about the performance of IT and NGDP targeting rules for monetary policy in Israel.

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[3] See Eq. 2.

[4] See Eq. 55 in Appendix A.6.

[5] A different version of this rule is also available in Eckstein and Segal (2010).

[6] Additional results are available upon request.

3.1 Flexible Inflation Targeting

The literature touts the merits of IT for several reasons (Svensson, 2003a, 2010): the clear inflation anchor they provide,[7] the economic stability they presumably preserve,[8] and their global credibility.[9]

This section compares the IT monetary policy rule tailored to the Israeli economy (MOISE rule) with the well-known Taylor (1993) rule. Our focus centers on evaluating the performance of IT rules in the context of monetary policy modeling for Israel.

Figure 1 compares two IT rules for Israel, the MOISE rule (Eq. 1) and the Taylor (1993) rule, with the Bank of Israel's interest rate.[10]

Figure 1 shows that deviations of the MOISE rule from the effective nominal interest rate around the dot-com crisis and after the GFC are significant in terms of policy–several times more than 25 basis points. On average, the Taylor rule has lower root mean square errors than the MOISE rule.

These results are consistent with the Bank of Israel's Annual Report.[11] From 2007:Q2, the accuracy of predictions from both types of IT rules decreased. Thus, the issue may not be the calibration of a particular IT rule but the variables themselves, namely, the consideration of variables such as forward rates, nominal depreciation, or the output gap.

In addition, the MOISE rule (Eq. 1) may be misunderstood by the public and does not often match the Bank of Israel's monetary policy decisions or objectives.

> *During the period preceding the financial crisis, the interest rate rule accurately describes the path of the actual interest rate, and that from the outbreak of the global economic crisis in the beginning of 2008 onward a gap appears between them although their fluctuations remained correlated. It appears therefore that during the period of the global economic crisis, monetary*

[7]IT fosters stable inflation expectations, key for long-term growth.

[8]IT prevents both high and low inflation, supporting businesses and consumers.

[9]IT's transparency, flexibility, and widespread adoption enhance its effectiveness. Moreover, the inflation rate is more well-measured and known by the public or entrepreneurs than NGDP.

[10]In Figure 1, $\widehat{rr}_t^{fwd}$ is computed identically for both rules, such as:

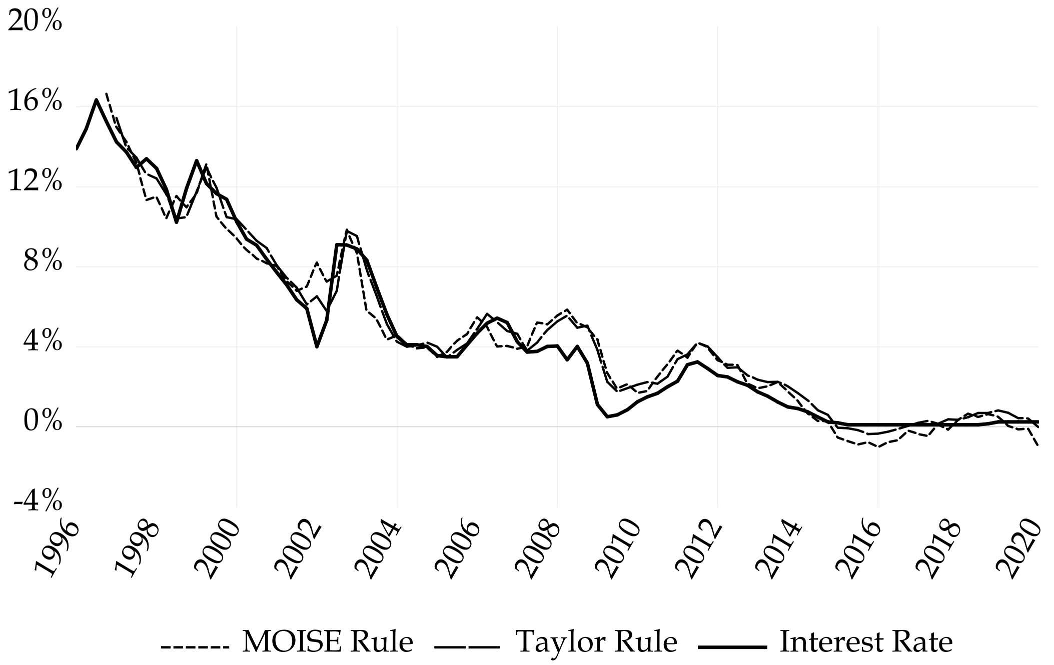
$$\widehat{rr}_t^{fwd} = 100 \times \left(\frac{\left(\left(1 + r_t^{10y}\right)/100\right)^{10}}{\left(\left(1 + r_t^{5y}\right)/100\right)^{5}} \right)^{1/5} - 1 \tag{3}$$

where r_t^{10y} and r_t^{5y} are the zero-coupon 10 and 5 years real interest rates, respectively.

The output gap is computed as the deviation of output from its Hodrick-Prescott (HP) trend (Kiley, 2013). The historical values of the inflation target, $\widehat{\overline{\pi}}_t$, and the other data sources are from the Bank of Israel.

[11]Chapter 3, Figure 3.9, p. 102, Annual Report, Bank of Israel, 2012.

Figure 1. MOISE IT Rules and the Interest Rate



Notes: The values are in percentage. In this figure, we use a standard calibration for the MOISE rule (Argov et al., 2012): $\phi_R = 0.8$, $\phi_\Pi = 2.5$, $\phi_y = 0.8$, and $\phi_{\Delta S} = 0.1$. The Taylor rule follows standard calibration such as: $\phi_R = 0.8$, $\phi_\Pi = 1.5$, $\phi_y = 0.8$, and $\phi_{\Delta S} = 0$.

> *policy was conducted differently, affected by factors that are not included in the interest rate equation—in particular, risk factors originating in the global economy and expectations of their future moderating effect on the Israeli economy led to a lower rate of interest than that dictated by the equation (Annual Report, Bank of Israel, 2012, Chapter 3, pages 102-103).*

In closed-economy models, monetary policy rules usually target inflation and output gaps. Since the exchange rate influences the interest rate in SOEs, we test whether the Bank of Israel targeted the exchange rate (nominal depreciation), among other variables (Taylor, 2001). The exchange rate influences the inflation rate and the output gap through its pass-through effect (Ball, 1998; Taylor, 2001; Batini et al., 2003). In addition, including the exchange rate in the IT rule can significantly alter the inflation and output dynamics after specific shocks (Caraiani, 2013). For emerging countries' central banks, an IT rule augmented with an exchange rate-related variable is useful (Filardo et al., 2011), but may be less relevant for a developed country like Israel.

In this paper, we also examine whether the Bank of Israel targets real output growth ($\Delta\hat{y}_t$) rather than the real output gap ($\hat{y}_t^{GAP}$). Most of the rules considered in the current debates on monetary policy rules assume that potential output, a necessary component of the output gap, is observable in real-time by the central bank. Many also assume that the natural rate of interest is observable. One argument supporting NGDP targeting rules is that targeting deviations of NGDP from a fixed growth rate or levels path does not require the central bank to estimate the output gap. Considering additional rules independent of the potential output or natural interest rate would be interesting. To this end, we also analyze rules targeting output growth and the micro-founded natural interest rate.

Of course, these rules may not deliver performance on par with what can be achieved under rules assuming that the Bank of Israel can observe real-time potential output and natural interest rate without error. It would be interesting to identify which rule would best describe the Bank of Israel's actual historical decisions, as well as which rule would yield the best performance within this more highly constrained class.

In light of variable targets, forward-looking IT rules seem to provide a reasonable description of the central bank's behavior in Turkey and Israel, even if only two response variables are included in the rule, such as deviation from the inflation target and output gap. There are other variations of augmented IT rules, responding to money growth, real exchange rate, and deviation of the real exchange rate from equilibrium. These variables do not appear to be significant in these countries (Yazgan and Yilmazkuday, 2007).

Over the last decades, the primary central bank objective has become the inflation target, while the exchange rate has become a secondary indicator variable set by the market. Crucially, as inflation targets become more credible than other targets and exchange rate flexibilities increase, the extent of exchange rate pass-through to prices is likely to decrease over time (Leiderman and Bar-Or, 2002). Therefore, we test various monetary policy rule alternatives, as well as NGDP rules without the exchange rate or the output gap.

3.2 NGDP Targeting

In this subsection, we provide insights into the performance of NGDP growth and level targeting rules for monetary policy modeling in Israel. Targeting a nominal value is essential for stabilizing expectations more effectively (Eusepi and Preston, 2010; Honkapohja and Mitra, 2020), but not all agree on the choice of target variables. Some suggested central banks target a price level rather than targeting an inflation rate and use monetary policy instruments to achieve it in the medium term (Kahn, 2009). In fact, even if IT stabilizes inflation, it does not compensate for the years when it did not achieve its target and agents continue to face uncertainty about future general price levels. Price level targeting removes that uncertainty, encouraging businesses and companies to spend more when activity is low and manage their investments more effectively over the long term. In low inflation periods, generating positive inflation expectations would allow negative nominal interest rates to persist, thereby encouraging agents to invest more.

Sumner (2014) and proponents of *market monetarism* recommend that central banks target NGDP. In order to prevent the economy from entering a recession in nominal terms, the monetary authority could aim for 5% NGDP growth to stimulate aggregate demand effectively. If the central bank fails to generate 5% NGDP growth in one year, it can always catch up in subsequent years. If the Fed had targeted NGDP during the GFC, it would have eased monetary policy and deployed more unconventional measures more rapidly (Sheedy, 2014). By allowing the economy to grow faster out of recession and for NGDP to return to pre-GFC levels, the monetary authority would also be able to stimulate the recovery more effectively (Sumner, 2014, 2015).

For illustration purposes, we use a simple NGDP targeting rule structure such as:

$$\hat{r}_t = (1 - \phi_R) \left[\widehat{\overline{\pi}}_t + \phi_n NGDP_t \right] + \phi_R \hat{r}_{t-1}, \tag{4}$$

where $NGDP_t$ and ϕ_n are the growth (or the level) of NGDP, and the associated weight, respectively (Rudebusch, 2002; Benchimol and Fourçans, 2019).

Figure 2 compares NGDP growth and level targeting rules.[12]

Figure 2 shows that the two rules performed similarly from 2000:Q1 to 2007:Q2. The NGDP level targeting rule better fits the interest rate path than the NGDP Growth targeting rule from 2007:Q3, and the differences are sometimes significant from a monetary policy perspective–larger than 25 basis points.

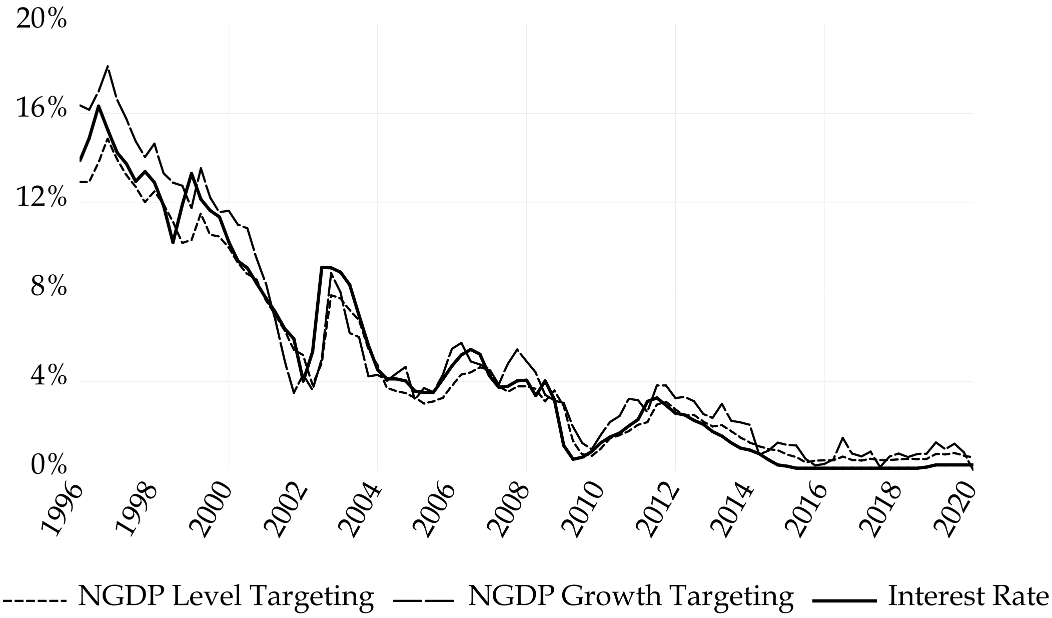
In contrast to NGDP growth rules, the NGDP rule reacts to the NGDP gap, i.e., the difference between NGDP and the HP trend obtained with a standard coefficient of 1600 for quarterly data (Hodrick and Prescott, 1997). This NGDP level rule reproduces the Bank of Israel's monetary policy decisions more accurately than IT rules after the GFC.

Figure 2 displays the dynamics of the nominal interest rate, which never reached the zero lower bound (ZLB), being always above 0.1%.

Figure 3 compares the IT rule as in MOISE (Eq. 1) with the NGDP level rule

[12] In Figure 2, the NGDP growth is calculated as the difference between the 4-quarter log deviation of NGDP and the 4% target, normalized at quarter frequency. The NGDP level is defined as in the literature (Koenig, 1996; McCallum and Nelson, 1999; Rudebusch, 2002; Hendrickson, 2012), i.e., the deviation of the NGDP from its HP trend. The historical values of the inflation target, $\widehat{\overline{\pi}}_t$, and the other data sources are from the Bank of Israel.

Figure 2. NGDP Targeting and the Interest Rate



Notes: The values are in percentage. In this figure, we use a standard calibration for NGDP growth and level targeting rules, $\phi_n = 1.5$ and $\phi_n = 0.5$, respectively (Rudebusch, 2002; Benchimol and Fourçans, 2019). The calibration of the smoothing parameter is as before ($\phi_R = 0.8$).

(Eq. 4).

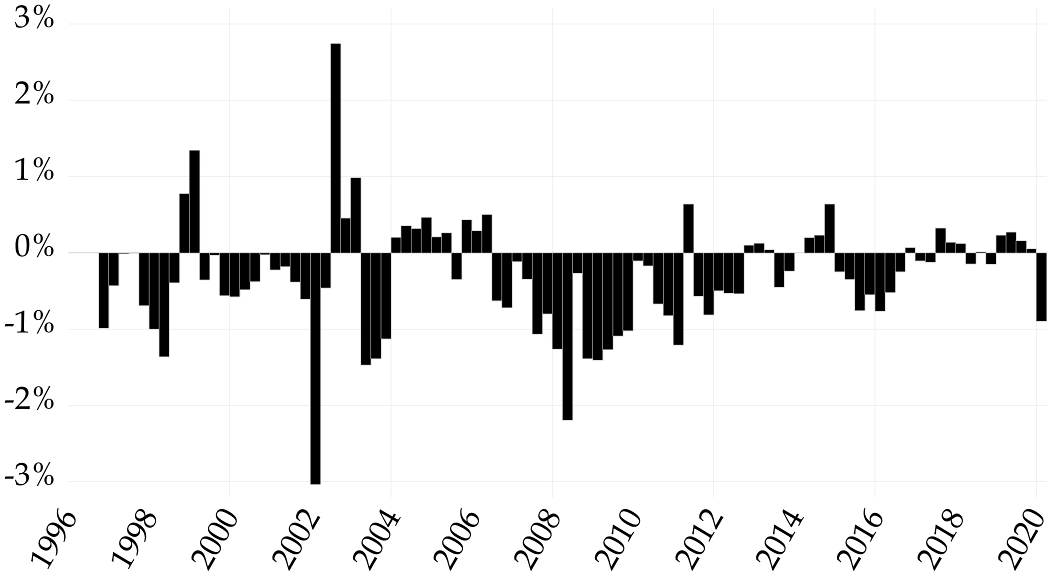
From 2002:Q3 to 2003:Q1, and from 2004:Q1 to 2006:Q2, the IT rule better fits the Bank of Israel's monetary policy decisions than the NGDP level targeting rule. Outside these short periods, Figure 3 shows that the NGDP level targeting rule better fits the Bank of Israel's interest rate decisions than the MOISE rule (IT). This can be interpreted as evidence for weight changes in one of the rules, regime changes (Second Intifada, Israel–Hezbollah War), or changes in the economic structure that made one rule unable to fit all the states of the economy.

These intuition do not provide a sufficient basis for prescribing a rule for monetary policy conduct. To account for central bank objectives, the various domestic and foreign shocks hitting the economy, and to match the overall model to economic dynamics, we adopt the DSGE perspective described below.

4 The Models

In this study, the MOISE model (Argov et al., 2012, 2015) is used as the core model and only the ad-hoc domestic monetary policy rule is replaced with a monetary policy rule from Table 1. Several alternative rules are presented in this section and despite their different formulations, they all include a smoothing process

Figure 3. Inflation and NGDP Targeting



Notes: The values represent the difference in the errors between the MOISE rule and the NGDP level targeting rule in percentage points to the effective interest rate. The NGDP level targeting rule better fits the path of the interest rate than the MOISE rule when the bar is negative. A positive bar indicates the superiority of the MOISE rule (IT).

that captures the rule-specific degree of interest rate smoothing.

Table 1 presents the monetary policy rules used in this study. To make these rules correspond to the literature, we consider inflation and price variables extracted from the GDP deflator ($\hat{\pi}_t^Y$ and p_t^Y) and the CPI ($\hat{\pi}_t^C$) for NGDP and IT rules, respectively. All the data and variables are calculated as in Argov et al. (2012).

Appendix A describes the core MOISE model. The monetary policy rule is intricately linked to the first-order condition associated with domestic bonds, establishing the connection between the nominal interest rate and the dynamics of domestic debt markets. The risk-adjusted Uncovered Interest Parity (UIP) condition also plays a pivotal role, demonstrating how exchange rate considerations and risk adjustments are related to interest rate decisions. Furthermore, monetary policy is also related to the interest rate on working capital. These are the main direct connections of the model to the monetary policy rule.

4.1 NGDP Targeting Rules

- Rule **1** targets the NGDP growth $\left(\hat{\pi}_t^Y - \widehat{\overline{\pi}}_t + \Delta\hat{y}_t\right)$, the nominal depreciation (ΔS_t), and the forward-based natural interest rate ($\widehat{rr}_t^{fwd} + \widehat{\overline{\pi}}_t$).

Table 1. Summary of monetary policy rules used in this study

Models	Targeting	Monetary policy rules
1	NGDP Growth + FX	$\hat{r}_t = (1-\phi_R)\left[\widehat{rr}_t^{fwd} + \widehat{\widehat{\pi}}_t + \phi_n\left(\hat{\pi}_t^Y - \widehat{\widehat{\pi}}_t + \Delta\hat{y}_t\right) + \phi_{\Delta S}\Delta S_t\right] + \phi_R\hat{r}_{t-1} + \eta_t^R$
2	NGDP Growth + FX + NIR	$\hat{r}_t = (1-\phi_R)\left[\hat{r}_t^n + \widehat{\widehat{\pi}}_t + \phi_n\left(\hat{\pi}_t^Y - \widehat{\widehat{\pi}}_t + \Delta\hat{y}_t\right) + \phi_{\Delta S}\Delta S_t\right] + \phi_R\hat{r}_{t-1} + \eta_t^R$
3	NGDP Growth	$\hat{r}_t = (1-\phi_R)\left[\widehat{rr}_t^{fwd} + \widehat{\widehat{\pi}}_t + \phi_n\left(\hat{\pi}_t^Y - \widehat{\widehat{\pi}}_t + \Delta\hat{y}_t\right)\right] + \phi_R\hat{r}_{t-1} + \eta_t^R$
4	NGDP Growth + NIR	$\hat{r}_t = (1-\phi_R)\left[\hat{r}_t^n + \widehat{\widehat{\pi}}_t + \phi_n\left(\hat{\pi}_t^Y - \widehat{\widehat{\pi}}_t + \Delta\hat{y}_t\right)\right] + \phi_R\hat{r}_{t-1} + \eta_t^R$
5	NGDP Level + FX	$\hat{r}_t = (1-\phi_R)\left[\widehat{rr}_t^{fwd} + \widehat{\widehat{\pi}}_t + \phi_n\left(p_t^Y + \hat{y}_t^{GAP}\right) + \phi_{\Delta S}\Delta S_t\right] + \phi_R\hat{r}_{t-1} + \eta_t^R$
6	NGDP Level + FX + NIR	$\hat{r}_t = (1-\phi_R)\left[\hat{r}_t^n + \widehat{\widehat{\pi}}_t + \phi_n\left(p_t^Y + \hat{y}_t^{GAP}\right) + \phi_{\Delta S}\Delta S_t\right] + \phi_R\hat{r}_{t-1} + \eta_t^R$
7	NGDP Level	$\hat{r}_t = (1-\phi_R)\left[\widehat{rr}_t^{fwd} + \widehat{\widehat{\pi}}_t + \phi_n\left(p_t^Y + \hat{y}_t^{GAP}\right)\right] + \phi_R\hat{r}_{t-1} + \eta_t^R$
8	NGDP Level + NIR	$\hat{r}_t = (1-\phi_R)\left[\hat{r}_t^n + \widehat{\widehat{\pi}}_t + \phi_n\left(p_t^Y + \hat{y}_t^{GAP}\right)\right] + \phi_R\hat{r}_{t-1} + \eta_t^R$
9	Inflation and RGDP Growth + FX	$\hat{r}_t = (1-\phi_R)\left[\widehat{rr}_t^{fwd} + \widehat{\widehat{\pi}}_t + \phi_\Pi\left(\hat{\pi}_t^C - \widehat{\widehat{\pi}}_t\right) + \phi_y\Delta\hat{y}_t + \phi_{\Delta S}\Delta S_t\right] + \phi_R\hat{r}_{t-1} + \eta_t^R$
10	Inflation and RGDP Growth + FX + NIR	$\hat{r}_t = (1-\phi_R)\left[\hat{r}_t^n + \widehat{\widehat{\pi}}_t + \phi_\Pi\left(\hat{\pi}_t^C - \widehat{\widehat{\pi}}_t\right) + \phi_y\Delta\hat{y}_t + \phi_{\Delta S}\Delta S_t\right] + \phi_R\hat{r}_{t-1} + \eta_t^R$
11	Inflation and RGDP Growth	$\hat{r}_t = (1-\phi_R)\left[\widehat{rr}_t^{fwd} + \widehat{\widehat{\pi}}_t + \phi_\Pi\left(\hat{\pi}_t^C - \widehat{\widehat{\pi}}_t\right) + \phi_y\Delta\hat{y}_t\right] + \phi_R\hat{r}_{t-1} + \eta_t^R$
12	Inflation and RGDP Growth + NIR	$\hat{r}_t = (1-\phi_R)\left[\hat{r}_t^n + \widehat{\widehat{\pi}}_t + \phi_\Pi\left(\hat{\pi}_t^C - \widehat{\widehat{\pi}}_t\right) + \phi_y\Delta\hat{y}_t\right] + \phi_R\hat{r}_{t-1} + \eta_t^R$
13	Inflation and RGDP Gap + FX	$\hat{r}_t = (1-\phi_R)\left[\widehat{rr}_t^{fwd} + \widehat{\widehat{\pi}}_t + \phi_\Pi\left(\hat{\pi}_t^C - \widehat{\widehat{\pi}}_t\right) + \phi_y\hat{y}_t^{GAP} + \phi_{\Delta S}\Delta S_t\right] + \phi_R\hat{r}_{t-1} + \eta_t^R$
14	Inflation and RGDP Gap + FX + NIR	$\hat{r}_t = (1-\phi_R)\left[\hat{r}_t^n + \widehat{\widehat{\pi}}_t + \phi_\Pi\left(\hat{\pi}_t^C - \widehat{\widehat{\pi}}_t\right) + \phi_y\hat{y}_t^{GAP} + \phi_{\Delta S}\Delta S_t\right] + \phi_R\hat{r}_{t-1} + \eta_t^R$
15	Inflation and RGDP Gap	$\hat{r}_t = (1-\phi_R)\left[\widehat{rr}_t^{fwd} + \widehat{\widehat{\pi}}_t + \phi_\Pi\left(\hat{\pi}_t^C - \widehat{\widehat{\pi}}_t\right) + \phi_y\hat{y}_t^{GAP}\right] + \phi_R\hat{r}_{t-1} + \eta_t^R$
16	Inflation and RGDP Gap + NIR	$\hat{r}_t = (1-\phi_R)\left[\hat{r}_t^n + \widehat{\widehat{\pi}}_t + \phi_\Pi\left(\hat{\pi}_t^C - \widehat{\widehat{\pi}}_t\right) + \phi_y\hat{y}_t^{GAP}\right] + \phi_R\hat{r}_{t-1} + \eta_t^R$

- Rule **2** targets the NGDP growth, the nominal depreciation, and the model-based natural interest rate ($\hat{r}_t^n + \widehat{\overline{\pi}}_t$), where $\hat{r}_t^n$ is the real interest rate that would prevail under flexible prices (Galí, 2015). Because of the log form of the utility function used in MOISE, technology shock differences from $t+1$ to t can represent this natural interest rate.

- Rule **3** targets the NGDP growth and the forward-based natural interest rate.

- Rule **4** targets the NGDP growth and the model-based natural interest rate.

- Rule **5** targets the NGDP level $\left(p_t^Y + \hat{y}_t^{GAP}\right)$, where GDP deflator inflation $\hat{\pi}_t^Y = p_t^Y - p_{t-1}^Y$, the nominal depreciation, and the forward-based natural interest rate.

- Rule **6** targets the NGDP level, the nominal depreciation, and the model-based natural interest rate.

- Rule **7** targets the NGDP level and the forward-based natural interest rate.

- Rule **8** targets the NGDP level and the model-based natural interest rate.

4.2 Inflation Targeting Rules

- Rule **9** targets the inflation gap $\left(\hat{\pi}_t^C - \widehat{\overline{\pi}}_t\right)$, the output growth ($\Delta\hat{y}_t$), the nominal depreciation (ΔS_t), and the forward-based natural interest rate ($\widehat{rr}_t^{fwd} + \widehat{\overline{\pi}}_t$).

- Rule **10** targets the inflation gap, the output growth, the nominal depreciation, and the model-based natural interest rate.

- Rule **11** targets the inflation gap, the output growth, and the forward-based natural interest rate.

- Rule **12** targets the inflation gap, the output growth, and the model-based natural interest rate.

- Rule **13** targets the inflation gap, the output gap ($\hat{y}_t^{GAP}$), the nominal depreciation, and the forward-based natural interest rate.

- Rule **14** targets the inflation gap, the output gap, the nominal depreciation, and the model-based natural interest rate.

- Rule **15** targets the inflation gap, the output gap, and the forward-based natural interest rate.

- Rule **16** targets the inflation gap, the output gap, and the model-based natural interest rate.

4.3 Summary

As indicated in Table 1 and explained above, there are four groups of rules. Rules 1 to 4 target the growth of the NGDP. Rules 5 to 8 target the level of the NGDP. Rules 9 to 12 target CPI inflation and output growth, while rules 13 to 16 target CPI inflation and the output gap.

Rules 1, 2, 5, and 6 are hybrid NGDP targeting rules that also respond to the exchange rate. Flexible IT strategies are represented by rules 11, 12, 15, and 16, and hybrid IT strategies by rules 9, 10, 13, and 14. Odd-numbered rules target the forward-based natural rate, while even-numbered rules target the model-based natural rate.

Since these rules are all ad hoc, they do not require modifications to the core model. The models only differ from each other in their monetary policy rules. Concerning NGDP level targeting rules (models 5 to 8), we add to the core model and the monetary policy rule the definition of the price level, derived from $\hat{\pi}_t^Y = p_t^Y - p_{t-1}^Y$, where p_t^Y represents the log-price deflator index at time t.

5 Methodology

5.1 Data

To estimate the MOISE models, we use 24 time series that reflect the economic dynamics of the Israeli and foreign economies from 1994:Q1 to 2019:Q4.

- **Rate data**: long run forward nominal rate abroad (5-10 years); long run forward real rate (5-10 years); inflation target of the Bank of Israel; nominal interest rate.

- **Price data**: inflation in foreign price deflator; oil prices; nominal wage growth; inflation in market-price GDP deflator; inflation in factor price (no VAT and vegetables).

- **Production data**: per capita RGDP growth; per capita real consumption growth; per capita real investment growth (excluding inventories); ratio of the current account surplus to NGDP; per capita real government expenditures growth; worked hours (log difference); employment rate; consumption tax rate (VAT).

- **Open economy data**: foreign nominal interest rate; foreign demand growth; world import growth; inflation in export deflator (NIS terms); nominal depreciation rate; per capita real export growth; per capita real import growth.

These data are collected at the Bank of Israel and the Central Bureau of Statistics. Data detrending and transformations are the same as those detailed in Argov et al. (2012).

5.2 Calibration

To maintain consistency across models for comparison purposes, we calibrate all non-policy model parameter priors (i.e., except for the priors of the monetary policy rules) according to Argov et al. (2012). For all rules, the prior for the smoothing parameter, ϕ_R, is calibrated to 0.75. For the rules targeting the nominal depreciation rate (rules 1, 2, 5, 6, 9, 10, 13, and 14), the prior of the coefficient $\phi_{\Delta S}$ is calibrated to 0.2. For the rules targeting the NGDP growth (rules 1 to 4), the prior for ϕ_n is calibrated to 1.5, and for the rules targeting the NGDP level (rules 5 to 8), the prior for ϕ_n is calibrated to 0.5 (Rudebusch, 2002; Benchimol and Fourçans, 2019). For the flexible IT rules (rules 9 to 16), the prior for ϕ_Π is calibrated to 2.5, and ϕ_y to 0.2, corresponding to the estimates of Argov et al. (2012).

5.3 Estimation

The MOISE models are estimated using Bayesian techniques using the 24 macroeconomic series presented in Section 5.1 between 1994:Q1 and 2019:Q4.

To avoid undue complexity, we focus on analyzing the estimated parameters of the different monetary rules presented in Section 7. The estimation results of the other parameters are available in the Appendix B.

We achieve draw acceptance rates between 20% and 30% for each model and each period, without customizing the tuning parameter on the covariance matrix. Our results are obtained from the standard Metropolis-Hastings algorithm with 200 000 draws of 2 parallel chains, where 100 000 draws are used for burn-in.

We compute the 12-period ahead point and mean forecasts using the Kalman smoother to provide initial conditions for Monte Carlo simulations based on our Bayesian estimations. For the point forecasts, we draw vectors of parameters from the posterior distribution. To determine the initial condition of each vector with the smoother, we simulate the model by adding Gaussian innovations for the exogenous variables during the forecast. We obtain a posterior empirical distribution of the forecasts, from which we can compute different moments. The construction of mean forecasts follows the same approach except that future innovations are set to zero (i.e., we do not draw future innovations according to a normal distribution). The posterior distribution of the mean forecasts does not incorporate the uncertainty arising from the shocks. In every draw for every parameter vector, we draw parameters from the posterior distribution and iterate on the state space. Finally, the mean is taken over the draws.[13]

In addition to full sample estimates ($\mathbb{E}_T[L_t]$ where T is the full sample size and L_t is our variable of interest at time $t < T$), we also compute limited information estimates that only use information up to the current date t for inference ($\mathbb{E}_t[L_t]$) and are computed at the posterior mean with the standard Kalman smoother.

6 In-sample Fit

The in-sample fit is assessed to determine whether the estimated model fits historical data. Table 2 shows the estimated log marginal data densities. The Metropolis-Hastings-based sample of the posterior distribution is used to evaluate the marginal likelihood of the model, and we calculate the modified harmonic mean to evaluate the integral over the posterior sample following Geweke (1999).

According to Table 2, the IT rule targeting the inflation gap, the output gap, the nominal depreciation, and the model-based natural interest rate best fits the historical data during the last three decades (rule 14). A rule targeting the inflation gap, the output growth, and the forward-based natural interest rate is the worst in terms of in-sample fitting (rule 11), as far as IT rules are concerned.

Among the NGDP rules group, the rule targeting the NGDP growth, the nominal depreciation, and the model-based natural interest rate (rule 2) best fits the historical data, whereas a rule targeting the NGDP level and the model-based

[13]This method is different from frequentist econometrics, where we iterate on the state space equation for the single mean parameter vector to recover the forecast uncertainty related to the future innovations (iteration on the covariance matrix of the innovations). The Bayesian approach considers the uncertainty related to the inference more easily (i.e., the posterior distribution of the parameters), especially if the model is nonlinear with respect to the parameters.

Table 2. Log Marginal Data Density - Full Sample

Targeting	*Rules*							
	1	2	3	4	5	6	7	8
NGDP	7707.9	**7709.4**	7683.7	7688.0	7662.1	7672.5	7654.9	7650.2
	9	10	11	12	13	14	15	16
IT	7732.9	7742.0	7731.2	7734.2	7742.1	**7742.7**	7741.6	7742.0

Notes: bold (underlined) numbers represent the highest (lowest) log marginal data density for each monetary policy rule type.

natural interest rate (rule 8) performs worst.

Rule 14 replicates the historical interest rate better than rule 2 over the full sample. Additional results show that rule 8 replicated better historical interest rates than other rules after the GFC[14] (Section 3). This indicates that the Bank of Israel may have followed an NGDP level targeting rule after the GFC rather than an IT rule.

7 Monetary Rule Parameters

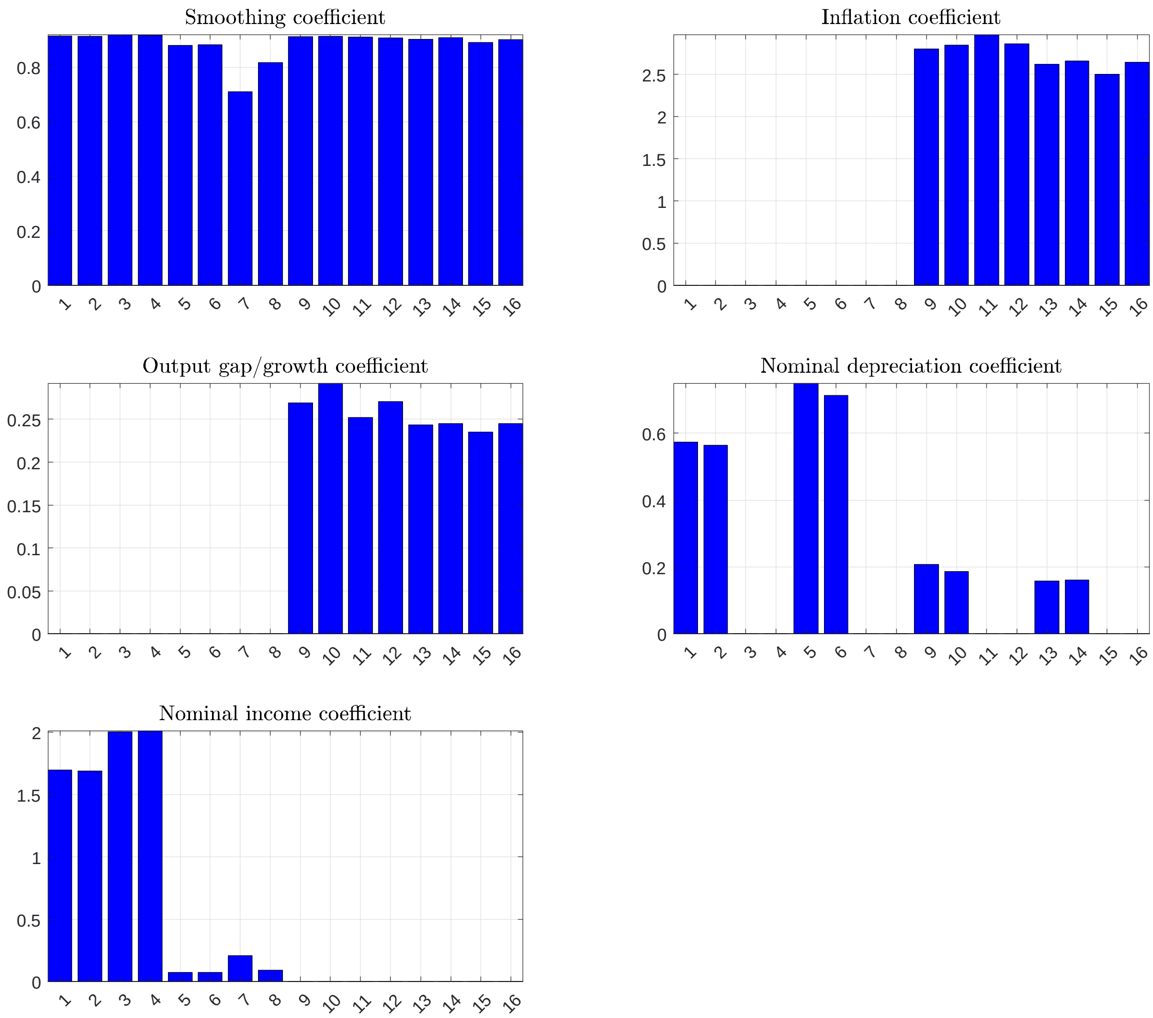
Figure 4 presents the results of the estimated coefficients of the rules presented in Section 4 across the entire sample.

Figure 4 shows that the estimated parameters are relatively stable among the models. Only rule 7 displays a low but plausible smoothing coefficient. The other parameters are consistent with the literature. As explained in Rudebusch (2002), ϕ_n is higher than one for NGDP growth targeting rules, and is positive and smaller than one for NGDP level targeting rules. The NGDP level parameters are close to 0.2 in Figure 4, which is close to the value estimated for the US between 2007 and 2017 (Benchimol and Fourçans, 2019).

IT rule coefficients for Israel are in line with the literature (Argov et al., 2012; Benchimol, 2016). Interestingly, NGDP targeting rules react more strongly to exchange rate changes than IT rules. Indeed, NGDP targeting considers more (nominal) output than IT, making NGDP rules more sensitive to economic fluctuations and, therefore, nominal depreciation. During downturns, NGDP targeting allows for looser monetary policy (e.g., weaker currency) than IT, hence the higher sensitivity to exchange rate changes.

[14] Additional results are available upon request.

Figure 4. Estimated Coefficients of the Rules



8 Central Bank Losses

In this section, we present several loss measures based on the variance of the variables of interest from the central bank's perspective. These variances are estimated for each model and for each period. Our methodology intends to summarize all standard possibilities of central bank loss functions, commonly used in the literature (Svensson and Williams, 2009; Taylor and Wieland, 2012; Adolfson et al., 2014). We compute ex-post loss functions according to estimated DSGE models in Section 4 for various sets of policy objectives. This approach is used in the literature to investigate empirical monetary policy rules (Taylor, 1979; Fair and Howrey, 1996; Taylor, 1999; Svensson, 2003b) and is different from the optimal monetary policy literature (Schmitt-Grohé and Uribe, 2007; Billi, 2017; Benchimol and Bounader, 2023).

In accordance with the literature (Jensen, 2002; Garín et al., 2016; Billi, 2017) and given our research question, we consider ad hoc loss functions that are not necessarily derived from household utility. This ad hoc methodology can be preferable to the micro-founded methodology, as illustrated in Clarida et al. (1999): if some groups suffer more than others from certain distortions, then an agent's utility might not provide an accurate measure of cyclical fluctuations in welfare.

Our general central bank loss function, L_t, is defined as[15]

$$L_t = var\left(\hat{\pi}_t\right) + \lambda_y var\left(\hat{y}_t^{GAP}\right), \tag{6}$$

where $var\left(.\right)$ is the variance operator, $\hat{\pi}_t \in \left\{\hat{\pi}_t^Y, \hat{\pi}_t^C, \hat{\pi}_t^H\right\}$ is the price inflation of various types, $\hat{y}_t^{GAP}$ the output gap, and λ_y the weight on output gap variances the policymaker would choose. $\hat{\pi}_t^H$ is the domestic intermediate good inflation, presented in Appendix A (Eq. 21). The weight on price inflation variance is normalized to unity.

Through the remainder of this section, we examine a spectrum of possible values for λ_y in order to analyze the central bank's loss function under full and limited information (Section 8.1 and 8.2, respectively).

8.1 Full Information

In this subsection, we present the estimation results, assuming all the information available in the full sample is known. Table 3 presents the loss for each model and variable according to the estimated variance across the full sample.

Table 3 shows that as far as GDP deflator inflation ($\hat{\pi}_t^Y$), domestic intermediate good inflation ($\hat{\pi}_t^H$), and GDP gap ($\hat{y}_t^{GAP}$) are concerned, NGDP level targeting rules lead to lower estimated variances compared to other rules. CPI inflation ($\hat{\pi}_t^C$) variance is best minimized by IT rules targeting RGDP growth instead of the output gap. NGDP level targeting and IT rules perform similarly as far as nominal depreciation (ΔS_t) and output growth ($\Delta \hat{y}_t$) are concerned.

The results differ in the variance of simulated impulse response functions (IRF), since it depends on the type of shocks. Table 4 presents the loss for each model and variable according to the IRF-based variances for different types of

[15] See Galí (2015) for further details. Another loss measure based on the squared distance of variables generated by the models can be defined as

$$L_t = \pi_t^2 + \lambda_y \left(\hat{y}_t^{GAP}\right)^2. \tag{5}$$

According to the variance operator definition, this type of formulation results in the same ranking as Eq. 6.

Table 3. Estimated Variances

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$	0.14	0.15	0.24	0.23	0.12	0.17	0.13	0.16	0.14	0.14	0.15	0.15	0.17	0.19	0.18	0.20
$\hat{\pi}_t^C$	0.12	0.13	0.22	0.21	0.14	0.15	0.14	0.13	0.08	0.08	0.08	0.08	0.12	0.14	0.14	0.15
$\hat{\pi}_t^H$	0.09	0.10	0.16	0.15	0.06	0.13	0.06	0.10	0.09	0.09	0.09	0.09	0.12	0.13	0.13	0.14
$\hat{y}_t^{GAP}$	0.04	0.04	0.04	0.04	0.05	0.04	0.05	0.03	0.04	0.04	0.04	0.04	0.03	0.04	0.03	0.03
$\Delta\hat{y}_t$	0.34	0.34	0.35	0.34	0.33	0.42	0.32	0.37	0.39	0.40	0.39	0.39	0.32	0.33	0.32	0.33
ΔS_t	0.88	0.88	1.49	1.45	1.11	0.76	1.26	1.30	0.74	0.76	0.84	0.85	0.81	0.85	0.88	0.93

Notes: Losses are based on estimated variance from the Bayesian estimation for each rule (1 to 16). The shading scheme is defined independently for each row, where lighter shading indicates lower losses (rescaled numbers).

shocks.

Table 4 highlights the high performance of NGDP level targeting rules in mitigating GDP deflator and CPI inflation variances following domestic and foreign price markup shocks.[16] For instance, rule 6 (NGDP level targeting) minimizes output growth, nominal depreciation, GDP deflator and CPI inflation variances following a foreign price markup shock. IT rules also perform well in minimizing GDP deflator inflation and CPI inflation variances, while NGDP level rules minimize domestic intermediate good inflation, output gap and growth, and nominal depreciation variances, following a consumption preference shock. Following a productivity shock, NGDP growth targeting rules perform well in minimizing output growth and nominal depreciation variances, while the variances of other variables are minimized similarly by both types of rules. This may reflect the stabilization properties of NGDP rules compared to IT rules (Hendrickson, 2012; Beckworth and Hendrickson, 2020).

Table 5 shows the full sample estimated losses from a spectrum of central bank loss functions.[17]

Given objectives that minimize the variance of domestic intermediate good inflation ($\hat{\pi}_t^H$) and GDP deflator inflation ($\hat{\pi}_t^Y$), estimated loss is significantly lower under NGDP level targeting rules 5 and 7 than under other rules. IT rules with output growth targeting perform well for the CPI inflation ($\hat{\pi}_t^C$) objective, especially rule 9. The best rules from this targeting regime also appear to target the nominal depreciation. However, these loss functions are estimated by assuming that the central bank knows all of the information available in the (full) sample ($\mathbb{E}_T [L_t]$), and does not consider specific responses of inflation and the output gap following a price-markup shock, critical to central bank policies.

As discussed in the literature (Steinsson, 2003; Baeriswyl and Cornand, 2010; Garín et al., 2016), we can assess the loss responses following a price markup shock. Table 6 presents the IRF-based losses following a positive shock to domestic and foreign price markup, productivity and consumption preferences for a spectrum of central bank loss functions.

The IRF-based losses presented in Table 6 point to the superiority of rule 3 for most policymaker preferences regarding domestic price markup shocks. Rule 11 also performs well for GDP deflator inflation, but the results are not significantly different from rule 3.

If the central bank seeks to stabilize the different measures of inflation, and

[16]Only positive shocks are considered. Due to the linearity of the MOSIE model, results should not differ for negative shocks.

[17]If the full sample contains T periods, Table 5 considers $\mathbb{E}_T [L_t]$, which corresponds to estimations over the full information set.

Table 4. Impulse Response-Based Variances

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$	0.29	0.25	0.48	0.32	0.22	0.22	0.25	0.08	0.20	0.16	0.19	0.15	0.15	0.12	0.14	0.11
$\hat{\pi}_t^C$	0.16	0.13	0.27	0.17	0.03	0.18	0.04	0.07	0.08	0.05	0.07	0.05	0.04	0.03	0.04	0.02
$\hat{\pi}_t^H$	0.35	0.35	0.55	0.43	0.34	0.40	0.37	0.28	0.31	0.30	0.31	0.30	0.27	0.27	0.26	0.26
$\hat{y}_t^{GAP}$	0.04	0.04	0.06	0.05	0.04	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
$\Delta\hat{y}_t$	0.18	0.36	0.29	0.43	0.79	0.63	0.81	0.92	0.24	0.46	0.25	0.48	0.30	0.58	0.31	0.61
ΔS_t	0.02	0.15	0.04	0.17	1.05	1.00	1.13	2.45	0.15	0.56	0.20	0.65	0.40	0.99	0.47	1.14

Productivity Shock

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$	0.06	0.06	0.12	0.11	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01
$\hat{\pi}_t^C$	0.04	0.04	0.09	0.09	0.03	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
$\hat{\pi}_t^H$	0.03	0.03	0.08	0.07	0.00	0.04	0.00	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.01	0.02
$\hat{y}_t^{GAP}$	0.09	0.09	0.10	0.10	0.05	0.10	0.04	0.08	0.09	0.09	0.09	0.09	0.07	0.07	0.07	0.07
$\Delta\hat{y}_t$	4.49	4.42	4.59	4.41	3.55	5.21	3.40	4.87	4.82	4.76	4.76	4.71	4.39	4.30	4.32	4.25
ΔS_t	0.57	0.60	0.77	0.89	0.58	0.01	0.54	0.04	0.04	0.05	0.05	0.05	0.20	0.21	0.23	0.23

Consumption Preference Shock

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$	1.93	1.90	1.50	1.80	4.51	2.02	4.62	2.40	1.52	1.53	1.47	1.48	1.83	1.86	1.81	1.82
$\hat{\pi}_t^C$	1.17	1.15	0.91	1.10	2.64	1.22	2.73	1.48	0.94	0.95	0.92	0.93	1.13	1.15	1.11	1.13
$\hat{\pi}_t^H$	2.74	2.70	2.11	2.57	6.23	2.89	6.39	3.49	2.67	2.70	2.69	2.71	3.09	3.11	3.11	3.11
$\hat{y}_t^{GAP}$	0.04	0.04	0.03	0.04	0.13	0.04	0.13	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.04	0.04
$\Delta\hat{y}_t$	1.10	1.07	0.82	0.97	3.19	1.11	3.25	1.42	1.45	1.45	1.51	1.49	1.47	1.43	1.51	1.46
ΔS_t	0.02	0.02	0.02	0.02	0.03	0.00	0.03	0.00	0.42	0.43	0.55	0.53	0.52	0.47	0.62	0.56

Domestic Price Markup Shock

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$	0.27	0.30	0.32	0.33	0.46	0.17	0.49	0.28	0.74	0.76	0.82	0.84	0.80	0.78	0.89	0.86
$\hat{\pi}_t^C$	5.18	5.68	5.97	5.97	7.59	3.67	8.05	5.62	4.75	4.80	4.68	4.75	4.76	4.81	4.78	4.82
$\hat{\pi}_t^H$	0.13	0.15	0.16	0.16	0.31	0.16	0.35	0.25	0.09	0.10	0.09	0.10	0.11	0.12	0.11	0.12
$\hat{y}_t^{GAP}$	0.02	0.03	0.03	0.03	0.04	0.02	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
$\Delta\hat{y}_t$	1.35	1.50	1.66	1.65	1.85	1.00	1.90	1.51	1.19	1.21	1.18	1.20	1.18	1.20	1.17	1.19
ΔS_t	0.07	0.07	0.11	0.12	0.06	0.00	0.07	0.01	2.29	2.40	2.86	2.88	2.95	2.80	3.45	3.27

Foreign Price Markup Shock

Notes: Losses are based on variances of the IRFs computed over 40 periods after the Bayesian estimation over the full sample for each rule (1 to 16). Shock processes are defined in Argov et al. (2012). The shock size estimates are available in Appendix B. The shading scheme is defined independently for each row, where lighter shading indicates lower losses (rescaled numbers).

Table 5. Loss Functions - Estimated Variances

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$ $\lambda_y=0.0$	1.44	1.49	2.44	2.28	1.20	1.72	1.31	1.63	1.43	1.43	1.47	1.46	1.73	1.86	1.84	1.97
$\hat{\pi}_t^Y$ $\lambda_y=0.5$	1.64	1.69	2.66	2.48	1.46	1.94	1.57	1.79	1.64	1.65	1.68	1.68	1.90	2.04	2.00	2.14
$\hat{\pi}_t^Y$ $\lambda_y=1.0$	1.84	1.89	2.88	2.68	1.72	2.16	1.83	1.96	1.86	1.87	1.90	1.90	2.07	2.22	2.17	2.31
$\hat{\pi}_t^C$ $\lambda_y=0.0$	1.22	1.28	2.23	2.12	1.42	1.45	1.42	1.35	0.77	0.79	0.81	0.82	1.24	1.38	1.36	1.48
$\hat{\pi}_t^C$ $\lambda_y=0.5$	1.42	1.48	2.45	2.32	1.69	1.68	1.68	1.51	0.98	1.00	1.03	1.04	1.42	1.55	1.53	1.65
$\hat{\pi}_t^C$ $\lambda_y=1.0$	1.62	1.68	2.67	2.52	1.95	1.90	1.94	1.67	1.20	1.22	1.24	1.26	1.59	1.73	1.69	1.83
$\hat{\pi}_t^H$ $\lambda_y=0.0$	0.93	0.99	1.63	1.50	0.64	1.31	0.65	0.98	0.89	0.91	0.89	0.90	1.20	1.34	1.28	1.41
$\hat{\pi}_t^H$ $\lambda_y=0.5$	1.13	1.19	1.85	1.70	0.91	1.53	0.91	1.15	1.10	1.13	1.10	1.12	1.37	1.52	1.44	1.58
$\hat{\pi}_t^H$ $\lambda_y=1.0$	1.33	1.39	2.07	1.90	1.17	1.75	1.17	1.31	1.32	1.34	1.32	1.34	1.54	1.69	1.61	1.76

Notes: Central bank losses from estimated variances, for each rule (1 to 16) over the full sample. The shading scheme is defined independently for each row, where lighter shading indicates lower losses.

Table 6. Impulse Response-Based Loss Functions

Productivity Shock

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$ λ_y=0.0	2.86	2.51	4.82	3.24	2.16	2.19	2.51	0.84	2.02	1.59	1.93	1.49	1.48	1.17	1.38	1.07
$\hat{\pi}_t^Y$ λ_y=0.5	3.07	2.72	5.09	3.50	2.35	2.36	2.69	0.99	2.18	1.76	2.09	1.65	1.62	1.31	1.52	1.21
$\hat{\pi}_t^Y$ λ_y=1.0	3.28	2.93	5.37	3.75	2.53	2.53	2.87	1.14	2.35	1.92	2.25	1.82	1.77	1.45	1.67	1.35
$\hat{\pi}_t^C$ λ_y=0.0	1.56	1.28	2.73	1.69	0.31	1.82	0.44	0.66	0.81	0.53	0.73	0.47	0.43	0.28	0.37	0.24
$\hat{\pi}_t^C$ λ_y=0.5	1.77	1.49	3.01	1.94	0.50	1.99	0.61	0.81	0.97	0.69	0.89	0.63	0.57	0.43	0.51	0.38
$\hat{\pi}_t^C$ λ_y=1.0	1.97	1.69	3.28	2.20	0.68	2.16	0.79	0.96	1.14	0.86	1.05	0.80	0.72	0.57	0.65	0.52
$\hat{\pi}_t^H$ λ_y=0.0	3.54	3.52	5.54	4.26	3.41	4.00	3.74	2.82	3.09	3.02	3.08	2.97	2.72	2.72	2.64	2.65
$\hat{\pi}_t^H$ λ_y=0.5	3.75	3.72	5.82	4.51	3.60	4.17	3.92	2.96	3.26	3.18	3.24	3.14	2.86	2.86	2.78	2.79
$\hat{\pi}_t^H$ λ_y=1.0	3.96	3.93	6.09	4.76	3.78	4.35	4.09	3.11	3.42	3.35	3.41	3.30	3.01	3.01	2.93	2.93

Consumption Preference Shock

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$ λ_y=0.0	0.06	0.06	0.12	0.11	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01
$\hat{\pi}_t^Y$ λ_y=0.5	0.10	0.10	0.17	0.16	0.04	0.08	0.04	0.07	0.07	0.07	0.07	0.07	0.05	0.05	0.04	0.04
$\hat{\pi}_t^Y$ λ_y=1.0	0.14	0.14	0.22	0.21	0.07	0.13	0.06	0.11	0.11	0.11	0.11	0.11	0.08	0.08	0.08	0.08
$\hat{\pi}_t^C$ λ_y=0.0	0.04	0.04	0.09	0.09	0.03	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
$\hat{\pi}_t^C$ λ_y=0.5	0.08	0.08	0.14	0.13	0.05	0.06	0.04	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05
$\hat{\pi}_t^C$ λ_y=1.0	0.12	0.12	0.19	0.18	0.07	0.11	0.06	0.10	0.10	0.10	0.10	0.10	0.08	0.08	0.08	0.08
$\hat{\pi}_t^H$ λ_y=0.0	0.03	0.03	0.08	0.07	0.00	0.04	0.00	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.01	0.02
$\hat{\pi}_t^H$ λ_y=0.5	0.07	0.08	0.13	0.12	0.02	0.10	0.02	0.08	0.07	0.07	0.07	0.07	0.05	0.05	0.05	0.05
$\hat{\pi}_t^H$ λ_y=1.0	0.12	0.12	0.18	0.16	0.05	0.15	0.04	0.12	0.12	0.12	0.12	0.12	0.09	0.09	0.08	0.08

Domestic Price Markup Shock

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$ λ_y=0.0	1.93	1.90	1.50	1.80	4.51	2.02	4.62	2.40	1.52	1.53	1.47	1.48	1.83	1.86	1.81	1.82
$\hat{\pi}_t^Y$ λ_y=0.5	1.95	1.92	1.52	1.82	4.58	2.04	4.69	2.42	1.54	1.55	1.49	1.51	1.85	1.88	1.83	1.84
$\hat{\pi}_t^Y$ λ_y=1.0	1.97	1.94	1.53	1.84	4.65	2.05	4.76	2.45	1.56	1.57	1.52	1.53	1.87	1.90	1.85	1.87
$\hat{\pi}_t^C$ λ_y=0.0	1.17	1.15	0.91	1.10	2.64	1.22	2.73	1.48	0.94	0.95	0.92	0.93	1.13	1.15	1.11	1.13
$\hat{\pi}_t^C$ λ_y=0.5	1.18	1.17	0.92	1.12	2.71	1.24	2.79	1.50	0.96	0.97	0.94	0.95	1.15	1.17	1.14	1.15
$\hat{\pi}_t^C$ λ_y=1.0	1.20	1.18	0.94	1.14	2.78	1.26	2.86	1.52	0.99	1.00	0.96	0.97	1.17	1.19	1.16	1.17
$\hat{\pi}_t^H$ λ_y=0.0	2.74	2.70	2.11	2.57	6.23	2.89	6.39	3.49	2.67	2.70	2.69	2.71	3.09	3.11	3.11	3.11
$\hat{\pi}_t^H$ λ_y=0.5	2.76	2.72	2.12	2.59	6.30	2.91	6.46	3.52	2.69	2.72	2.71	2.73	3.11	3.14	3.13	3.13
$\hat{\pi}_t^H$ λ_y=1.0	2.78	2.74	2.14	2.61	6.36	2.93	6.53	3.54	2.71	2.75	2.73	2.75	3.14	3.16	3.15	3.15

Foreign Price Markup Shock

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$ λ_y=0.0	0.03	0.03	0.03	0.03	0.05	0.02	0.05	0.03	0.07	0.08	0.08	0.08	0.08	0.08	0.09	0.09
$\hat{\pi}_t^Y$ λ_y=0.5	0.03	0.03	0.03	0.03	0.05	0.02	0.05	0.03	0.07	0.08	0.08	0.08	0.08	0.08	0.09	0.09
$\hat{\pi}_t^Y$ λ_y=1.0	0.03	0.03	0.03	0.04	0.05	0.02	0.05	0.03	0.08	0.08	0.08	0.09	0.08	0.08	0.09	0.09
$\hat{\pi}_t^C$ λ_y=0.0	0.52	0.57	0.60	0.60	0.76	0.37	0.81	0.56	0.48	0.48	0.47	0.48	0.48	0.48	0.48	0.48
$\hat{\pi}_t^C$ λ_y=0.5	0.52	0.57	0.60	0.60	0.76	0.37	0.81	0.56	0.48	0.48	0.47	0.48	0.48	0.48	0.48	0.48
$\hat{\pi}_t^C$ λ_y=1.0	0.52	0.57	0.60	0.60	0.76	0.37	0.81	0.56	0.48	0.48	0.47	0.48	0.48	0.48	0.48	0.48
$\hat{\pi}_t^H$ λ_y=0.0	0.01	0.01	0.02	0.02	0.03	0.02	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
$\hat{\pi}_t^H$ λ_y=0.5	0.01	0.02	0.02	0.02	0.03	0.02	0.04	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
$\hat{\pi}_t^H$ λ_y=1.0	0.02	0.02	0.02	0.02	0.03	0.02	0.04	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Notes: Central bank losses following a positive domestic and foreign price markup, productivity and consumption preference shock, based on variances of the IRFs computed over 40 periods after the Bayesian estimation over the full sample for each rule (1 to 16). Shock processes are defined in Argov et al. (2012). The shock size estimates are available in Appendix B. The shading scheme is defined independently for each row, where lighter shading indicates lower losses (rescaled numbers).

assuming the central bank knows all the information in the (full) sample to estimate their economic models, an NGDP growth targeting should outperform alternatives following domestic price markup shocks.

Table 6 highlights that NGDP level targeting stabilizes central bank loss functions based on GDP deflator and CPI inflation rates better than IT rules following a foreign price markup shock (i.e., import or international price shocks), key for SOEs like Israel. An increase in the world price of imported goods is one form of terms of trade shock, with oil prices being a good example for Israel. By definition, targeting the exchange rate prevents the currency from depreciating, which results in adverse trade balance and GDP consequences. For CPI targeting to be effective, the currency must appreciate to avoid a rise in CPI inflation, which would severely affect trade balances and growth. Contrary to this, NGDP targeting does not cause currency appreciation. The adverse shock is split between inflation and RGDP growth rather than growth alone.

Following Garín et al. (2016), we can measure the central bank loss functions following demand and supply shocks. To this end, we analyze the responses of central bank losses following a productivity shock (supply shock) and a consumption preference shock (demand shock).

Table 6 shows that, following a productivity shock, IT rules minimize domestic intermediate good price variance better than NGDP rules, except when the policymaker includes the GDP deflator inflation in his loss function. In that case, rule 8 (NGDP level targeting) best minimizes central bank losses. As inflation should decrease following a positive productivity (technology) shock, IT implies that monetary policy must be eased enough to counter any price decrease, leading to higher RGDP growth. When NGDP is targeted, inflation and RGDP growth are equally considered, thereby mitigating the central bank's reaction to a productivity shock. Unlike emerging markets where NGDP targeting should outperform IT following supply shocks (Frankel, 2014; Bhandari and Frankel, 2017), Table 6 shows that it depends on the policymaker's loss function, and that the flexibility of IT is not sufficient for countering the shock when GDP deflator inflation is considered in the loss function.

Table 6 shows that following consumption preference shocks, NGDP level targeting rules are generally effective at minimizing loss functions for almost all inflation objectives (except for $\hat{\pi}_t^Y$ and $\hat{\pi}_t^C$ when $\lambda_y = 0$). To offset the price and output effects of a negative aggregate demand shock, central bank policymakers generally lower the policy interest rate to stimulate aggregate demand. In the face of demand shocks, path targets for either the price level or NGDP are attractive because they lead to faster recovery after a recession (Bean, 1983; Fackler and McMillin, 2020). Despite targeting inflation, between 1 and 3 percent, the Bank of Israel has effectively stabilized the NGDP level path over the past decade. Demand shocks in Israel have not adversely affected growth.

Appendix C presents counterfactual analyses under full information using the best-fit model. The posteriors from the best-fit model are used as the experimental framework. By filtering the model under posterior draws using the best-fit rule (Rule 14), shock sequences are generated for an identical model operating outside of a new monetary policy rule. By comparing counterfactual measures of output and inflation variances, we assess the potential enhancement offered by alternative monetary policies. This process is simulated across multiple posterior draws, generating a distribution of outcomes for each potential alternative rule. These simulations show that NGDP rules are not necessarily rejected and sometimes provide the best alternative to Taylor-type rules.

Appendix D presents the results of the reestimations of the models over the pre-ZLB period (1994-2015) to test the robustness of the full sample results presented in this section, and how the absence of the ZLB period changes our main results. The results indicate that controlling for the ZLB does not significantly change the results obtained over the full sample.

Appendix D presents the results of re-estimating the models over the pre-ZLB period (1994-2015) to assess the robustness of the full-sample results. The results show that controlling for the ZLB period does not affect our main conclusions.

8.2 Limited Information

NGDP targeting rules could produce lower volatility in both inflation and the output gap in comparison with IT rules under limited information (Beckworth and Hendrickson, 2020). Consequently, we estimate the expected value of our models' variables given the information available at the current date t.

Table 7 presents the estimations of the expected value of loss functions given the information available at the current date ($\mathbb{E}_t [L_t]$).

Under this limited information setup, NGDP level targeting rules appear to minimize all central bank loss functions. This result is important for several reasons. First, limited information estimates only use information up to the current date t, which is the case for real-world policymakers. Central bank modelers do not know the next period when they estimate their decision models. Second, although rules 5 to 7 do not best replicate the historical data, they perform best under limited information. This indicates the potential usefulness of NGDP level targeting rules for real-world decision-making.

Controlling for the ZLB and under limited information, NGDP level targeting

Table 7. Loss Functions - Estimated Variances Under Limited Information

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$ λ_y=0.0	1.14	1.14	1.24	1.24	0.86	1.13	0.90	1.10	1.18	1.18	1.20	1.20	1.17	1.18	1.18	1.19
$\hat{\pi}_t^Y$ λ_y=0.5	1.19	1.19	1.31	1.31	0.95	1.15	1.01	1.25	1.22	1.23	1.24	1.25	1.19	1.20	1.20	1.21
$\hat{\pi}_t^Y$ λ_y=1.0	1.24	1.24	1.37	1.39	1.04	1.18	1.11	1.39	1.27	1.28	1.29	1.29	1.21	1.22	1.23	1.24
$\hat{\pi}_t^C$ λ_y=0.0	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
$\hat{\pi}_t^C$ λ_y=0.5	0.92	0.92	0.93	0.94	0.95	0.89	0.97	1.01	0.91	0.91	0.91	0.91	0.89	0.88	0.89	0.89
$\hat{\pi}_t^C$ λ_y=1.0	0.97	0.97	0.99	1.01	1.04	0.91	1.07	1.15	0.95	0.96	0.95	0.96	0.91	0.91	0.91	0.91
$\hat{\pi}_t^H$ λ_y=0.0	0.76	0.77	0.79	0.80	0.45	0.72	0.46	0.67	0.79	0.80	0.80	0.80	0.80	0.80	0.80	0.81
$\hat{\pi}_t^H$ λ_y=0.5	0.82	0.82	0.85	0.87	0.53	0.74	0.56	0.81	0.83	0.84	0.84	0.85	0.82	0.82	0.82	0.83
$\hat{\pi}_t^H$ λ_y=1.0	0.87	0.88	0.92	0.95	0.62	0.77	0.66	0.96	0.87	0.89	0.89	0.90	0.84	0.85	0.85	0.86

Notes: Central bank losses from the estimated variances under limited information, for each rule (1 to 16). The shading scheme is defined independently for each row, where lighter shading indicates lower losses.

rules remain the preferred regimes over various inflation measures and central bank losses (Appendix D).

9 Policy Implications

In order to achieve its objectives, a central bank cannot always follow a single rule. There is a preferred monetary policy reaction function for each period (Benchimol and Fourçans, 2017, 2019) and context (Kazinnik and Papell, 2021; Benchimol and Bounader, 2023). A given central bank reaction function performs better than others for each type of period (stable, crisis, recovery) and shock. In general, however, looking at various central bank loss functions, our results indicate the superiority of NGDP level targeting rules for Israel even though some IT rules produce good results for some loss functions and best match the full sample economic dynamics.

These results may indicate that the flexible IT operated during the last decades would have been changed if alternative rules had been considered. This does not necessarily assume the MOISE model perfectly reflects the Israeli economic dynamics, as the comparison was held among the same model's structure and calibration. Yet, our findings suggest that NGDP level targeting rules should be considered in future assessments of any monetary policy framework.

Parameter estimates vary based on the period and rule considered. Forecasts and recommendations made by policy institutions based on such models should be updated and completed regularly to reflect the variety of plausible alternative outcomes. In accordance with Wieland et al. (2012), our analysis demonstrates the need for central bank examinations of multiple monetary policies to back their decisions on a broader set of outcomes rather than a single model or rule.

Most central banks use DSGE models with IT monetary policy rules. In addition, it is standard practice to assume that a central bank attempts to minimize a loss function that includes at least inflation and output variances. Does this minimization process always and necessarily result in a flexible IT regime? Our results indicate that this may not be the case. When minimization of a loss function of the estimated variance over the full sample is required, some IT rules perform well. When minimization of a loss function is under full or limited information is considered, NGDP level targeting is often the most effective monetary policy rule, especially when information is limited, as it is in practice.

The finding that NGDP level targeting rules outperform others in a limited information setting suggests their potential utility in guiding real-world decision-making and supports the generalizability of these rules across various economic conditions. This mirrors the inherent uncertainty faced by policymakers who lack knowledge of future periods when formulating their strategies, enhancing their appeal for policymakers who must contend with changing economic landscapes and evolving information sets.

Lastly, our loss functions consider various inflation types, while our NGDP targeting models consider GDP deflator inflation and IT models the CPI inflation. Our results are thus robust to the policymaker preferences regarding the inflation component in the central bank objective.

In summary, as far as using a monetary policy rule is crucial (e.g., commitment), NGDP level targeting rules should be the most frequently recommended, especially during periods of crisis and instability, while some IT rules may also perform well during more stable times. According to the risk-sharing theory of NGDP outlined in the literature, NGDP gap differences among countries are related to financial stability (Azariadis et al., 2019; Bullard and DiCecio, 2021). Providing the policymaker with robust decision scenarios requires a regular recalculation of the models and parameters as well as the consideration of alternative rules and loss functions.

10 Conclusion

Several conclusions can be drawn from this study. First, an IT rule that also targets the output gap, the micro-founded natural interest rate, and the nominal depreciation is the most appropriate reaction function when data-matching to the last three decades of Israeli economic dynamics is considered. Second, the various central bank objectives are well achieved with NGDP targeting versus flexible IT under full information. Third, NGDP-level targeting rules are the most desirable rules under limited information and are recommended to policymakers since they do not have complete information about future data during their decision-making process.

In addition, we demonstrate that central bank objectives cannot always be achieved by one single rule, depending on the type of shock (productivity, consumption preference, domestic or foreign price markup) or central bank objective (CPI, GDP deflator, or domestic intermediate good inflation). For this reason, central banks, which base their forecasts and policy recommendations on such models and rules, should regularly update their estimates: Regular model evaluation and updating favor robust policy analysis and disciplined forecasting. These central bank loss estimates should consider full and limited information setups and several empirical monetary policy rules to assess the spectrum of interest rate decisions and paths.

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11 Appendix

A Log-linearized Model

This appendix presents most of the log-linearized system of equations constituting the MOISE model.

A.1 Households' Choice of Allocations

The marginal utility from consumption is

$$\hat{\lambda}_t = -\frac{1}{1-\kappa/g_z}\,\hat{c}_t + \frac{\kappa/g_z}{1-\kappa/g_z}\,\hat{c}_{t-1} - \frac{\kappa/g_z}{1-\kappa/g_z}\,\hat{g_{z,t}} - \frac{1}{1+0.78\,\tau^c}\,\hat{\tau}_t^C + \hat{\epsilon}_t^C, \quad (7)$$

where $\hat{\lambda}_t$ is the Lagrange multiplier on the budget constraint, $\hat{c}_t$ is real consumption, $\hat{g_{z,t}}$ is the labor productivity growth rate, $\hat{\tau}_t^C$ is the rate of value added tax (VAT), and $\hat{\epsilon}_t^C$ is the consumption preference shock. κ is the degree of external habit persistence, g_z is the long-run productivity growth rate (steady-state of $g_{z,t}$), and τ^c is the long run VAT (steady-state of $\hat{\tau}_t^C$).

The first-order condition with respect to capital (Tobin's Q) is

$$\begin{aligned}\hat{Q}_t \;=\;& \frac{\beta\,(1-\delta)}{g_z}\mathbb{E}_t\left[\hat{Q}_{t+1}\right] + \mathbb{E}_t\left[\hat{\lambda}_{t+1}\right] - \hat{\lambda}_t - \mathbb{E}_t\left[\hat{g}_{z,t+1}\right] \\ & - \frac{\beta\,\left(1-\tau^K\right)\,\gamma_{u,1}}{g_z}\mathbb{E}_t\left[\frac{1}{1-\tau^K}\,\hat{\tau}_{t+1}^K - \hat{r}_{k,t+1}\right] + \frac{\beta\,\delta}{g_z}\mathbb{E}_t\,\left[\hat{\tau}_{t+1}^K + \tau^K\,\hat{p}_{I,t+1}\right] \quad (8)\end{aligned}$$

where $\hat{\tau}_t^K$ is the capital income tax, $\hat{r}_{k,t}$ is the rate on capital utilization, and $\hat{p}_{I,t}$ is the price of the investment good. β is the static discount factor, δ is the depreciation rate of capital, τ^K is the tax rate on net capital income, and $\gamma_{u,1}$ is the capital-utilization cost.

The first-order condition with respect to investment is

$$\begin{aligned}
\hat{\imath}_t \;=\; & \frac{1}{1+(1-\omega_{\Gamma_I})^2\,\beta+\omega_{\Gamma_I}^2\,\beta^2}\begin{pmatrix} \omega_{\Gamma_I}\,\beta^2\,\mathbb{E}_t\left[\hat{\imath}_{t+2}\right]+(1-\omega_{\Gamma_I})\;\beta\;(1-\omega_{\Gamma_I}\,\beta)\,\mathbb{E}_t\left[\hat{\imath}_{t+1}\right] \\ +\,(1-\omega_{\Gamma_I})\;(1-\omega_{\Gamma_I}\,\beta)\;\hat{\imath}_{t-1}+\omega_{\Gamma_I}\,\hat{\imath}_{t-2} \end{pmatrix} \\
& +\frac{1}{1+(1-\omega_{\Gamma_I})^2\,\beta+\omega_{\Gamma_I}^2\,\beta^2}\begin{pmatrix} \omega_{\Gamma_I}\,\beta^2\,\mathbb{E}_t\left[\hat{g}_{z,t+2}\right]+\left(\omega_{\Gamma_I}^2\,\beta^2+(1-\omega_{\Gamma_I})\;\beta\right)\mathbb{E}_t\left[\hat{g}_{z,t+1}\right] \\ +\hat{g}_{z,t}\;(\beta\,\omega_{\Gamma_I}\;(1-\omega_{\Gamma_I})-1)+\omega_{\Gamma_I}\,\hat{g}_{z,t-1} \end{pmatrix} \\
& +\frac{1}{\left(1+(1-\omega_{\Gamma_I})^2\;\beta+\omega_{\Gamma_I}^2\,\beta^2\right)\;\gamma_I\,g_z^{2\,(1-\omega_{\Gamma_I})}}\left(\hat{Q}_t-\hat{p}_{I,t}+\hat{\epsilon}_t^I\right),
\end{aligned} \tag{9}$$

where $\hat{\imath}_t$ is real investment, $\hat{\epsilon}_t^I$ is the investment specific technology shock. ω_{Γ_I} is the weight of the investment adjustment cost, and γ_I is the investment adjustment cost.

The first-order condition with respect to capital utilization is

$$\hat{r}_{k,t}=\hat{p}_{I,t}+\frac{\gamma_{u,2}}{\gamma_{u,1}}\hat{u}_t, \tag{10}$$

where $\hat{u}_t$ is the intensity of capital utilization and $\gamma_{u,2}$ is the capital-utilization cost of variation.

The first-order condition with respect to domestic bonds is

$$\hat{\lambda}_{t+1}-\hat{\lambda}_t-g_{z,t+1}+\hat{r}_t-\hat{\pi}_{C,t+1}+\hat{\epsilon}_t^{RP}+\hat{\epsilon}_t^{DRP}=0, \tag{11}$$

where $\hat{\pi}_{C,t}$ is CPI inflation ($\hat{\pi}_t^C$ in the paper for reading ease reasons), $\hat{\epsilon}_t^{RP}$ is the market risk premium shock, and $\hat{\epsilon}_t^{DRP}$ is the domestic risk premium shock.

The risk-adjusted UIP condition is

$$\begin{aligned}
\hat{r}_t-\hat{r}_t^* \;=\; & (1-\gamma_S)\left(\mathbb{E}_t\left[\hat{s}_{t+1}\right]-\hat{s}_t+\mathbb{E}_t\left[\hat{\pi}_{Y,t+1}\right]-\hat{\pi}_{Y,t+1}^*\right)-\gamma_S\,\left(\hat{s}_t-\hat{s}_{t-1}+\hat{\pi}_{Y,t}-\hat{\pi}_{y,t}^*\right) \\
& +\gamma_S\,\left(\mathbb{E}_t\left[\hat{\bar{\pi}}_{t+1}-\hat{\bar{\pi}}_{t+1}^*\right]+\hat{\bar{\pi}}_t-\hat{\bar{\pi}}_t^*\right)-\gamma_B\,\mathbb{E}_t\left[\hat{s}_{B^*,t+1}\right]+\hat{\epsilon}_t^{RP^*}-\hat{\epsilon}_t^{DRP},
\end{aligned} \tag{12}$$

where $\hat{r}_t$ is the domestic nominal interest rate, $\hat{r}_t^*$ is the foreign nominal interest rate, $\hat{s}_t$ is the exchange rate, $\hat{\pi}_{Y,t}$ is the domestic GDP deflator inflation rate ($\hat{\pi}_t^Y$ in the paper for reading ease reasons), $\hat{\pi}_{Y,t}^*$ is the foreign GDP deflator inflation rate, $\hat{\bar{\pi}}_t$ is the domestic inflation target and $\hat{\bar{\pi}}_t^*$ is the foreign inflation target, and $\hat{\epsilon}_t^{RP^*}$ is the foreign exchange rate risk-premium shock. γ_S is the modified UIP parameter and γ_B is the risk premium function parameter.

The capital accumulation dynamics is

$$\hat{k}_{t+1} = (1-\delta)\,\frac{\hat{k}_t}{g_z} - (1-\delta)\,\frac{\hat{g}_{z,t}}{g_z} + \hat{\epsilon}_t^I\,\left(1 - \frac{1-\delta}{g_z}\right) + \hat{\imath}_t\,\left(1 - \frac{1-\delta}{g_z}\right), \tag{13}$$

where $\hat{k}_t$ is capital.

A.2 Labor Supply and Wage Setting

The after-tax real wage is

$$\hat{w}_{\tau,t} = \hat{w}_t - \frac{1}{1-\tau^N-\tau^{W_h}}\hat{\tau}_t^N - \frac{1}{1-\tau^N-\tau^{W_h}}\hat{\tau}_t^{W_h}, \tag{14}$$

where $\hat{w}_t$ is the real wage, $\hat{\tau}_t^N$ is the households income tax and $\hat{\tau}_t^{W_h}$ is the worker national-insurance-tax rate.

The marginal rate of substitution between consumption and leisure is

$$\widehat{mrs}_t = \hat{\epsilon}_{N,t} + \zeta\,\hat{n}_t - \hat{\lambda}_t, \tag{15}$$

where $\hat{n}_t$ is worked hours, $\hat{\epsilon}_{N,t}$ is the disutility of labor shock, and ζ is the inverse of Frisch elasticity of labor supply.

The nominal wage inflation is

$$\begin{aligned}
&\hat{g}_{z,t} + \hat{w}_t - \hat{w}_{t-1} + \hat{\pi}_{C,t} - \left(\chi_W\,\hat{\pi}_{C,t-1} + \hat{\bar{\pi}}_t\,(1-\chi_W) + \hat{g}_{z,t-1}\,\chi_{W,g_z}\right) = \\
&\beta\,\left(\mathbb{E}_t\left[\hat{g}_{z,t+1}\right] + \mathbb{E}_t\left[\hat{\pi}_{C,t+1}\right] - \left(\hat{\pi}_{C,t}\,\chi_W + \mathbb{E}_t\left[\hat{\bar{\pi}}_{t+1}\,(1-\chi_W)\right] + \hat{g}_{z,t}\,\chi_{W,g_z}\right)\right) \\
&-\frac{(1-\beta\,\xi_W)\,(1-\xi_W)}{\xi_W\,\left(1+\zeta\,\frac{\phi_w}{\phi_w-1}\right)}\left(\begin{array}{c}\hat{w}_t - \left(\frac{1}{1-\tau^N-\tau^{W_h}}\,\hat{\tau}_t^N + \frac{1}{1-\tau^N-\tau^{W_h}}\,\hat{\tau}_t^{W_h}\right) \\ -\left(\hat{\epsilon}_{N,t} + \zeta\,\hat{n}_t - \hat{\lambda}_t\right) - \hat{\phi}_{w,t}\end{array}\right) + \mathbb{E}_t\left[\hat{w}_{t+1}\right] - \hat{w}_t,
\end{aligned} \tag{16}$$

where $\hat{\phi}_{w,t}$ is the wage markup shock, χ_W is the weight of inflation indexation in wage setting, χ_{W,g_z} is the weight of indexation to (lagged) productivity in wage setting, ξ_W is the nominal-wage Calvo (1983) parameter, and ϕ_w is the steady-state markup of net-wages over the marginal rate of substitution.

A.3 Intermediate-good Firms Resource Allocation

The production technology is

$$\hat{h}_{s,t} = \left(1 + \frac{\psi}{h}\right)\,\left(\hat{\epsilon}_t + \alpha\,\left(\hat{k^s}_t - \hat{g}_{z,t}\right) + \hat{n}_t\,(1-\alpha)\right), \tag{17}$$

where $\hat{\epsilon}_t$ is the technology shock, and $\hat{k^s}_t$ is capital service. ψ is the production fixed cost, h is the steady-state production, and α is the share of capital in the production.

The resource allocation is

$$\hat{r}_{k,t} = \hat{w}_t + \hat{n}_t + \frac{\hat{\tau}_t^{W_f}}{1+\tau^{W_f}} + \hat{R}_{f,t} - \left(\hat{k}_t^s - \hat{g}_{z,t}\right). \tag{18}$$

where $\hat{\tau}_t^{W_f}$ is the payroll tax paid by firms, $\hat{k}_t^s$ is capital service, and $\hat{R}_{f,t}$ is the interest rate on working capital (Eq. 20).

The real marginal cost expressed in terms of CPI is

$$\widehat{mc}_t = -\hat{\epsilon}_t + \hat{r}_{k,t}\,\alpha + (1-\alpha)\left(\hat{R}_{f,t} + \hat{w}_t + \frac{\hat{\tau}_t^{W_f}}{1+\tau^{W_f}}\right). \tag{19}$$

The interest rate on working capital is

$$\hat{R}_{f,t} = \frac{\nu^f\, R}{1-\nu^f\,(R-1)}\left(\hat{r}_t + \hat{\epsilon}_t^{RP} + \hat{\epsilon}_t^F\right) + \frac{\nu^f\,(R-1)}{1-\nu^f\,(R-1)}\hat{\nu}_{f,t}, \tag{20}$$

where $\hat{\nu}_{f,t}$ is the weight of working capital, ν^f is the steady-state weight of working capital, and R is the steady-state nominal interest rate.

A.4 Intermediate-good Firms Price Setting (Phillips Curves)

The Phillips curve of the domestic intermediate goods firm is

$$\begin{aligned}\hat{\pi}_{H,t} - \hat{\bar{\pi}}_t \;=\;& \frac{\beta}{1+\beta\chi_H}\left(\mathbb{E}_t\left[\hat{\pi}_{H,t+1}\right] - \mathbb{E}_t\left[\hat{\bar{\pi}}_{t+1}\right]\right) + \frac{\chi_H}{1+\beta\chi_H}\left(\hat{\pi}_{H,t-1} - \hat{\bar{\pi}}_t\right) \\ &+ \frac{\beta\chi_H}{1+\beta\chi_H}\left(\mathbb{E}_t\left[\hat{\bar{\pi}}_{t+1}\right] - \hat{\bar{\pi}}_t\right) + \frac{(1-\beta\xi_H)\,(1-\xi_H)}{(1+\beta\chi_H)\,\xi_H}\left(\widehat{mc}_t^H + \hat{\varphi}_t^H\right),\end{aligned} \tag{21}$$

where $\hat{\pi}_{H,t}$ is the domestic intermediate good inflation rate ($\hat{\pi}_t^H$ in the paper for reading ease reasons), $\widehat{mc}_t^H$ is defined below (Eq. 22), and $\hat{\varphi}_t^H$ is the domestic price markup. χ_H is the degree of indexation to past aggregate domestic inflation, and ξ_H is the Calvo (1983) probability that a firm does not receive an exogenous and idiosyncratic reoptimization signal.

The real marginal cost in terms of the domestic price index is

$$\widehat{mc}_t^H = \widehat{mc}_t - \hat{p}_{H,t}. \tag{22}$$

The real domestic price index in terms of CPI is

$$\hat{p}_{H,t} = \hat{\pi}_{H,t} + \hat{p}_{H,t-1} - \hat{\pi}_{C,t}. \tag{23}$$

The Phillips Curve of the foreign intermediate goods firm (denominated in terms of the local currency) is

$$\begin{aligned} \hat{\pi}_{IM,t} - \hat{\bar{\pi}}_t \quad = \quad & \frac{\beta^*}{1+\beta^*\,\chi^*}\mathbb{E}_t\left[\hat{\pi}_{IM,t+1} - \hat{\bar{\pi}}_{t+1}\right] + \frac{\chi^*}{1+\beta^*\,\chi^*}\left(\hat{\pi}_{IM,t-1} - \hat{\bar{\pi}}_t\right) \\ & + \left(\mathbb{E}_t\left[\hat{\bar{\pi}}_{t+1}\right] - \hat{\bar{\pi}}_t\right)\frac{\beta^*\,\chi^*}{1+\beta^*\,\chi^*} + \frac{\left(1-\beta^*\,\xi^*\right)\left(1-\xi^*\right)}{\left(1+\beta^*\,\chi^*\right)\xi^*}\left(\widehat{mc}_{IM,t} + \hat{\varphi}^*_t\right), \end{aligned} \tag{24}$$

where $\hat{\pi}_{IM,t}$ is imported inflation, $\widehat{mc}_{IM,t}$ is defined below (Eq. 25), and $\hat{\varphi}^*_t$ is the foreign price markup. β^* is the foreign static discount factor, χ^* is the weight of inflation indexation in import price, and ξ^* is the import-price Calvo (1983) probability.

The real marginal cost of the foreign intermediate goods firm in terms of the price of imported goods is

$$\widehat{mc}_{IM,t} = \hat{s}_t + \hat{p}_{Y,t} + \omega^*\,\left(\hat{p}_{OIL,t} - \left(\hat{\pi}^*_{Y,t} + \hat{p}_{OIL,t} - \hat{p}_{OIL,t-1}\right)\right) - \hat{p}_{IM,t}, \tag{25}$$

where $\hat{p}_{Y,t}$ is the GDP deflator price index, $\hat{p}_{OIL,t}$ is the relative foreign price of oil, $\hat{p}_{IM,t}$ is defined below (Eq. 26), and ω^* is the weight of oil in imports.

The real price of imported goods in local currency, in terms of CPI, is

$$\hat{p}_{IM,t} = \hat{\pi}_{IM,t} + \hat{p}_{IM,t-1} - \hat{\pi}_{C,t}. \tag{26}$$

A.5 Final-Good Firms: Technology, Inputs and Prices

In what follows, prices are expressed in real terms, with the denominator being the CPI.[18]

A.5.1 Final Private Consumption Good

The demand for domestic intermediate goods is

$$\hat{h}_{C,t} = \hat{q}_{C,t} - \hat{p}_{H,t}\,\mu_c + \hat{\nu}_{C,t}, \tag{27}$$

where $\hat{q}_{C,t}$ is the production technology of the final domestic intermediate good, $\hat{p}_{H,t}$ is the real price of the domestic intermediate good (with respect to the CPI),

[18] e.g., $\hat{p}_{H,t} \equiv \ln\left(P_{H,t}/P_{C,t}\right)$.

μ_c is the CES aggregator parameter between domestic and imported consumption goods, and $\hat{\nu}_{C,t}$ is the home bias in the production of the final consumption good.

The demand for imported consumption intermediate goods is

$$\widehat{im}_{C,t} = \hat{q}_{C,t} - \mu_c \left(\hat{p}_{IM,t} - \hat{\Gamma}^{+}_{IMC,t}\right) - \hat{\nu}_{C,t} \frac{\nu_C}{1-\nu_C}, \tag{28}$$

where $\hat{p}_{IM,t}$ is the real price of imported goods in local currency (with respect to the CPI), $\hat{\Gamma}^{+}_{IMC,t}$ is the import share adjustment costs for domestic intermediate goods defined below (Eq. 29), and ν_C is the consumption home-bias.

The import share adjustment costs for domestic intermediate goods is

$$\hat{\Gamma}^{+}_{IMC,t} = \hat{\epsilon}^{IM}_t - \gamma^{C}_{IM} \left(\widehat{im}_{C,t} - \hat{q}_{C,t} - \left(\widehat{im}_{C,t-1} - \hat{q}_{C,t-1}\right)\right), \tag{29}$$

where γ^{C}_{IM} is the imported consumption adjustment-cost parameter, and $\hat{\epsilon}^{IM}_t$ is the import demand shock.

The private consumption good pricing equation is

$$\hat{p}_{H,t}\, \nu_C\, p_H^{1-\mu_C} + \left(\hat{p}_{IM,t} - \hat{\Gamma}^{+}_{IMC,t}\right) (1-\nu_C)\; p_{IM}^{1-\mu_C} + \hat{\nu}_{C,t} \frac{\nu_C}{1-\mu_C} \left(p_H^{1-\mu_C} - p_{IM}^{1-\mu_C}\right) = 0, \tag{30}$$

where p_H is the steady-state price of domestic intermediate goods.

A.5.2 Final Investment Good

The demand for investment intermediate goods is

$$\hat{h}_{I,t} = \hat{q}_{I,t} - \mu_I \left(\hat{p}_{H,t} - \hat{p}_{I,t}\right) + \hat{\nu}_{I,t}, \tag{31}$$

where $\hat{q}_{I,t}$ is the production technology of the final investment good, $\hat{p}_{I,t}$ is the real price of the investment good defined below (Eq. 34), $\hat{\nu}_{I,t}$ is the home bias in production of the final investment good, and μ_I is the CES aggregator parameter between domestic and imported investment.

The demand for imported investment intermediate goods is

$$\widehat{im}_{I,t} = \hat{q}_{I,t} - \mu_I \left(\hat{p}_{IM,t} - \hat{p}_{I,t} - \hat{\Gamma}^{+}_{IMI,t}\right) - \hat{\nu}_{I,t} \frac{\nu_I}{1-\nu_I}, \tag{32}$$

where $\hat{\Gamma}^{+}_{IMI,t}$ is the import share adjustment cost defined below (Eq. 33), and ν_I is the investment home-bias.

The import share adjustment cost for imported investment intermediate goods is

$$\hat{\Gamma}^{+}_{IMI,t} = \hat{\epsilon}^{IM}_{t} - \gamma^{I}_{IM}\left(\widehat{im}_{I,t} - \hat{q}_{I,t} - \left(\widehat{im}_{I,t-1} - \hat{q}_{I,t-1}\right)\right), \tag{33}$$

where γ^{I}_{IM} is the imported investment adjustment-cost parameter.

The price of the investment good is

$$\begin{aligned} \hat{p}_{I,t} &= \hat{p}_{H,t}\,\nu_I\left(\frac{p_H}{p_I}\right)^{1-\mu_I} + (1-\nu_I)\left(\frac{p_{IM}}{p_I}\right)^{1-\mu_I}\left(\hat{p}_{IM,t} - \hat{\Gamma}^{+}_{IMI,t}\right) \\ &\quad + \hat{\nu}_{I,t}\,\frac{\nu_I}{1-\mu_I}\left(\left(\frac{p_H}{p_I}\right)^{1-\mu_I} - \left(\frac{p_{IM}}{p_I}\right)^{1-\mu_I}\right), \end{aligned} \tag{34}$$

where p_I is the steady-state price of investment intermediate goods.

A.5.3 Final Public Consumption Good

The demand for public consumption goods is

$$\hat{h}_{G,t} = \hat{q}_{G,t} - \mu_G\left(\hat{p}_{H,t} - \hat{p}_{G,t}\right) + \hat{\nu}_{G,t}, \tag{35}$$

where $\hat{q}_{G,t}$ is the production technology of the final public consumption good, $\hat{p}_{G,t}$ is the price of the public consumption good defined below (Eq. 38), $\hat{\nu}_{G,t}$ is the home bias in production of the final government consumption good, and μ_G is the CES aggregator parameter between domestic and imported government consumption.

The demand for imported intermediate public consumption goods is

$$\widehat{im}_{G,t} = \hat{q}_{G,t} - \mu_G\left(\hat{p}_{IM,t} - \hat{p}_{G,t} - \hat{\Gamma}^{+}_{IMG,t}\right) - \hat{\nu}_{G,t}\frac{\nu_G}{1-\nu_G}, \tag{36}$$

where $\hat{\Gamma}^{+}_{IMG,t}$ is the import share adjustment cost defined below (Eq. 37), and ν_G is the government consumption home-bias.

The import share adjustment cost for imported intermediate public consumption goods is

$$\hat{\Gamma}^{+}_{IMG,t} = \hat{\epsilon}^{IM}_{t} - \gamma^{G}_{IM}\left(\widehat{im}_{G,t} - \hat{q}_{G,t} - \left(\widehat{im}_{G,t-1} - \hat{q}_{G,t-1}\right)\right), \tag{37}$$

where γ^{G}_{IM} is the import government consumption adjustment-cost parameter.

The price of the public consumption good is

$$
\begin{aligned}
\hat{p}_{G,t} \;=\; & \hat{p}_{H,t}\nu_G \left(\frac{p_H}{p_G}\right)^{1-\mu_G} + (1-\nu_G)\left(\frac{p_{IM}}{p_G}\right)^{1-\mu_G} \left(\hat{p}_{IM,t} - \hat{\Gamma}^{+}_{IMG,t}\right) \\
& + \hat{v}_{G,t}\,\frac{\nu_G}{1-\mu_G}\left(\left(\frac{p_H}{p_G}\right)^{1-\mu_G} - \left(\frac{p_{IM}}{p_G}\right)^{1-\mu_G}\right), \qquad (38)
\end{aligned}
$$

where p_G is the steady-state price of public consumption goods.

A.5.4 Final Exports Good

The demand for exported goods is

$$
\hat{h}_{X,t} = \hat{q}_{X,t} - \mu_X \left(\hat{p}_{H,t} - \hat{p}_{DX,t}\right) + \hat{v}_{X,t}\,, \qquad (39)
$$

where $\hat{q}_{X,t}$ is the production technology of the final exports good, $\hat{p}_{DX,t}$ is the domestic price of the exported good defined below (Eq. 42), $\hat{v}_{X,t}$ is the home bias in production of the final export good, and μ_X is the CES aggregator parameter between domestic and imported goods in exports.

The demand for imported intermediate goods is

$$
\widehat{im}_{X,t} = \hat{q}_{X,t} - \mu_X \left(\hat{p}_{IM,t} - \hat{p}_{DX,t} - \hat{\Gamma}^{+}_{IMX,t}\right) - \hat{v}_{X,t}\frac{\nu_X}{1-\nu_X}, \qquad (40)
$$

where $\hat{\Gamma}^{+}_{IMX,t}$ is the import share adjustment cost for import for export goods defined below (Eq. 41), $\hat{p}_{IM,t}$ is the real price of imported goods in local currency defined above (Eq. 26), and ν_X is the home-bias in exports.

The import share adjustment cost for exported goods is

$$
\hat{\Gamma}^{+}_{IMX,t} = \hat{\epsilon}^{X}_{t} - \gamma^{X}_{IM}\left(\widehat{im}_{X,t} - \hat{q}_{X,t} - \left(\widehat{im}_{X,t-1} - \hat{q}_{X,t-1}\right)\right), \qquad (41)
$$

where $\hat{\epsilon}^{X}_{t}$ is the export shock, and γ^{X}_{IM} is the export-share (in foreign output) adjustment cost parameter.

The domestic price of exported goods is

$$
\begin{aligned}
\hat{p}_{DX,t} \;=\; & \hat{p}_{H,t}\nu_x \left(\frac{p_H}{p_{DX}}\right)^{1-\mu_x} + (1-\nu_X)\left(\frac{p_{IM}}{p_{DX}}\right)^{1-\mu_X} \left(\hat{p}_{IM,t} - \hat{\Gamma}^{+}_{IMX,t}\right) \\
& + \hat{v}_{X,t}\frac{\nu_X}{1-\mu_X}\left(\left(\frac{p_H}{p_{DX}}\right)^{1-\mu_X} - \left(\frac{p_{IM}}{p_{DX}}\right)^{1-\mu_X}\right), \qquad (42)
\end{aligned}
$$

where p_{DX} is the steady-state domestic price of the exported good.

A.5.5 Exports to Foreign Markets: Monopolistic Firms

The Phillips Curve for the price of the exported good (in foreign currency) is

$$\begin{aligned}\hat{\pi}_{X,t} - \hat{\bar{\pi}}^*_t \quad = \quad & \frac{\beta}{1+\beta\,\chi_X}\mathbb{E}_t\left[\hat{\pi}_{X,t+1} - \hat{\bar{\pi}}^*_{t+1}\right] + \frac{\chi_X}{1+\beta\,\chi_X}\left(\mathbb{E}_t\left[\hat{\bar{\pi}}^*_{t+1}\right] - \hat{\bar{\pi}}^*_t\right) \\ & + \frac{\beta\,\chi_X}{1+\beta\,\chi_X}\left(\mathbb{E}_t\left[\hat{\bar{\pi}}^*_{t+1}\right] - \hat{\bar{\pi}}^*_t\right) + \frac{(1-\beta\,\xi_X)\,(1-\xi_X)}{(1+\beta\,\chi_X)\,\xi_X}\left(\widehat{mc}^X_t + \hat{\varphi}^X_t\right).\end{aligned} \tag{43}$$

where $\hat{\pi}_{X,t}$ is exported inflation in foreign currency, $\hat{\bar{\pi}}^*_t$ is the foreign inflation target, $\hat{\varphi}^X_t$ is the export price markup shock, and $\widehat{mc}^X_t$ is the real marginal cost of exporters defined below (Eq. 44).

The real marginal cost of exporters with respect to the price of the exported good is

$$\widehat{mc}^X_t = \hat{p}_{DX,t} - \hat{s}_t - \hat{p}_{X,t} - \hat{p}_{Y,t}. \tag{44}$$

where $\hat{p}_{X,t}$ is the real price of the exported good in the foreign currency defined below (Eq. 45).

The real price of the exported good in foreign currency, with respect to the foreign output deflator, is

$$\hat{p}_{X,t} = \hat{\pi}_{X,t} + \hat{p}_{X,t-1} - \hat{\pi}^*_{Y,t}. \tag{45}$$

where $\hat{\pi}^*_{Y,t}$ is the foreign inflation.

A.6 Fiscal and Monetary Authorities

The government consumption is

$$\hat{g}_t = \rho_G\,\hat{g}_{t-1} + \eta^G_t. \tag{46}$$

where η^G_t is the government consumption shock.

The direct consumption tax is

$$\hat{\tau}^C_t = \rho_{\tau^C}\,\hat{\tau}^C_{t-1} + \eta^{\tau^C}_t. \tag{47}$$

where $\eta^{\tau^C}_t$ is the direct consumption tax shock.

The dividend tax is

$$\hat{\tau}^D_t = \rho_{\tau^D}\,\hat{\tau}^D_{t-1} + \eta^{\tau^D}_t. \tag{48}$$

where $\eta^{\tau^D}_t$ is the dividend tax shock.

The capital rental tax is

$$\hat{\tau}_t^k = \rho_{\tau^K} \, \hat{\tau}_{t-1}^K + \eta_t^{\tau^K}. \tag{49}$$

where $\eta_t^{\tau^K}$ is the capital rental tax shock.

The income tax on households is

$$\hat{\tau}_t^N = \rho_{\tau^N} \, \hat{\tau}_{t-1}^N + \eta_t^{\tau^N}. \tag{50}$$

where $\eta_t^{\tau^N}$ is the household income tax shock.

The additional payroll tax on households is

$$\hat{\tau}_t^{W_h} = \rho_{\tau^{W_h}} \, \hat{\tau}_{t-1}^{W_h} + \eta_t^{\tau^{W_h}}, \tag{51}$$

and the additional payroll tax on firms is

$$\hat{\tau}_t^{W_f} = \rho_{\tau^{W_f}} \, \hat{\tau}_{t-1}^{W_f} + \eta_t^{\tau^{W_f}}. \tag{52}$$

where $\eta_t^{\tau^{W_h}}$ and $\eta_t^{\tau^{W_f}}$ is the household and firm payroll tax shock, respectively.

The output growth is defined as

$$\hat{g}_{Y,t} = \hat{g}_{z,t} + \hat{y}_t - \hat{y}_{t-1}. \tag{53}$$

where $\hat{g}_{z,t}$ is the labor productivity growth rate.

The Taylor rule of the original MOISE model (Argov et al., 2012), which is replaced by rules presented in Table 1, is

$$\hat{r}_t = (1-\phi_R) \left(\hat{rr}_t^{fw} + \hat{\bar{\pi}}_t + \phi_\Pi \left(\hat{\pi}_t^{CB} - \hat{\bar{\pi}}_t \right) + \phi_y \, \hat{y}_t^{GAP} + \phi_{\Delta S} \, \Delta \hat{S}_t \right) + \phi_R \, \hat{r}_{t-1} + \eta_t^R. \tag{54}$$

where $\Delta\hat{S}_t$ is the nominal depreciation defined below (Eq. 58) and the time-varying inflation objective is

$$\hat{\bar{\pi}}_t = \rho_{\bar{\pi}} \, \hat{\bar{\pi}}_{t-1} + \eta_t^{\overline{\Pi}}. \tag{55}$$

where $\eta_t^{\overline{\Pi}}$ is the inflation target shock.

The inflation target appears outside the inflation gap term, as in Eq. 1 in Taylor (1993), and similar to Eq. 15 in Adolfson et al. (2007), and Eq. 65 in Christoffel et al. (2008).

The real interest rate is defined as

$$\hat{ri}_t = \hat{r}_t - \hat{\pi}_{C,t+1}. \tag{56}$$

The forward 5 to 10 years expected real interest rate is

$$\hat{rr}_t^{fw} = \frac{1}{20}\mathbb{E}_t\left[\hat{ri}_{t+20} + ... + \hat{ri}_{t+39}\right]. \tag{57}$$

The nominal depreciation is

$$\Delta\hat{S}_t = \hat{s}_t - \hat{s}_{t-1} + \hat{\pi}_{Y,t} - \hat{\pi}^*_{Y,t}. \tag{58}$$

The output gap, defined as the deviation of production inputs from trend, is

$$\hat{y}_t^{GAP} = \hat{y}_t - \hat{\epsilon}_t. \tag{59}$$

where $\hat{\epsilon}_t$ is the transitory technological shock.

The inflation that the central bank is attentive to is

$$\hat{\pi}_t^{CB} = \frac{1}{4}\left(\mathbb{E}_t\left[\hat{\pi}_{C,t+1}\right] + \hat{\pi}_{C,t} + \hat{\pi}_{C,t-1} + \hat{\pi}_{C,t-2}\right). \tag{60}$$

A.7 Net Foreign Assets and the Current Account

The ratio of trade balance to domestic output is

$$\hat{s}_{TB,t} = \hat{s}_{X,t} - \hat{s}_{IM,t}, \tag{61}$$

where $\hat{s}_{X,t}$ is the ratio of exports to domestic output and $\hat{s}_{IM,t}$ is the ratio of imports to domestic output detailed below.

The ratio of exports to domestic output is

$$\hat{s}_{X,t} = \frac{s\, p_X\, x}{y}\left(\hat{s}_t + \hat{p}_{X,t} + \hat{x}_t - \hat{y}_t\right). \tag{62}$$

where $\hat{x}_t$ is the export demand function, x and y are the steady-state values of export demand and output, respectively.

The ratio of imports to domestic output is

$$\hat{s}_{IM,t} = s_{IM}\left(\hat{p}_{IM,t} + \widehat{im}_t - \hat{p}_{Y,t} - \hat{y}_t\right). \tag{63}$$

where $\widehat{im}_t$ is the variation of total imported intermediate goods.

The ratio of the current account to domestic output is

$$(CA/Y)_t = \hat{s}_{TB,t} + \hat{s}_{FTR,t}. \tag{64}$$

where the ratio of foreign transfers to domestic output is

$$\hat{s}_{FTR,t} = \rho_{FTR}\, \hat{s}_{FTR,t-1} + \eta_t^{FTR}. \tag{65}$$

The export demand function is

$$\begin{aligned} \hat{x}_t &= \hat{\hat{z}}_t + \widehat{im}_t^* + \hat{v}_t^* \\ &\quad -\mu^* \left(\hat{p}_{x,t} - \hat{p}_{x,t}^* + \gamma^* \left(\hat{x}_t - \widehat{im}_t^* - \hat{\hat{z}}_t - \left(\hat{x}_{t-1} - \widehat{im}_{t-1}^* - \hat{\hat{z}}_{t-1}\right)\right)\right). \end{aligned} \tag{66}$$

where $\widehat{im}_t^*$ is the world import gap presented below (Eq. 84).

The ratio of net foreign assets to domestic output is

$$\frac{\mathbb{E}_t\left[s_{B_{t+1}^*}\right]}{r^*} = (CA/Y)_t + \frac{s_{B^*}\mathbb{E}_{t-1}\left[s_{B_t^*}\right]}{g_z\, \pi^*}. \tag{67}$$

The real exchange rate in CPI terms is

$$\hat{s}_t = \hat{c}_t + \hat{p}_{Y,t}. \tag{68}$$

where $\hat{p}_{Y,t}$ is the price deflator.

A.8 Market Clearing Conditions

The market clearing condition in the domestic intermediate good markets is

$$\hat{h}_t^s = \hat{h}_t. \tag{69}$$

The market clearing condition in the final consumption good market is

$$\hat{q}_{C,t} = \hat{c}_t. \tag{70}$$

The market clearing condition in the final investment good market is

$$\hat{q}_{I,t} = \hat{\imath}_t \frac{i}{q_i} + \hat{u}_t \frac{\gamma_{u,1}}{g_z} \frac{k}{q_i} + \frac{y}{q_i}\left(\Delta \widehat{inv}_t + \hat{y}_t\, \Delta inv\right). \tag{71}$$

The market clearing condition in the final government good market is

$$\hat{q}_{G,t} = \hat{g}_t. \tag{72}$$

The market clearing condition in the final export good market is

$$\hat{q}_{X,t} = \hat{x}_t \frac{x}{q_x}. \tag{73}$$

The market clearing in the capital market is

$$\hat{u}_t + \hat{k}_t = \hat{k}_{s,t}. \tag{74}$$

The aggregate resource constraint is

$$\begin{aligned}
\hat{p}_{Y,t} + \hat{y}_t \;\; = \;\; & \hat{c}_t \frac{p_C c}{p_y y} + \frac{p_I\, i}{P_y y}\left(\hat{\imath}_t + \hat{p_{I,t}}\right) + \frac{p_I k}{p_y y} \hat{u}_t\, \gamma_{u,1} \; + \frac{p_I}{P_Y}\left(\hat{y}_t\, \Delta inv + \Delta \widehat{inv}_t + \hat{p}_{I,t}\, \Delta inv\right) \\
& + \frac{p_G g}{p_Y g}\,\left(\hat{p}_{g,t} + \hat{g}_t\right) + \frac{s\, p_X\, x}{y}\,\left(\hat{x}_t + \hat{s}_t + \hat{p}_{Y,t} + \hat{p}_{X,t}\right) \\
& - \frac{p_{IM}\, im_C}{p_Y y}\left(\hat{p}_{IM,t} + \widehat{im}_{C,t} - \hat{\Gamma}^{+}_{IM^{C},t}\right) - \frac{p_{IM}\, im_I}{p_Y y}\left(\hat{p}_{IM,t} + \widehat{im}_{I,t} - \hat{\Gamma}^{+}_{IM^{I},t}\right) \\
& - \frac{p_{IM}\, im_G}{p_Y y}\left(\hat{p}_{IM,t} + \widehat{im}_{G,t} - \hat{\Gamma}^{+}_{IM^{G},t}\right) - \frac{p_{IM}\, im_X}{p_Y y}\left(\hat{p}_{IM,t} + \widehat{im}_{X,t} - \hat{\Gamma}^{+}_{IM^{X},t}\right).
\end{aligned} \tag{75}$$

The inflation in GDP deflator terms is

$$\hat{\pi}_{Y,t} = \hat{\pi}_{C,t} + \hat{p}_{y,t} - \hat{p}_{y,t-1}. \tag{76}$$

The output deflator is

$$\hat{p}_{Y,t} + \hat{y}_t = \frac{h\, p_H}{y\, p_Y}\left(\hat{p}_{H,t} + \hat{h}_t\right) + \frac{x\, s\, p_X\, p_Y}{P_Y Y}\left(\hat{c}_t + \hat{p}_{X,t} + \hat{p}_{Y,t} + \hat{x}_t\right) - \frac{p_{DX}\, q_X}{P_Y Y}\left(\hat{q}_{X,t} + \hat{p}_{DX,t}\right). \tag{77}$$

The total imported intermediate goods is

$$\widehat{im}_t = \frac{im_C}{im}\widehat{im}_{C,t} + \frac{im_I}{im}\widehat{im}_{I,t} + \frac{im_G}{im}\widehat{im}_{G,t} + \frac{im_X}{im}\widehat{im}_{X,t}. \tag{78}$$

The aggregate resource constraint defined in market prices is

$$\begin{aligned}
\hat{y}_t + \hat{p}^M_{Y,t} \quad = \quad & \frac{(1+0.78\,\tau_c)\ c}{p^M_Y y} \left(\hat{c}_t + \frac{1}{1+0.78\,\tau_c}\,\hat{\tau}^c_t\right) + \frac{p_I i}{p^M_Y y}\left(\hat{\imath}_t + \hat{p}_{I,t}\right) + \frac{p_I k}{p^M_Y y}\hat{u}_t\,\gamma_{u,1} \\
& + \frac{p_I}{p^M_Y}\left(\hat{y}_t\,\Delta inv + \Delta\widehat{inv}_t + \hat{p}_{I,t}\,\Delta inv\right) + \frac{p_G g}{p^M_Y y}\left(\hat{p}_{G,t} + \hat{g}_t\right) \qquad (79) \\
& + \frac{xs\,p_x\,p_y}{p^M_Y y}\left(\hat{x}_t + \hat{c}_t + \hat{p}_{Y,t} + \hat{p}_{X,t}\right) \\
& - \frac{p_{IM}\,im_C}{p^M_Y y}\left(\hat{p}_{IM,t} + \widehat{im}_{C,t} - \hat{\Gamma}^+_{IM^C,t}\right) - \frac{P_{IM}\,im_I}{p^M_Y y}\left(\hat{p}_{IM,t} + \widehat{im}_{I,t} - \hat{\Gamma}^+_{IM^I,t}\right) \\
& - \frac{p_{IM}\,im_G}{y\,p^M_Y}\left(\hat{p}_{IM,t} + \widehat{im}_{G,t} - \hat{\Gamma}^+_{IM^G,t}\right) - \frac{P_{IM}\,im_X}{p^M_Y y}\left(\hat{p}_{IM,t} + \widehat{im}_{X,t} - \hat{\Gamma}^+_{IM^X,t}\right).
\end{aligned}$$

The real GDP is

$$\hat{y}_t = \hat{h}_{s,t}. \qquad (80)$$

A.9 The Foreign Economy

The foreign output is

$$\hat{y}^*_t = c_{y^*,+}\,\mathbb{E}_t\left[\hat{y}^*_{t+1}\right] + \left(1 - c_{y^*,+}\right)\hat{y}^*_{t-1} - 4c_{y^*,r}\left(\widehat{ri}^*_t - \widehat{fw}_{ri^*,t}\right) + \hat{\epsilon}_{Y^*,t}. \qquad (81)$$

The foreign nominal interest rate is

$$\begin{aligned}
4\hat{r}^*_t \quad = \quad & (1 - c_{r^*,-})\left(\begin{array}{c} 4\left(\bar{\pi}^*_t + \widehat{fw}_{ri^*,t}\right) + \hat{y}^*_t\,c_{r^*,y} \\ +4\,c_{r^*,\pi}\left(0.2\mathbb{E}_t\left[\hat{\pi}^*_{y,t+1} + \hat{\pi}^*_{y,t} + \hat{\pi}^*_{y,t-1} + \hat{\pi}^*_{y,t+2} + \hat{\pi}^*_{y,t+3}\right] - \bar{\pi}^*_t\right)\end{array}\right) \\
& +4c_{r^*,-}\ \hat{r}^*_{t-1} + \hat{\epsilon}_{R^*,t}. \qquad (82)
\end{aligned}$$

The foreign CPI inflation is

$$\begin{aligned}
4\hat{\pi}^*_{y,t} \quad = \quad & 4c_{\pi^*,+}\mathbb{E}_t\left[\hat{\pi}^*_{Y,t+1}\right] + 4\hat{\pi}^*_{Y,t-1}\left(1 - c_{\pi^*,+}\right) + c_{\pi^*,y}0.5\left(\hat{y}^*_t + \hat{y}^*_{t-1}\right) \qquad (83) \\
& + c_{\pi^*,OIL}\hat{p}_{OIL,t} + c_{\pi^*,\Delta OIL}\left(\hat{p}_{OIL,t} - \hat{p}_{OIL,t-2}\right) + \hat{\pi}^*_{Y,t}.
\end{aligned}$$

The world import gap is

$$\widehat{im}^*_t = c_{wt,y}\hat{y}^*_t + c_{wt,y-}\hat{y}^*_{t-1} + c^*_{wt,-}\,\widehat{im}^*_{t-1} + \hat{\epsilon}_{IM^*_t}. \qquad (84)$$

The relative foreign price of oil is

$$\hat{p}_{OILl,t} = c_{OIL,-}\hat{p}_{OIL,t-1} - c_{OIL,\Delta}\left(\hat{p}_{OIL,t-1} - \hat{p}_{OIL,t-2}\right) + \eta^{OIL}_t. \qquad (85)$$

A.10 Observation Equations

The real GDP per capita growth rate is

$$\Delta Y_t = \hat{g}_{z,t} + \hat{y}_t - \hat{y}_{t-1} + g_z - 1 + EX_{\Delta N,t}. \tag{86}$$

The real consumption per capita growth rate is

$$\Delta C_t = EX_{\Delta N,t} + g_z - 1 + \hat{g}_{z,t} + \hat{c}_t - \hat{c}_{t-1} + EX_{\Delta C,t}. \tag{87}$$

The real investment per capita growth rate, excluding inventories, is

$$\Delta I_{NI,t} = EX_{\Delta N,t} + g_z - 1 + \hat{g}_{z,t} + \hat{\imath}_t - \hat{\imath}_{t-1} + EX_{\Delta INI,t}. \tag{88}$$

The real government consumption per capita growth rate is

$$\Delta G_t = EX_{\Delta N,t} + g_z - 1 + \hat{g}_{z,t} + \hat{g}_t - \hat{g}_{t-1} + EX_{\Delta G,t}. \tag{89}$$

The real export per capita growth is

$$\Delta X_t = EX_{\Delta N,t} + g_z - 1 + \hat{g}_{z,t} + \hat{x}_t - \hat{x}_{t-1} + EX_{\Delta X,t}. \tag{90}$$

The real import per capita growth rate is

$$\Delta IM_t = EX_{\Delta N,t} + g_z - 1 + \hat{g}_{z,t} + \widehat{im}_t - \widehat{im}_{t-1} + EX_{\Delta IM,t}. \tag{91}$$

The inflation rate in market price in GDP deflator terms is

$$\Delta P^M_{Y,\,t} = \hat{\epsilon}_{OB\_DPY,t} + \hat{\pi}_{C,t} + \hat{p}^M_{Y,t} - \hat{p}^M_{Y,t-1} + \pi - 1 - \hat{\bar{\pi}}_t. \tag{92}$$

The inflation rate in factor price CPI, excluding VAT, fruits and vegetables, is

$$\Delta P_{C,t} = \hat{\pi}_{C,t} + \pi - 1 - \bar{\pi}_t. \tag{93}$$

The inflation rate in investment deflator, including measurement errors, is

$$\Delta P_{I,t} = \pi - 1 + \hat{\pi}_{C,t} + \hat{p}_{I,t} - \hat{p}_{I,t-1} - \bar{\pi}_t + \eta_t^{\Delta P_I}. \tag{94}$$

The annualized inflation target is

$$4\overline{\pi}^*_t = 4\left(\bar{\pi}_t + \pi - 1\right). \tag{95}$$

The employment per capita is

$$\Delta EM_t = EX_{\Delta N,t} + \hat{e}_t - \hat{e}_{t-1}. \tag{96}$$

and the employment per capita in deviation from its HP trend is

$$\hat{e}_t = \frac{\beta}{1+\beta\chi_E}\mathbb{E}_t\left[\hat{e}_{t+1}\right] + \frac{\chi_E}{1+\beta\chi_E}\hat{e}_{t-1} + \frac{(1-\beta\xi_E)\ (1-\xi_E)}{(1+\beta\chi_E)\ \xi_E}\left(\hat{n}_t - \hat{e}_t\right) + \hat{\epsilon}_{OB\_E,t}. \tag{97}$$

The labor input per capita is

$$\Delta N_t = EX_{\Delta N,t} + \hat{n}_t - \hat{n}_{t-1}. \tag{98}$$

The nominal wage growth rate is

$$\Delta W_t = \pi - 1 + g_z - 1 + \hat{\pi}_{C,t} + \hat{g}_{z,t} + \hat{w}_t - \hat{w}_{t-1} - \bar{\pi}_t + EX_{\Delta W,t}. \tag{99}$$

The annualized nominal interest rate is

$$r_t^{OB} = 4\left(\hat{r}_t + r - 1\right) - 4\bar{\pi}_t. \tag{100}$$

The nominal depreciation rate is

$$\Delta S_t = \hat{c}_t - \hat{c}_{t-1} + \hat{\pi}_{Y,t} - \hat{\pi}^*_{Y,t} + \pi - 1 - (\pi^* - 1) - \bar{\pi}_t + EX_{\Delta S,t}. \tag{101}$$

The foreign output growth rate is

$$\Delta Y^*{}_t = g_z - 1 + \hat{g}_{z,t} + \hat{\tilde{z}}_t + \hat{y}^*_t - \hat{y}^*_{t-1} - \hat{\tilde{z}}_{t-1} + EX_{\Delta Y*,t}. \tag{102}$$

The inflation rate in foreign price deflator terms is

$$\Delta P_{Y^*,t} = \hat{\pi}^*_{Y,t} + \pi^* - 1. \tag{103}$$

The annualized foreign nominal interest rate is

$$R_t^{*OB} = 4\ \left(\hat{r}^*_t + r^* - 1\right). \tag{104}$$

The inflation rate in foreign competitor price terms is

$$\Delta P_{X^*,t} = \Delta P_{Y^*,t} + \hat{p}^*_{x,t} - \hat{p}^*_{x,t-1}. \tag{105}$$

The inflation rate in export deflator terms and domestic currency (new Israeli shekel, ILS) is

$$\Delta P_{X,t}^{NIS} = \Delta S_t + \Delta P_{Y^*,t} + \hat{p}_{x,t} - \hat{p}_{x,t-1}. \tag{106}$$

The forward long run 5 to 10 years expected real rate is

$$rr_t^{fwd\_ob} = \hat{\epsilon}_{fwd\_ob,t} + 4\left(\hat{fw}_{ri^*,t} + \frac{g_z}{\beta} - 1\right) + tp, \tag{107}$$

where tp is an average term premium.

The observable ratio of the current account to GDP is

$$S_{CA,t} = (CA/Y)_t. \tag{108}$$

The observable consumption tax rate is

$$\tau_t^{C\_OB} = \tau_c + \hat{\tau}_t^c. \tag{109}$$

The observable income tax rate is

$$\tau_t^{N\_OB} = \tau_n + \hat{\tau}_t^n. \tag{110}$$

The observable change in oil prices is

$$\Delta P_{OIL,t} = \hat{p}_{OIL,t} - \hat{p}_{OIL,t-1} + \Delta P_{Y^*,t} + EX_{\Delta POIL,t}. \tag{111}$$

The change in inventories as a share of GDP is

$$\Delta inv_t = \Delta\widehat{inv}_t + \Delta inv + EX_{\Delta INV,t}. \tag{112}$$

The forward long run expected nominal 5 to 10 years rate abroad is

$$r_t^{*fwd\_ob} = \hat{\epsilon}_{fwd\_ob^*,t} + 4\left(\bar{\pi}_t^* + \widehat{fw}_{ri^*,t} + r^* - 1\right) + tp^*, \tag{113}$$

where tp^* is an average term premium.

The observable world import growth rate is

$$\Delta WT_t^* = \hat{g}_{z,t} + \hat{\hat{z}}_t + \widehat{im}_t^* - \widehat{im}_{t-1}^* - \hat{\hat{z}}_{t-1} + g_z - 1 + EX_{\Delta WT*,t}. \tag{114}$$

A.11 Idiosyncratic Trend Shocks

The autoregressive shock process for the unbalanced growth of nominal depreciation growth is

$$EX_{\Delta S,t} = \rho_{EX}^{\Delta S} EX_{\Delta S,t-1} + \eta_{EX,t}^{S}. \tag{115}$$

The autoregressive shock process for the unbalanced growth of nominal wage growth is

$$EX_{\Delta W,t} = \left(1 - \rho_{EX}^{\Delta W}\right) \left(g_{\Delta W} - g_z - (\pi - 1)\right) + \rho_{EX}^{\Delta W} EX_{\Delta W,t-1} + \eta_{EX,t}^{W}. \tag{116}$$

The autoregressive shock process for the unbalanced growth of active population growth is

$$EX_{\Delta N,t} = \left(1 - \rho_{EX}^{N}\right) g_{\Delta N} + \rho_{EX}^{N} EX_{\Delta N,t-1} + \eta_{EX,t}^{N}. \tag{117}$$

The autoregressive shock process for the unbalanced growth of real per-capita consumption growth is

$$EX_{\Delta C,t} = \left(1 - \rho_{EX}^{C}\right) \left(g_{\Delta C} - g_z - g_{\Delta N}\right) + \rho_{EX}^{C} EX_{\Delta C,t-1} + \eta_{EX,t}^{C}. \tag{118}$$

The autoregressive shock process for the unbalanced growth of real per-capita investment growth (excluding inventories) is

$$EX_{\Delta INI,t} = \left(1 - \rho_{EX}^{I}\right) \left(g_{\Delta I} - g_z - g_{\Delta N}\right) + \rho_{EX}^{I} EX_{\Delta INI,t-1} + \eta_{EX,t}^{I}. \tag{119}$$

The autoregressive shock process for the unbalanced growth of real per-capita import growth is

$$EX_{\Delta IM,t} = \left(1 - \rho_{EX}^{IM}\right) \left(g_{\Delta IM} - g_z - g_{\Delta N}\right) + \rho_{EX}^{IM} EX_{\Delta IM,t-1} + \eta_{EX,t}^{IM}. \tag{120}$$

The autoregressive shock process for the unbalanced growth of real per-capita export growth is

$$EX_{\Delta X,t} = \left(1 - \rho_{EX}^{X}\right) \left(g_{\Delta X} - g_z - g_{\Delta N}\right) + \rho_{EX}^{X} EX_{\Delta X,t-1} + \eta_{EX,t}^{X}. \tag{121}$$

The autoregressive shock process for the unbalanced growth of inventory investment to GDP is

$$EX_{\Delta INV,t} = \eta_{EX,t}^{\Delta INV}. \tag{122}$$

The autoregressive shock process for the unbalanced growth of real per-capita government consumption growth is

$$0 = \frac{c}{y} EX_{\Delta C,t} + \frac{i}{y} EX_{\Delta INI,t} + \Delta inv\, EX_{\Delta INV,t} + s_G\, EX_{\Delta G,t} + s_X EX_{\Delta X,t} - \frac{im}{y} EX_{\Delta IM,t}\,. \tag{123}$$

The autoregressive shock process for the unbalanced growth of foreign demand growth is

$$EX_{\Delta Y*,t} = \left(1 - \rho_{EX}^{Y^*}\right)\,(g_{\Delta Y^*} - g_z) + \rho_{EX}^{Y^*}\, EX_{\Delta Y*,t-1} + \eta_{EX,t}^{Y^*}. \tag{124}$$

The autoregressive shock process for the unbalanced growth of world import growth is

$$EX_{\Delta WT*,t} = \left(1 - \rho_{EX}^{WT^*}\right)\,(g_{\Delta WT*} - g_z) + \rho_{EX}^{WT^*}\, EX_{\Delta WT*,t-1} + \eta_{EX,t}^{WT^*}. \tag{125}$$

The autoregressive shock process for the unbalanced growth of oil price growth is

$$EX_{\Delta POil,t} = \rho_{EX}^{P^*_{OIL}}\, EX_{\Delta POil,t-1} + \eta_{EX,t}^{P^*_{OIL}}. \tag{126}$$

B Estimation Results

Tables 8 and 9 present the estimation results (posterior means) of the parameters.[19]

[19] Detailed results are available upon request.

Table 8. Posterior Mean Results (1)

	Rules															
Parameter Name	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Capital share	0.332	0.334	0.346	0.340	0.344	0.335	0.433	0.334	0.338	0.342	0.340	0.345	0.332	0.343	0.333	0.344
Consumption habit-formation	0.727	0.738	0.744	0.754	0.783	0.763	0.620	0.734	0.737	0.740	0.729	0.739	0.700	0.702	0.686	0.701
Weight of partial indexation employment	0.484	0.489	0.443	0.467	0.539	0.540	0.470	0.542	0.465	0.476	0.448	0.465	0.455	0.467	0.459	0.457
Weight of inflation indexation in domestic-output price	0.315	0.318	0.322	0.324	0.372	0.361	0.378	0.375	0.312	0.309	0.311	0.308	0.329	0.322	0.330	0.324
Weight of inflation indexation in import price	0.333	0.323	0.336	0.331	0.363	0.370	0.333	0.350	0.355	0.352	0.361	0.354	0.355	0.358	0.360	0.366
Weight of inflation indexation in wage setting	0.335	0.333	0.348	0.338	0.401	0.389	0.361	0.396	0.353	0.351	0.357	0.360	0.355	0.354	0.355	0.356
Weight of inflation indexation in export prices	0.261	0.263	0.250	0.260	0.269	0.276	0.258	0.262	0.270	0.271	0.276	0.262	0.278	0.276	0.272	0.274
Employment Calvo	0.737	0.731	0.766	0.754	0.717	0.710	0.719	0.693	0.734	0.725	0.736	0.725	0.702	0.699	0.702	0.700
Domestic-output-price Calvo	0.681	0.682	0.698	0.686	0.627	0.623	0.625	0.608	0.661	0.651	0.656	0.653	0.651	0.649	0.653	0.653
Import-price Calvo	0.591	0.589	0.609	0.605	0.604	0.593	0.596	0.567	0.502	0.505	0.497	0.493	0.508	0.505	0.494	0.496
Nominal-wage Calvo	0.622	0.625	0.636	0.647	0.506	0.521	0.572	0.506	0.562	0.578	0.569	0.574	0.616	0.623	0.622	0.626
Export-price Calvo	0.523	0.518	0.552	0.552	0.514	0.526	0.546	0.558	0.526	0.523	0.521	0.532	0.514	0.515	0.527	0.518
Weight of second lag in investment adjustment cost	0.444	0.444	0.464	0.459	0.403	0.405	0.464	0.405	0.425	0.424	0.440	0.433	0.438	0.444	0.444	0.448
Export-share in foreign output adjustment-cost	0.347	0.344	0.323	0.331	0.394	0.385	0.335	0.366	0.393	0.389	0.396	0.393	0.368	0.368	0.364	0.363
Risk-premium-function parameter	0.006	0.006	0.006	0.006	0.007	0.007	0.010	0.011	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Modified UIP parameter	0.266	0.269	0.270	0.258	0.339	0.314	0.256	0.257	0.289	0.289	0.311	0.308	0.344	0.339	0.357	0.348
Weight of oil in imports	0.153	0.153	0.158	0.155	0.169	0.168	0.168	0.157	0.139	0.139	0.140	0.137	0.151	0.148	0.149	0.148
Capital-utilization-cost parameter	0.020	0.020	0.020	0.022	0.016	0.017	0.017	0.016	0.018	0.018	0.018	0.018	0.020	0.021	0.021	0.021
5-10 year term premium	0.008	0.007	0.009	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
5-10 year foreign term premium	0.020	0.020	0.019	0.019	0.020	0.019	0.019	0.019	0.019	0.020	0.019	0.020	0.019	0.019	0.019	0.020
Foreign inflation equation: relative oil price	0.013	0.014	0.013	0.014	0.004	0.005	0.003	0.003	0.014	0.014	0.014	0.014	0.009	0.008	0.009	0.008
Foreign inflation equation: change in relative oil price	0.019	0.019	0.020	0.019	0.025	0.025	0.022	0.026	0.018	0.018	0.018	0.018	0.020	0.020	0.019	0.020
Foreign inflation equation: output	0.093	0.093	0.094	0.093	0.093	0.094	0.094	0.093	0.095	0.094	0.095	0.096	0.096	0.096	0.096	0.096
Persistence of foreign inflation shock	0.130	0.133	0.136	0.127	0.136	0.130	0.132	0.132	0.128	0.129	0.127	0.123	0.131	0.133	0.129	0.127
Foreign output equation: expectations	0.226	0.228	0.226	0.219	0.242	0.234	0.229	0.225	0.230	0.227	0.226	0.230	0.241	0.240	0.227	0.235
Foreign output equation: real interest rate	0.114	0.114	0.114	0.112	0.122	0.124	0.105	0.118	0.119	0.120	0.119	0.119	0.118	0.120	0.125	0.124

Notes: The complete estimation results are available upon request.

Table 9. Posterior Mean Results (2)

	Rules															
Parameter Name	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Persistence of technological shock	0.726	0.751	0.782	0.769	0.679	0.713	0.762	0.703	0.710	0.723	0.706	0.727	0.663	0.706	0.669	0.711
Persistence of labor-productivity-growth rate	0.853	0.862	0.871	0.888	0.741	0.711	0.859	0.674	0.816	0.824	0.813	0.826	0.716	0.734	0.704	0.717
Persistence of market premium shock	0.870	0.862	0.857	0.834	0.895	0.895	0.898	0.901	0.851	0.839	0.846	0.833	0.840	0.831	0.838	0.823
Persistence of FX risk-premium shock	0.629	0.626	0.663	0.674	0.676	0.655	0.680	0.716	0.534	0.537	0.527	0.528	0.471	0.481	0.455	0.474
Persistence of consumption-preference shock	0.255	0.252	0.260	0.265	0.234	0.249	0.345	0.263	0.259	0.259	0.265	0.265	0.279	0.286	0.286	0.285
Persistence of investment-specific technology shock	0.569	0.572	0.571	0.589	0.646	0.654	0.531	0.653	0.613	0.610	0.609	0.611	0.632	0.620	0.623	0.627
Persistence of inventories investment	0.756	0.745	0.673	0.670	0.841	0.846	0.881	0.906	0.755	0.746	0.765	0.752	0.840	0.842	0.858	0.849
Persistence of government expenditure	0.445	0.450	0.461	0.463	0.445	0.431	0.477	0.456	0.462	0.449	0.464	0.474	0.440	0.452	0.457	0.472
Persistence of export preference shock	0.968	0.969	0.963	0.963	0.970	0.966	0.928	0.912	0.972	0.972	0.972	0.973	0.979	0.979	0.979	0.982
Persistence of home-bias in production of consumption-good	0.967	0.967	0.968	0.965	0.936	0.937	0.959	0.942	0.966	0.965	0.967	0.966	0.967	0.963	0.967	0.964
Persistence of domestic-price-markup shock	0.215	0.209	0.216	0.212	0.211	0.219	0.222	0.223	0.207	0.207	0.202	0.208	0.211	0.205	0.206	0.211
Persistence of import-price-markup shock	0.275	0.268	0.270	0.269	0.260	0.263	0.267	0.256	0.268	0.263	0.259	0.266	0.261	0.262	0.261	0.261
Persistence of wage-markup shock	0.373	0.371	0.369	0.385	0.328	0.334	0.342	0.338	0.342	0.350	0.342	0.351	0.368	0.366	0.368	0.374
Persistence of export-price shock	0.231	0.241	0.234	0.233	0.248	0.237	0.238	0.230	0.229	0.237	0.242	0.233	0.247	0.245	0.244	0.255
Persistence of foreign transfers in domestic nominal output	0.289	0.295	0.319	0.306	0.280	0.283	0.617	0.322	0.291	0.288	0.289	0.292	0.271	0.271	0.280	0.269
Persistence of GDP deflator observation error	-0.199	-0.192	-0.243	-0.235	-0.135	-0.140	-0.144	-0.155	-0.179	-0.170	-0.170	-0.169	-0.175	-0.169	-0.168	-0.178
Persistence of per-capita employment shock	0.424	0.420	0.443	0.411	0.369	0.368	0.366	0.338	0.477	0.472	0.512	0.489	0.506	0.480	0.486	0.481
Persistence of fw-rate observation error	0.949	0.954	0.935	0.940	0.962	0.969	0.960	0.965	0.948	0.957	0.943	0.952	0.961	0.967	0.962	0.968
Persistence of foreign fw-rate observation error	0.743	0.743	0.736	0.740	0.741	0.737	0.748	0.751	0.735	0.739	0.742	0.732	0.741	0.735	0.735	0.733
Persistence of foreign demand shock	0.460	0.454	0.470	0.460	0.426	0.427	0.449	0.435	0.448	0.449	0.449	0.450	0.449	0.450	0.453	0.454
Foreign inflation equation: expectations	0.963	0.964	0.967	0.967	0.964	0.964	0.965	0.964	0.963	0.966	0.964	0.966	0.963	0.966	0.965	0.966
Foreign interest rate equation: smoothing	0.842	0.841	0.842	0.839	0.845	0.843	0.853	0.836	0.845	0.842	0.846	0.846	0.850	0.849	0.851	0.850
Foreign interest rate equation: inflation	1.638	1.638	1.647	1.633	1.676	1.706	1.744	1.590	1.687	1.630	1.682	1.697	1.737	1.722	1.742	1.719
Foreign interest rate equation: output gap	0.336	0.339	0.338	0.337	0.313	0.317	0.287	0.319	0.307	0.320	0.327	0.316	0.313	0.304	0.313	0.304
Persistence of foreign-interest rate shock	0.306	0.307	0.305	0.314	0.297	0.297	0.310	0.279	0.303	0.307	0.307	0.305	0.304	0.297	0.301	0.295
Investment-adjustment cost	2.751	2.860	3.063	3.084	2.745	2.670	2.689	2.545	2.772	2.823	2.811	2.848	2.591	2.501	2.521	2.564
Elasticity of world imports wrt GDP	2.545	2.580	2.516	2.545	2.567	2.579	2.634	2.583	2.565	2.565	2.531	2.530	2.556	2.552	2.564	2.570
Weight of lagged foreign output in world import gap	1.886	1.837	1.882	1.904	1.903	1.907	1.904	1.928	1.904	1.884	1.945	1.895	1.922	1.920	1.914	1.892
Persistence of world import gap	0.093	0.092	0.086	0.080	0.102	0.112	0.104	0.096	0.093	0.091	0.092	0.092	0.102	0.102	0.097	0.100
Persistence AR(1) of relative oil price	0.807	0.790	0.809	0.794	0.936	0.920	0.956	0.945	0.797	0.798	0.803	0.799	0.861	0.873	0.868	0.876
Persistence AR(2) of relative oil price	-0.265	-0.268	-0.261	-0.266	-0.211	-0.226	-0.208	-0.227	-0.280	-0.277	-0.280	-0.280	-0.266	-0.260	-0.274	-0.270

Notes: The complete estimation results are available upon request.

C Counterfactual Analysis

To avoid any leap in the normative sense, we compare the losses of monetary policy rules within the same model (i.e., all parameters except the policy rule remain constant) without assuming different shocks (since they were estimated each time in the previous sections), allowing us to draw normative conclusions.

As a laboratory, we assume posteriors from the best-fit model (see Table 2). Filtering the model under posterior draws from the best-fit rule (Rule 14), we provide shock sequences that can be fed into an otherwise identical model outside the monetary policy rule. In order to evaluate the potential benefits of alternative monetary policies, we compare counterfactual measures of output and inflation variances. As a result, a distribution of outcomes is generated for each potential alternative rule.

Table 10 presents the loss for each model and variables according to the estimated variance using posteriors from the best-fit model across the full sample.

Table 10. Estimated Variances - Laboratory

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$	0.18	0.19	0.21	0.23	0.17	0.17	0.17	0.18	0.15	0.15	0.16	0.16	0.17	0.17	0.18	0.18
$\hat{\pi}_t^C$	0.20	0.21	0.25	0.27	0.17	0.18	0.19	0.20	0.08	0.08	0.09	0.09	0.11	0.11	0.12	0.13
$\hat{\pi}_t^H$	0.11	0.12	0.14	0.16	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.11	0.11	0.12	0.12
$\hat{y}_t^{GAP}$	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.03	0.03	0.03	0.03
$\Delta\hat{y}_t$	0.33	0.34	0.33	0.34	0.43	0.46	0.44	0.46	0.42	0.43	0.42	0.43	0.36	0.37	0.35	0.36
ΔS_t	1.30	1.30	1.55	1.56	1.41	1.50	1.63	1.75	0.77	0.79	0.86	0.87	0.82	0.84	0.90	0.93

Notes: Losses based on variances simulated after Bayesian estimation of the best-fit model over the full sample. The losses are presented for each rule (1 to 16). The shading scheme is defined independently for each row, where lighter shading indicates lower losses (rescaled numbers).

Table 10 shows that variances of GDP deflator ($\hat{\pi}_t^Y$) and CPI inflation ($\hat{\pi}_t^C$) rates are low when Taylor-type rules are considered, while NGDP level rules reduce domestic intermediate good inflation ($\hat{\pi}_t^H$) variances. NGDP growth rules reduce GDP growth variances better than other rules.

Table 11 presents the variances of policymaker variables under scrutiny following critical economic shocks, similar to Table 4, using posteriors from the best-fit model.

Table 11 highlights the high performance of NGDP targeting rules in mitigating GDP deflator and CPI inflation variances following domestic and foreign price markup shocks. For instance, rule 6 (NGDP level targeting) minimizes output growth, nominal depreciation, GDP deflator and CPI inflation variances following a foreign price markup shock. IT rules also perform well in minimizing GDP deflator inflation and CPI inflation variances, while NGDP level rules minimize domestic intermediate good inflation, output gap and growth, and nominal depreciation variances, following a consumption preference shock. Following a productivity shock, NGDP growth targeting rules minimize output growth and nominal depreciation variances, while the variances of other variables are minimized similarly by both types of rules. This may reflect the stabilization properties of NGDP rules compared to IT rules (Hendrickson, 2012; Beckworth and Hendrickson, 2020).

Table 12 shows the full sample estimated losses from a spectrum of central bank loss functions.[20]

Given central bank objectives to minimize the variance of domestic intermediate good inflation ($\hat{\pi}_t^H$), NGDP level targeting performs better than other rules. IT rules with output growth targeting perform well for the GDP deflator ($\hat{\pi}_t^Y$) and CPI ($\hat{\pi}_t^C$) inflation objectives, especially rule 9. The best rules from this targeting regime also appear to target nominal depreciation.

Table 13 shows the IRF-based losses following domestic and foreign price markup shocks, a productivity shock, and a consumption preference shock for a spectrum of central bank loss functions simulated according to the best-fit model.

The IRF-based losses presented in Table 13 are also point to the superiority of NGDP rules for several policymaker preferences, except following domestic price markup shocks where Taylor-type rules perform better for most inflation measures. However, this is less critical regarding SOEs significantly affected by foreign price markup shocks.

If the central bank seeks to stabilize the different measures of inflation, and as-

[20]If the full sample contains T periods, Table 5 considers $\mathbb{E}_T[L_t]$, which corresponds to estimations over the full information set.

Table 11. Impulse Response-Based Variances - Laboratory

Productivity Shock

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$	0.34	0.26	0.35	0.28	0.25	0.11	0.24	0.09	0.22	0.15	0.22	0.15	0.17	0.11	0.17	0.11
$\hat{\pi}_t^C$	0.19	0.15	0.20	0.17	0.11	0.13	0.10	0.13	0.08	0.05	0.08	0.05	0.05	0.03	0.04	0.02
$\hat{\pi}_t^H$	0.42	0.36	0.43	0.38	0.34	0.26	0.34	0.24	0.34	0.28	0.33	0.28	0.30	0.26	0.30	0.25
$\hat{y}_t^{GAP}$	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
$\Delta\hat{y}_t$	0.20	0.38	0.19	0.40	0.29	0.76	0.29	0.82	0.30	0.48	0.30	0.51	0.36	0.54	0.37	0.57
ΔS_t	0.04	0.14	0.04	0.17	0.06	1.74	0.08	2.08	0.19	0.53	0.22	0.61	0.47	0.93	0.53	1.05

Consumption Preference Shock

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$	0.10	0.10	0.12	0.13	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01
$\hat{\pi}_t^C$	0.09	0.09	0.12	0.12	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
$\hat{\pi}_t^H$	0.06	0.06	0.08	0.08	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02
$\hat{y}_t^{GAP}$	0.09	0.09	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.09	0.09	0.09	0.09
$\Delta\hat{y}_t$	4.60	4.62	4.62	4.64	5.33	5.36	5.34	5.37	5.27	5.28	5.28	5.29	4.85	4.86	4.82	4.82
ΔS_t	1.27	1.28	1.41	1.42	0.02	0.02	0.02	0.02	0.06	0.06	0.07	0.07	0.22	0.22	0.25	0.25

Home Price Markup Shock

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$	2.45	2.45	2.47	2.46	2.46	2.46	2.46	2.46	1.91	1.91	1.89	1.89	2.03	2.03	2.02	2.02
$\hat{\pi}_t^C$	1.48	1.48	1.49	1.49	1.46	1.46	1.46	1.46	1.15	1.15	1.14	1.14	1.23	1.23	1.23	1.23
$\hat{\pi}_t^H$	3.48	3.48	3.49	3.49	3.46	3.46	3.46	3.46	3.35	3.35	3.35	3.35	3.41	3.41	3.41	3.41
$\hat{y}_t^{GAP}$	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.07	0.07	0.07	0.07	0.05	0.05	0.05	0.05
$\Delta\hat{y}_t$	1.40	1.40	1.39	1.39	1.42	1.42	1.42	1.42	1.97	1.97	1.98	1.98	1.67	1.67	1.67	1.67
ΔS_t	0.05	0.04	0.05	0.05	0.00	0.00	0.00	0.00	0.65	0.65	0.71	0.71	0.61	0.61	0.64	0.64

Foreign Price Markup Shock

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$	0.49	0.48	0.49	0.49	0.38	0.38	0.38	0.38	1.03	1.03	1.06	1.07	1.08	1.08	1.12	1.12
$\hat{\pi}_t^C$	8.14	8.13	8.19	8.19	8.03	8.03	8.03	8.04	6.35	6.35	6.31	6.30	6.31	6.30	6.26	6.26
$\hat{\pi}_t^H$	0.24	0.24	0.25	0.25	0.20	0.20	0.20	0.20	0.13	0.13	0.13	0.13	0.15	0.15	0.15	0.15
$\hat{y}_t^{GAP}$	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
$\Delta\hat{y}_t$	2.15	2.15	2.14	2.14	2.35	2.35	2.35	2.35	1.64	1.64	1.62	1.62	1.65	1.65	1.63	1.63
ΔS_t	0.21	0.21	0.26	0.25	0.01	0.01	0.01	0.01	3.91	3.91	4.20	4.20	4.21	4.21	4.51	4.51

Notes: Losses based on simulated variances of the IRFs computed over 40 periods after the Bayesian estimation of the best-fit model over the full sample. Shock processes are defined in Argov et al. (2012) and shock size estimates are available in Appendix B, Rule 14. The shading scheme is defined independently for each row, where lighter shading indicates lower losses (rescaled numbers).

Table 12. Loss Functions - Estimated Variances - Laboratory

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$ λ_y=0.0	1.77	1.89	2.08	2.26	1.67	1.68	1.75	1.76	1.50	1.52	1.56	1.57	1.69	1.71	1.79	1.83
$\hat{\pi}_t^Y$ λ_y=0.5	2.00	2.12	2.31	2.49	1.91	1.91	1.98	1.99	1.74	1.75	1.79	1.81	1.85	1.88	1.96	1.99
$\hat{\pi}_t^Y$ λ_y=1.0	2.22	2.34	2.54	2.72	2.14	2.15	2.21	2.23	1.97	1.98	2.03	2.04	2.02	2.05	2.12	2.15
$\hat{\pi}_t^C$ λ_y=0.0	1.98	2.10	2.49	2.66	1.70	1.81	1.87	1.99	0.80	0.83	0.87	0.90	1.11	1.15	1.23	1.27
$\hat{\pi}_t^C$ λ_y=0.5	2.21	2.32	2.72	2.89	1.94	2.04	2.10	2.22	1.03	1.06	1.10	1.13	1.28	1.32	1.39	1.44
$\hat{\pi}_t^C$ λ_y=1.0	2.43	2.54	2.95	3.12	2.17	2.27	2.33	2.45	1.27	1.29	1.34	1.37	1.45	1.49	1.55	1.60
$\hat{\pi}_t^H$ λ_y=0.0	1.11	1.25	1.36	1.56	0.85	0.87	0.86	0.89	0.90	0.92	0.93	0.95	1.09	1.12	1.17	1.21
$\hat{\pi}_t^H$ λ_y=0.5	1.34	1.47	1.59	1.79	1.08	1.11	1.09	1.12	1.14	1.16	1.16	1.19	1.26	1.29	1.33	1.37
$\hat{\pi}_t^H$ λ_y=1.0	1.56	1.69	1.82	2.02	1.32	1.34	1.32	1.35	1.37	1.39	1.40	1.42	1.43	1.46	1.50	1.54

Notes: Central bank losses from variances simulated after the Bayesian estimation of the best-fit model over the full sample, for each rule (1 to 16). The shading scheme is defined independently for each row, where lighter shading indicates lower losses.

Table 13. Impulse Response-Based Loss Functions - Laboratory

Productivity Shock

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$ λ_y=0.0	3.39	2.63	3.46	2.76	2.48	1.12	2.42	0.92	2.22	1.52	2.18	1.46	1.74	1.15	1.69	1.07
$\hat{\pi}_t^Y$ λ_y=0.5	3.59	2.82	3.66	2.95	2.67	1.31	2.61	1.10	2.39	1.69	2.35	1.62	1.90	1.30	1.85	1.23
$\hat{\pi}_t^Y$ λ_y=1.0	3.78	3.01	3.86	3.15	2.85	1.49	2.79	1.29	2.56	1.86	2.52	1.79	2.06	1.46	2.01	1.38
$\hat{\pi}_t^C$ λ_y=0.0	1.88	1.47	1.96	1.65	1.05	1.34	1.00	1.30	0.80	0.52	0.77	0.49	0.45	0.27	0.42	0.24
$\hat{\pi}_t^C$ λ_y=0.5	2.07	1.66	2.16	1.85	1.24	1.53	1.19	1.48	0.97	0.68	0.94	0.65	0.61	0.43	0.57	0.40
$\hat{\pi}_t^C$ λ_y=1.0	2.27	1.85	2.35	2.04	1.43	1.72	1.37	1.67	1.14	0.85	1.11	0.82	0.77	0.58	0.73	0.55
$\hat{\pi}_t^H$ λ_y=0.0	4.21	3.63	4.27	3.76	3.45	2.56	3.41	2.38	3.36	2.84	3.34	2.79	3.04	2.57	3.02	2.51
$\hat{\pi}_t^H$ λ_y=0.5	4.40	3.82	4.46	3.95	3.63	2.74	3.60	2.56	3.53	3.01	3.51	2.96	3.20	2.72	3.17	2.67
$\hat{\pi}_t^H$ λ_y=1.0	4.60	4.01	4.66	4.14	3.82	2.93	3.78	2.75	3.70	3.17	3.68	3.13	3.36	2.88	3.33	2.82

Consumption Preference Shock

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$ λ_y=0.0	0.10	0.10	0.12	0.13	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01
$\hat{\pi}_t^Y$ λ_y=0.5	0.14	0.15	0.17	0.17	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.06	0.06	0.06	0.06
$\hat{\pi}_t^Y$ λ_y=1.0	0.19	0.19	0.22	0.22	0.12	0.13	0.12	0.13	0.13	0.13	0.13	0.13	0.10	0.10	0.10	0.10
$\hat{\pi}_t^C$ λ_y=0.0	0.09	0.09	0.12	0.12	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
$\hat{\pi}_t^C$ λ_y=0.5	0.14	0.14	0.17	0.17	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.06	0.06
$\hat{\pi}_t^C$ λ_y=1.0	0.18	0.18	0.22	0.22	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.10	0.10	0.10	0.10
$\hat{\pi}_t^H$ λ_y=0.0	0.06	0.06	0.08	0.08	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02
$\hat{\pi}_t^H$ λ_y=0.5	0.10	0.10	0.13	0.13	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.06	0.06	0.06	0.06
$\hat{\pi}_t^H$ λ_y=1.0	0.15	0.15	0.17	0.17	0.13	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.11	0.11	0.11	0.11

Domestic Price Markup Shock

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$ λ_y=0.0	2.45	2.45	2.47	2.46	2.46	2.46	2.46	2.46	1.91	1.91	1.89	1.89	2.03	2.03	2.02	2.02
$\hat{\pi}_t^Y$ λ_y=0.5	2.48	2.48	2.49	2.49	2.49	2.49	2.49	2.49	1.95	1.95	1.93	1.93	2.05	2.05	2.05	2.05
$\hat{\pi}_t^Y$ λ_y=1.0	2.50	2.50	2.52	2.51	2.51	2.51	2.51	2.52	1.98	1.98	1.96	1.96	2.08	2.08	2.08	2.08
$\hat{\pi}_t^C$ λ_y=0.0	1.48	1.48	1.49	1.49	1.46	1.46	1.46	1.46	1.15	1.15	1.14	1.14	1.23	1.23	1.23	1.23
$\hat{\pi}_t^C$ λ_y=0.5	1.51	1.51	1.52	1.52	1.49	1.49	1.49	1.49	1.18	1.18	1.17	1.17	1.25	1.25	1.26	1.26
$\hat{\pi}_t^C$ λ_y=1.0	1.53	1.53	1.54	1.54	1.51	1.51	1.52	1.52	1.21	1.21	1.20	1.20	1.28	1.28	1.28	1.28
$\hat{\pi}_t^H$ λ_y=0.0	3.48	3.48	3.49	3.49	3.46	3.46	3.46	3.46	3.35	3.35	3.35	3.35	3.41	3.41	3.41	3.41
$\hat{\pi}_t^H$ λ_y=0.5	3.51	3.51	3.51	3.51	3.48	3.49	3.49	3.49	3.39	3.39	3.38	3.38	3.43	3.43	3.44	3.44
$\hat{\pi}_t^H$ λ_y=1.0	3.53	3.53	3.54	3.54	3.51	3.51	3.51	3.51	3.42	3.42	3.42	3.42	3.46	3.46	3.46	3.46

Foreign Price Markup Shock

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$ λ_y=0.0	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11
$\hat{\pi}_t^Y$ λ_y=0.5	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11
$\hat{\pi}_t^Y$ λ_y=1.0	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
$\hat{\pi}_t^C$ λ_y=0.0	0.81	0.81	0.82	0.82	0.80	0.80	0.80	0.80	0.64	0.64	0.63	0.63	0.63	0.63	0.63	0.63
$\hat{\pi}_t^C$ λ_y=0.5	0.82	0.82	0.82	0.82	0.80	0.80	0.81	0.81	0.64	0.64	0.63	0.63	0.63	0.63	0.63	0.63
$\hat{\pi}_t^C$ λ_y=1.0	0.82	0.82	0.82	0.82	0.81	0.81	0.81	0.81	0.64	0.64	0.63	0.63	0.63	0.63	0.63	0.63
$\hat{\pi}_t^H$ λ_y=0.0	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02
$\hat{\pi}_t^H$ λ_y=0.5	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
$\hat{\pi}_t^H$ λ_y=1.0	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

Notes: Central bank losses based on variances of the IRFs simulated over 40 periods after the Bayesian estimation of the best-fit model over the full sample for each rule (1 to 16). Shock processes are defined in Argov et al. (2012) and shock size estimates are available in Appendix B, Rule 14. The shading scheme is defined independently for each row, where lighter shading indicates lower losses (rescaled numbers).

suming the central bank knows all the information in the (full) sample to estimate their economic models, an NGDP level targeting rule outperforms a number of alternatives.

Table 13 highlights that NGDP level targeting stabilizes central bank loss functions considering the GDP deflator ($\hat{\pi}_t^Y$) and domestic intermediate good ($\hat{\pi}_t^H$) inflation rates better than IT rules following a productivity shock, and only GDP deflator inflation following an import price markup shock (international shock), key for SOEs like Israel.

This *laboratory* counterfactual analysis does not exclude the relevance of NGDP rules for various shocks and inflation-type objectives.

D Zero Lower Bound

The estimations presented in the paper include a short period where the nominal interest rate was potentially at the ZLB. First, the duration of the ZLB period in our sample differs substantially between the US (approximately 30 quarters) and Israel (approximately 12 quarters), limiting cross-country comparability of the ZLB duration. Second, the nature of the ZLB in Israel is distinct from that of other economies. Notably, Israel never reached the zero nominal interest rate during the aforementioned 12 ZLB quarters, with the minimum nominal interest rate hovering at 0.10%. Finally, our estimations rely on a linear model where considering the ZLB would necessitate employing a non-linear model, which would significantly complicate, if not entirely preclude, the computational tractability of our analysis and potentially compromise the clarity of the paper.

Consequently, we reestimate our model over the pre-ZLB period (1994-2015) to test the robustness of our full sample results presented in the paper and how the absence of the ZLB period changes our main results.

The estimates of the monetary policy rule parameters over the full sample (Figure 4) did not change significantly when controlling for the ZLB period (Figure 5).

Figure 5 indicates that including the ZLB period in the estimation has little effect on the magnitude of the estimated monetary policy rule parameters.

Table 14 shows the losses for each model and variable based on the estimated variances calculated over the pre-ZLB period.

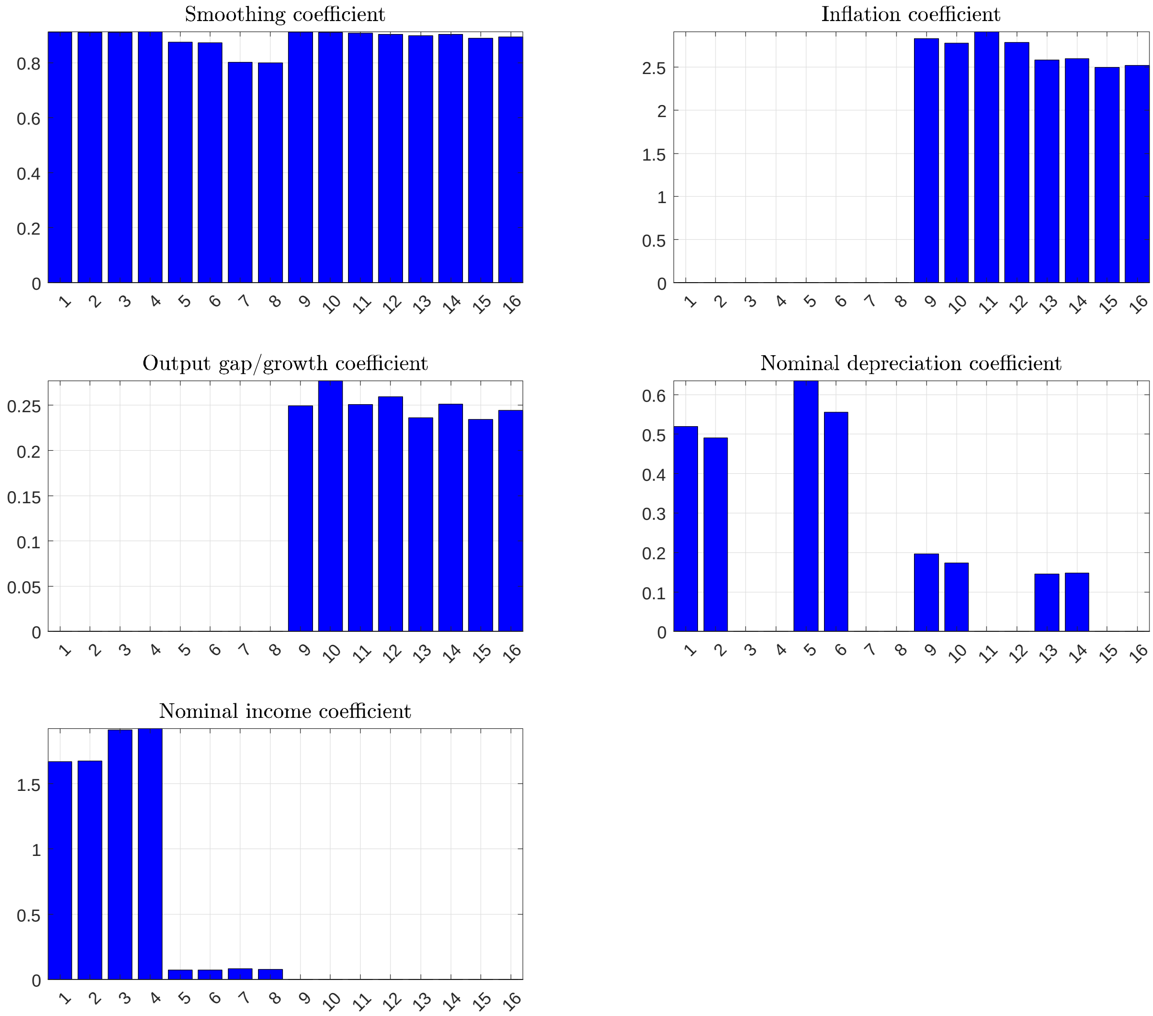
Table 14 shows that variances of the CPI inflation ($\hat{\pi}_t^C$) rate are low when Taylor-type rules are considered, while NGDP level rules best reduce GDP deflator ($\hat{\pi}_t^Y$) and domestic intermediate good ($\hat{\pi}_t^H$) inflation rate variances. NGDP level rules also reduce GDP growth and gap variances better than other rules.

Table 14. Estimated Variances - Pre-ZLB Period

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$	0.17	0.18	0.25	0.27	0.20	0.19	0.15	0.20	0.16	0.16	0.16	0.16	0.18	0.19	0.19	0.20
$\hat{\pi}_t^C$	0.15	0.16	0.23	0.25	0.16	0.16	0.16	0.16	0.09	0.09	0.09	0.10	0.12	0.14	0.14	0.15
$\hat{\pi}_t^H$	0.11	0.12	0.17	0.19	0.15	0.14	0.07	0.13	0.10	0.10	0.10	0.10	0.12	0.13	0.13	0.14
$\hat{y}_t^{GAP}$	0.04	0.04	0.03	0.04	0.04	0.04	0.04	0.03	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03
$\Delta\hat{y}_t$	0.37	0.38	0.36	0.39	0.45	0.46	0.34	0.43	0.43	0.43	0.42	0.43	0.36	0.37	0.35	0.36
ΔS_t	0.97	0.99	1.51	1.56	0.86	0.93	1.43	1.42	0.83	0.85	0.93	0.94	0.88	0.92	0.96	1.00

Notes: Losses based on estimated variance from the Bayesian estimation for each rule (1 to 16) over the pre-ZLB period. The shading scheme is defined independently for each row, where lighter shading indicates lower losses (rescaled numbers).

Figure 5. Estimated Coefficients of the Rules - Pre-ZLB Period



The relative performance of policy rules concerning each key central bank variable remains relatively the same from the estimations over the pre-ZLB period compared to the estimates obtained over the full sample.

Table 15 presents the variances of policymaker variables under scrutiny following critical economic shocks under the pre-ZLB period, similar to Table 4.

While the Israeli ZLB period involved strictly positive interest rates of +0.1%, including this ZLB period in the model estimation may introduce some nonlinearities and change the results obtained over the full sample presented in the paper. However, Table 15 shows that controlling for the ZLB period slightly alters the IRFs of the model compared to Table 4. Importantly, this difference does not affect the core results - the estimated central bank losses under full and limited information.

Table 15 further emphasizes the effectiveness of NGDP targeting rules in reducing variances of GDP deflator and CPI inflation after a foreign price markup

Table 15. Impulse Response-Based Variances - Pre-ZLB (1994-2015)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$	0.35	0.31	0.41	0.40	0.32	0.20	0.21	0.09	0.21	0.16	0.20	0.15	0.16	0.12	0.15	0.11
$\hat{\pi}_t^C$	0.19	0.16	0.23	0.22	0.17	0.17	0.06	0.09	0.09	0.06	0.08	0.05	0.05	0.03	0.05	0.03
$\hat{\pi}_t^H$	0.44	0.43	0.51	0.52	0.45	0.40	0.36	0.33	0.34	0.32	0.34	0.32	0.30	0.29	0.29	0.28
$\hat{y}_t^{GAP}$	0.04	0.04	0.04	0.05	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
$\Delta\hat{y}_t$	0.21	0.41	0.21	0.49	0.26	0.66	0.52	0.94	0.26	0.47	0.27	0.49	0.30	0.55	0.31	0.59
ΔS_t	0.02	0.13	0.04	0.17	0.02	1.11	0.59	2.61	0.17	0.55	0.21	0.64	0.39	0.94	0.46	1.09

Productivity Shock

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$	0.08	0.08	0.17	0.16	0.05	0.04	0.02	0.05	0.03	0.03	0.02	0.03	0.01	0.01	0.01	0.01
$\hat{\pi}_t^C$	0.06	0.06	0.15	0.14	0.03	0.02	0.02	0.04	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01
$\hat{\pi}_t^H$	0.05	0.05	0.12	0.10	0.06	0.05	0.00	0.06	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02
$\hat{y}_t^{GAP}$	0.10	0.10	0.12	0.12	0.12	0.12	0.06	0.11	0.11	0.11	0.10	0.10	0.09	0.09	0.08	0.08
$\Delta\hat{y}_t$	5.18	5.12	4.85	5.20	5.94	5.95	4.48	5.81	5.54	5.48	5.49	5.42	5.06	5.02	4.99	4.96
ΔS_t	0.71	0.73	1.15	0.99	0.01	0.02	0.48	0.04	0.05	0.05	0.05	0.06	0.21	0.21	0.24	0.25

Consumption Preference Shock

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$	2.24	2.18	2.29	2.10	2.32	2.32	3.75	2.80	1.68	1.70	1.63	1.66	2.00	2.04	1.97	2.00
$\hat{\pi}_t^C$	1.39	1.34	1.45	1.31	1.44	1.43	2.30	1.76	1.08	1.10	1.06	1.08	1.27	1.29	1.25	1.27
$\hat{\pi}_t^H$	3.26	3.16	3.39	3.06	3.40	3.40	5.40	4.15	3.07	3.11	3.10	3.13	3.49	3.53	3.48	3.52
$\hat{y}_t^{GAP}$	0.04	0.04	0.04	0.04	0.04	0.04	0.09	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05
$\Delta\hat{y}_t$	1.28	1.23	1.22	1.14	1.32	1.32	2.61	1.62	1.67	1.66	1.74	1.72	1.65	1.63	1.67	1.66
ΔS_t	0.02	0.02	0.03	0.03	0.00	0.00	0.02	0.00	0.49	0.49	0.63	0.60	0.57	0.54	0.67	0.64

Home Price Markup Shock

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$	0.21	0.23	0.21	0.23	0.15	0.17	0.45	0.21	0.67	0.68	0.75	0.76	0.71	0.71	0.79	0.78
$\hat{\pi}_t^C$	3.74	4.08	3.37	3.92	3.01	3.38	7.43	3.96	4.05	4.12	4.06	4.12	4.10	4.17	4.14	4.19
$\hat{\pi}_t^H$	0.11	0.12	0.13	0.11	0.14	0.16	0.36	0.19	0.09	0.10	0.09	0.10	0.12	0.12	0.12	0.13
$\hat{y}_t^{GAP}$	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01
$\Delta\hat{y}_t$	0.97	1.08	0.90	1.08	0.81	0.91	1.73	1.07	1.01	1.03	1.02	1.03	1.02	1.05	1.03	1.05
ΔS_t	0.05	0.06	0.07	0.08	0.00	0.00	0.06	0.00	2.04	2.08	2.54	2.50	2.54	2.48	2.99	2.88

Foreign Price Markup Shock

Notes: Losses based on simulated variances of the IRFs calculated over 40 periods and derived from the Bayesian estimation of the models over the pre-ZLB period. Shock processes are defined in Argov et al. (2012) and shock size estimates are available upon request. The shading scheme is defined independently for each row, where lighter shading indicates lower losses (rescaled numbers).

shock. For example, rule 5 (NGDP level targeting) minimizes output growth, nominal depreciation, and variances of both GDP deflator and CPI inflation following such a shock. IT rules also perform well in minimizing variances of GDP deflator and CPI inflation. However, NGDP level targeting rules outperform in minimizing variances of domestic intermediate good inflation, output gap, output growth, and nominal depreciation following a consumption preference shock. Finally, following a productivity shock, NGDP level targeting rules excel at minimizing GDP deflator variance, while NGDP growth targeting rules are best at minimizing output growth and nominal depreciation variances.

Table 16 shows the estimated losses over the pre-ZLB period from a spectrum of central bank loss functions.[21]

Table 16. Loss Functions - Estimated Variances - Pre-ZLB (1994-2015)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$ λ_y=0.0	1.69	1.76	2.46	2.69	1.98	1.92	1.50	2.00	1.58	1.59	1.63	1.63	1.79	1.89	1.91	2.02
$\hat{\pi}_t^Y$ λ_y=0.5	1.88	1.95	2.62	2.87	2.17	2.11	1.70	2.16	1.79	1.80	1.84	1.84	1.96	2.06	2.07	2.19
$\hat{\pi}_t^Y$ λ_y=1.0	2.06	2.13	2.79	3.06	2.36	2.30	1.90	2.31	1.99	2.00	2.04	2.04	2.13	2.23	2.23	2.35
$\hat{\pi}_t^C$ λ_y=0.0	1.47	1.55	2.28	2.51	1.61	1.64	1.63	1.59	0.88	0.91	0.93	0.96	1.25	1.37	1.38	1.51
$\hat{\pi}_t^C$ λ_y=0.5	1.65	1.74	2.45	2.69	1.81	1.83	1.84	1.75	1.08	1.11	1.14	1.16	1.42	1.54	1.54	1.67
$\hat{\pi}_t^C$ λ_y=1.0	1.84	1.92	2.61	2.88	2.00	2.02	2.04	1.90	1.29	1.32	1.34	1.36	1.59	1.72	1.70	1.84
$\hat{\pi}_t^H$ λ_y=0.0	1.13	1.22	1.67	1.86	1.47	1.43	0.74	1.30	0.97	1.00	0.98	1.00	1.19	1.31	1.28	1.41
$\hat{\pi}_t^H$ λ_y=0.5	1.32	1.40	1.83	2.05	1.66	1.62	0.94	1.46	1.17	1.20	1.18	1.20	1.36	1.48	1.44	1.57
$\hat{\pi}_t^H$ λ_y=1.0	1.51	1.59	2.00	2.23	1.86	1.81	1.15	1.61	1.38	1.40	1.38	1.40	1.53	1.65	1.61	1.74

Notes: Central bank losses based on estimated variance from the Bayesian estimation for each rule (1 to 16) over the pre-ZLB period. The shading scheme is defined independently for each row, where lighter shading indicates lower losses.

NGDP level targeting outperforms other rules in minimizing variances of do-

[21]If the pre-ZLB period contains T periods, Table 5 considers $\mathbb{E}_T[L_t]$, which corresponds to estimations over the full information set.

mestic intermediate good inflation ($\hat{\pi}_t^H$) and GDP deflator ($\hat{\pi}_t^Y$). For CPI inflation ($\hat{\pi}_t^C$) objectives, IT rules with output growth targeting perform well, particularly rule 9. Notably, the best rules within this regime also appear to target nominal depreciation.

Table 17 presents central bank losses based on IRFs following various domestic and foreign price markups, productivity, and consumption preference shocks. The losses are calculated for a range of estimated central bank loss functions over the pre-ZLB period.

The IRF-based losses presented in Table 17 also point to the superiority of NGDP rules for several policymaker preferences, even following domestic price markup shocks concerning the domestic intermediate good inflation. NGDP level targeting proves more effective than IT rules in stabilizing central bank loss functions, particularly for GDP deflator inflation ($\hat{\pi}_t^Y$) following productivity, consumption preference, and foreign price markup shocks.

The ZLB period may alter the trade-offs between stabilizing inflation, output, and exchange rates faced by the central bank. Controlling for the ZLB period does introduce minor changes to the transmission mechanism. As evidenced by comparing Table 17 with Table 6, the ZLB period slightly influences the estimated IRFs, involving the dynamics and transmission of shocks within our models to also slightly differ.

Our analysis under full information suggests that controlling for the ZLB period does not significantly change the estimated weights within the rules and central bank loss functions, even when considering various definitions and central bank preferences, compared to the results over the full sample.

Table 18 presents the estimations of the expected value of loss functions given the information available at the current date ($\mathbb{E}_t\left[L_t\right]$) over the pre-ZLB period.

Even when controlling for the ZLB period and limited to real-time information available up to the current date, like real-world policymakers, NGDP level targeting rules still appear to minimize most central bank loss functions. This suggests that NGDP targeting could be a valuable tool for real-world decision-making, even when controlling for potential nonlinearities introduced by the ZLB period.

Table 17. Impulse Response-Based Loss Functions - Pre-ZLB (1994-2015)

Productivity Shock

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$ λ_y=0.0	3.49	3.10	4.09	3.99	3.20	1.96	2.08	0.85	2.13	1.64	2.01	1.52	1.60	1.19	1.50	1.07
$\hat{\pi}_t^Y$ λ_y=0.5	3.69	3.31	4.29	4.25	3.36	2.13	2.22	1.01	2.28	1.80	2.17	1.68	1.74	1.32	1.64	1.21
$\hat{\pi}_t^Y$ λ_y=1.0	3.89	3.51	4.49	4.51	3.52	2.29	2.36	1.17	2.44	1.95	2.32	1.83	1.88	1.46	1.77	1.34
$\hat{\pi}_t^C$ λ_y=0.0	1.93	1.62	2.34	2.19	1.66	1.75	0.62	0.91	0.87	0.58	0.78	0.52	0.52	0.33	0.45	0.28
$\hat{\pi}_t^C$ λ_y=0.5	2.13	1.83	2.54	2.45	1.82	1.91	0.76	1.07	1.03	0.74	0.93	0.68	0.66	0.47	0.58	0.42
$\hat{\pi}_t^C$ λ_y=1.0	2.33	2.03	2.75	2.71	1.98	2.08	0.90	1.23	1.18	0.89	1.09	0.83	0.79	0.60	0.72	0.55
$\hat{\pi}_t^H$ λ_y=0.0	4.37	4.29	5.12	5.20	4.45	4.00	3.63	3.33	3.39	3.25	3.36	3.19	3.02	2.89	2.94	2.80
$\hat{\pi}_t^H$ λ_y=0.5	4.57	4.49	5.32	5.45	4.61	4.16	3.77	3.49	3.55	3.40	3.51	3.35	3.15	3.03	3.07	2.93
$\hat{\pi}_t^H$ λ_y=1.0	4.77	4.70	5.53	5.71	4.77	4.33	3.91	3.65	3.70	3.56	3.66	3.50	3.29	3.16	3.20	3.06

Consumption Preference Shock

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$ λ_y=0.0	0.08	0.08	0.17	0.16	0.05	0.04	0.02	0.05	0.03	0.03	0.02	0.03	0.01	0.01	0.01	0.01
$\hat{\pi}_t^Y$ λ_y=0.5	0.13	0.13	0.23	0.22	0.10	0.10	0.05	0.10	0.08	0.08	0.08	0.08	0.05	0.05	0.05	0.05
$\hat{\pi}_t^Y$ λ_y=1.0	0.18	0.19	0.29	0.27	0.16	0.16	0.08	0.16	0.13	0.13	0.13	0.13	0.10	0.10	0.10	0.10
$\hat{\pi}_t^C$ λ_y=0.0	0.06	0.06	0.15	0.14	0.03	0.02	0.02	0.04	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01
$\hat{\pi}_t^C$ λ_y=0.5	0.11	0.11	0.21	0.20	0.08	0.08	0.05	0.09	0.07	0.07	0.07	0.07	0.05	0.05	0.05	0.05
$\hat{\pi}_t^C$ λ_y=1.0	0.16	0.17	0.26	0.26	0.14	0.14	0.08	0.15	0.12	0.12	0.12	0.12	0.10	0.10	0.10	0.10
$\hat{\pi}_t^H$ λ_y=0.0	0.05	0.05	0.12	0.10	0.06	0.05	0.00	0.06	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02
$\hat{\pi}_t^H$ λ_y=0.5	0.10	0.10	0.17	0.16	0.12	0.11	0.03	0.11	0.09	0.09	0.08	0.08	0.06	0.06	0.06	0.06
$\hat{\pi}_t^H$ λ_y=1.0	0.15	0.15	0.23	0.22	0.17	0.17	0.07	0.17	0.14	0.14	0.14	0.14	0.11	0.11	0.10	0.10

Domestic Price Markup Shock

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$ λ_y=0.0	2.24	2.18	2.29	2.10	2.32	2.32	3.75	2.80	1.68	1.70	1.63	1.66	2.00	2.04	1.97	2.00
$\hat{\pi}_t^Y$ λ_y=0.5	2.27	2.20	2.31	2.12	2.34	2.34	3.79	2.82	1.71	1.73	1.66	1.69	2.02	2.06	1.99	2.03
$\hat{\pi}_t^Y$ λ_y=1.0	2.29	2.22	2.33	2.14	2.36	2.36	3.84	2.85	1.73	1.75	1.68	1.71	2.04	2.08	2.01	2.05
$\hat{\pi}_t^C$ λ_y=0.0	1.39	1.34	1.45	1.31	1.44	1.43	2.30	1.76	1.08	1.10	1.06	1.08	1.27	1.29	1.25	1.27
$\hat{\pi}_t^C$ λ_y=0.5	1.41	1.36	1.47	1.33	1.46	1.46	2.34	1.78	1.10	1.12	1.08	1.10	1.29	1.31	1.27	1.29
$\hat{\pi}_t^C$ λ_y=1.0	1.43	1.38	1.49	1.35	1.48	1.48	2.39	1.80	1.13	1.15	1.11	1.13	1.31	1.34	1.30	1.32
$\hat{\pi}_t^H$ λ_y=0.0	3.26	3.16	3.39	3.06	3.40	3.40	5.40	4.15	3.07	3.11	3.10	3.13	3.49	3.53	3.48	3.52
$\hat{\pi}_t^H$ λ_y=0.5	3.28	3.18	3.41	3.08	3.42	3.42	5.44	4.18	3.10	3.14	3.13	3.16	3.51	3.55	3.51	3.54
$\hat{\pi}_t^H$ λ_y=1.0	3.30	3.20	3.43	3.10	3.44	3.44	5.49	4.20	3.12	3.16	3.15	3.18	3.53	3.57	3.53	3.57

Foreign Price Markup Shock

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$ λ_y=0.0	0.02	0.02	0.02	0.02	0.02	0.02	0.04	0.02	0.07	0.07	0.07	0.08	0.07	0.07	0.08	0.08
$\hat{\pi}_t^Y$ λ_y=0.5	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.02	0.07	0.07	0.08	0.08	0.07	0.07	0.08	0.08
$\hat{\pi}_t^Y$ λ_y=1.0	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.02	0.07	0.07	0.08	0.08	0.07	0.07	0.08	0.08
$\hat{\pi}_t^C$ λ_y=0.0	0.37	0.41	0.34	0.39	0.30	0.34	0.74	0.40	0.41	0.41	0.41	0.41	0.41	0.42	0.41	0.42
$\hat{\pi}_t^C$ λ_y=0.5	0.38	0.41	0.34	0.39	0.30	0.34	0.74	0.40	0.41	0.41	0.41	0.41	0.41	0.42	0.41	0.42
$\hat{\pi}_t^C$ λ_y=1.0	0.38	0.41	0.34	0.39	0.30	0.34	0.75	0.40	0.41	0.41	0.41	0.41	0.41	0.42	0.42	0.42
$\hat{\pi}_t^H$ λ_y=0.0	0.01	0.01	0.01	0.01	0.01	0.02	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
$\hat{\pi}_t^H$ λ_y=0.5	0.01	0.01	0.01	0.01	0.02	0.02	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
$\hat{\pi}_t^H$ λ_y=1.0	0.01	0.01	0.01	0.01	0.02	0.02	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Notes: Central bank losses based on simulated variances of the IRFs calculated over 40 periods and derived from the Bayesian estimation of the models over the pre-ZLB period. Shock processes are defined in Argov et al. (2012) and shock size estimates are available upon request. The shading scheme is defined independently for each row, where lighter shading indicates lower losses (rescaled numbers).

Table 18. Loss Functions - Estimated Variances Under Limited Information - Pre-ZLB (1994-2015)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\hat{\pi}_t^Y$ λ_y=0.0	1.29	1.29	1.42	1.40	1.28	1.27	1.05	1.30	1.32	1.32	1.34	1.34	1.30	1.30	1.31	1.31
$\hat{\pi}_t^Y$ λ_y=0.5	1.34	1.34	1.46	1.45	1.32	1.31	1.19	1.43	1.35	1.35	1.37	1.37	1.32	1.32	1.34	1.34
$\hat{\pi}_t^Y$ λ_y=1.0	1.39	1.39	1.50	1.50	1.36	1.35	1.32	1.55	1.38	1.38	1.40	1.39	1.34	1.34	1.36	1.36
$\hat{\pi}_t^C$ λ_y=0.0	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
$\hat{\pi}_t^C$ λ_y=0.5	0.98	0.98	0.97	0.98	0.97	0.96	1.06	1.05	0.96	0.96	0.96	0.96	0.95	0.95	0.95	0.95
$\hat{\pi}_t^C$ λ_y=1.0	1.03	1.03	1.01	1.03	1.01	1.00	1.20	1.18	0.99	0.99	0.99	0.99	0.97	0.97	0.98	0.97
$\hat{\pi}_t^H$ λ_y=0.0	0.86	0.87	0.92	0.91	0.81	0.80	0.55	0.83	0.87	0.87	0.88	0.88	0.87	0.87	0.87	0.88
$\hat{\pi}_t^H$ λ_y=0.5	0.91	0.92	0.96	0.96	0.86	0.84	0.69	0.96	0.90	0.90	0.91	0.91	0.89	0.89	0.90	0.90
$\hat{\pi}_t^H$ λ_y=1.0	0.97	0.97	1.00	1.01	0.90	0.88	0.82	1.08	0.93	0.93	0.94	0.94	0.92	0.91	0.93	0.92

Notes: Central bank losses from the estimated variances under limited information and over the pre-ZLB period, for each rule (1 to 16). The shading scheme is defined independently for each row, where lighter shading indicates lower losses.