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Monetary Policy Rules and Oil Price Shocks

by

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Abstract:
This paper studies the relative performance of alternative monetary policy rules in the presence of oil price shocks in a small open economy optimizing model. Our analysis shows that it is important to distinguish between alternative price indices (CPI, core CPI, and GDP deflator) when modeling the effects of oil price increases. This distinction has important implications for monetary policy as the central bank has to decide which inflation rate to target. Our results demonstrate that targeting the change in the GDP deflator is an inferior monetary policy strategy in the presence of oil price shocks.

Keywords: Monetary policy rules; Open economy; Oil price shocks; Price indices.
JEL classification: E31, E32, E52, E58, F41

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1 Introduction

The surge in oil prices in the course of 1999 and 2000 and the following downswing of the world economy have led to renewed interest in the question whether oil price shocks cause recessions or whether monetary policy is at the root of the observed slowdown in economic activity. The first line of reasoning received support from the extensive empirical work of Hamilton (1983) and, more recently, Hamilton and Herrera (2000) who argued that all large oil price increases after World War II caused recessions in the United States. The second interpretation was favored by Bernanke et al. (1997) and has recently received additional support from Barsky and Kilian (2001). These authors argue that oil price increases alone cannot generate large and persistent declines in output, but that monetary policy is responsible for the observed losses in production. To date, neither of these two interpretations has emerged as the consensus view.

In the recent theoretical literature, the effects of oil price increases on output have received a lot of attention while the interaction between oil price shocks and monetary policy has in general not been addressed. Important work in the area has been done by Kim and Loungani (1992), Rotemberg and Woodford (1996) and Finn (2000). These studies have in common that they investigate the macroeconomic effects of oil price increases in a dynamic general equilibrium setting. Kim and Loungani as well as Finn analyze the impact of oil price increases under perfect competition, while Rotemberg and Woodford do so in an imperfect-competition framework. Finn as well as Rotemberg and Woodford show that their models generate realistic output dynamics in response to an exogenous oil price increase. None of theses studies, however, allows for a role of monetary policy since they abstract from sticky prices. Moreover, the above studies analyze the effects of oil price shocks in closed-economy settings. By that assumption they exclude a potentially important transmission mechanism, namely that oil price increases involve a transfer of income from oil-importing to oil-exporting countries. This transmission mechanism is included in Backus and Crucini (2000) who analyze the effects of oil price shocks on the terms of trade in a three-country real business cycle model. Yet, again there is no explicit role for monetary policy.

This paper addresses the interplay between oil price shocks and monetary policy in a small open economy setting. We employ a variant of the dynamic sticky-price monetary model developed by McCallum and Nelson (1999). Their model belongs to the new open macroeconomics literature initiated by the work of Obstfeld and Rogoff (1995). The important new feature introduced by McCallum and Nelson (1999) is that imported goods serve as an input good to domestic production. Therefore, their model is a leading candidate for the analysis of the effects of oil price shocks on the dynamics of key macroeconomic variables. Modeling oil as an input factor is in analogy to the models used by, e.g., Finn (2000) and Rotemberg and Woodford (1996) in which oil also serves as a production factor.

We extend the McCallum and Nelson (1999) model by assuming that imports serve as both an input good in domestic production and as a final perishable domestic consumption good. This extension allows us to distinguish between three price indices: the consumer price index (CPI), the deflator of gross domestic production (GDP), and the core CPI (all items less energy). In line with empirical evidence, our model predicts that oil price shocks drive a wedge between these three price indices. This has important implications for the conduct of monetary policy. Given the different responses of the price indices to oil price shocks, the central bank faces the problem which inflation rate to target. In theoretical work on optimal monetary policy, it is generally assumed that the central bank targets CPI inflation (Clarida et al. (2001)). In closed economy models without capital formation, the choice does not make any difference because all three price indices coincide.[1] In open economy models, however, these three price indices do not move together for all shocks. In empirical work on monetary policy rules, in contrast, it is often assumed that the change in the GDP deflator is the relevant target variable (see, e.g., Taylor (1993) and Clarida et al. (2000)).

Our results demonstrate that the assumption on the targeted inflation measure is not innocuous whenever the economy is hit by an oil price shock. We show that for shocks other than oil price shocks, it does not make a large difference whether the central bank targets CPI inflation, core inflation, or the change in the GDP deflator. In contrast, our results suggest that in the presence of an oil price shock, GDP deflator targeting turns out to be a suboptimal strategy. Rather, core inflation targeting seems to be a good strategy, as has also been shown by Aoki (2000) in a recent paper on the impact of relative price changes on inflation fluctuations.

The remainder of the paper is organized as follows. In Section 2, we present stylized facts on the dynamics of the three price indices and discuss the implications for monetary policy rules of the type suggested by Taylor (1993). In Section 3, we lay out our formal model. In Section 4, we analyze the properties of our model by means of impulse response functions and numerical simulations. Section 5 offers some concluding remarks.

[1] For example, Goodfriend and King (1997) analyze optimal monetary policy in response to an oil price shock in a closed economy new neoclassical synthesis model.

2 Alternative Inflation Measures and the Taylor Rule: Some Stylized Facts

To illustrate our argument, we first report some stylized facts on the behavior of different inflation measures over time. All data used in this section are taken from the FRED database of the Federal Reserve Bank of St. Louis.

— Insert Figure 1 about here —

Figure 1 depicts the evolution of CPI inflation, core inflation (all CPI items less energy), and changes in the GDP deflator in the period 1959-2001 for the United States. As can be seen from this figure, the three inflation measures are highly correlated over the entire sample. They deviate from each other, however, in all those periods during which large oil price changes occurred (shaded areas in the figure). This is especially true for the second oil price shock, which hit the U.S. economy in 1979-1980. The figure shows that the increase in CPI inflation was very strong during this period. In comparison, the increase in core inflation and the change in the GDP deflator were less pronounced. In the seventies, inflation was already on the rise before the respective oil price shocks occurred. This has recently been highlighted by Barsky and Kilian (2001) who argue that loose monetary policy in the seventies contributed to the rise in inflation and in oil prices. While it is true that monetary policy may have been the main source of rising inflation, it is also true that the divergence of the different inflation measures must be attributed to the evolution of oil prices.

This divergence of the different inflation measures is the focus of this paper as it has important implications for the conduct of monetary policy. A large body of literature, following Taylor (1993), shows that monetary policy can be well described by means of simple rules. A simple rule similar to the one originally suggested by Taylor (1993) takes the form $R_t = 2.0 + dp_t^i + 0.5(dp_t^i - 2.0) + 0.5\tilde{y}_t$, where R_t is the Federal funds rate, $\tilde{y}_t$ denotes the CBO output gap, and dp_t^i the inflation rate.[2] The index i stands for CPI inflation, core inflation, or changes in the GDP deflator, respectively. In line with Taylor, we assume that the long-run equilibrium real interest rate and the inflation target of the central bank are both equal to 2.0 percent.

— Insert Figure 2 about here —

In Figure 2 we compare monetary policy rules based on the different inflation measures. The upper panel shows the evolution of the nominal interest rate for a central bank targeting CPI inflation and core inflation, respectively. These two interest rate series are highly correlated and only deviate from each other significantly in times when oil price shocks hit the U.S. economy. As can be seen in the second panel, a similar result obtains when CPI inflation and changes in the GDP deflator are used in the calculation of the above monetary policy rule. The divergence between these series is especially striking during the second oil price shock. While the rule based on CPI inflation recommended a nominal interest of around 22 percent in 1980, the rule based on the change in the GDP deflator recommended a nominal interest rate of only 14 percent. Comparing the interest rates rules based on core inflation and changes in the GDP deflator (see the third panel of the figure) confirms the general picture, namely

[2] Clarida et al. (2000) provide state of the art estimations of monetary policy rules. They assume that the central bank is forward looking and seeks to smooth interest rates. In this section, we abstract from these complications as they do not affect our main conclusion.

that the nominal interest rates implied by these rules depart from each other during periods of oil price shocks.

In the following, we present a model which is able to capture the dynamics of the various measures of inflation and thus of nominal interest rates during periods of oil price shocks. With the help of the model, we can determine which inflation measure the central bank should target.

3 The Model

Our model is a variant of the dynamic general equilibrium small open economy model developed by McCallum and Nelson (1999). The economy is inhabited by a continuum of infinitely-lived consumer-producer households, indexed by $j \in [0,1]$. Each household produces a differentiated good and sells its output in a monopolistically competitive goods market. The output of the differentiated good produced by household j in period t is denoted by $Y_t(j)$. The production technology is described by a constant elasticity of substitution production function:

$$Y_t(j) = \left\{ a_1 (A_t N_t)^{v_1} + (1-a_1) Z_t^Y(j)^{v_1} \right\}^{1/v_1}, \tag{1}$$

where $a_1 \in (0,1)$ and v_1 may assume any value on the real line. In this production function, A_t is an exogenous productivity shift parameter, N_t denotes the quantity of labor hired by the household in period t, and $Z_t^Y(j)$ denotes the quantity of imported oil used in the production process. The oil price in domestic currency units, P_t^{ZY}, is given by $P_t^{ZY} = (P_t^{O*})S_t$, where P_t^{O*} denotes the oil price in foreign currency units.

Here and in the following, an asterisk denotes a foreign variable. The nominal exchange rate, S_t, is defined as the price of a foreign currency unit in terms of domestic currency units.

All households have identical preferences and seek to maximize their expected lifetime utility, U_t, given by:

$$U_t = \mathbb{E}_t \sum_{s=t}^{\infty} b^{t-s} [\exp(v_s) \frac{s}{s-1} \left(\frac{CX_s(j)}{CX_{s-1}^h(j)} \right)^{(s-1)/s} + (\frac{1}{1-c}) \left(\frac{M_s(j)}{P_s^{CX}} \right)^{1-c}] \, , \qquad (2)$$

where v_t denotes a preference shock and $0 < b < 1$, $s \neq 1$, $c \neq 1$, and the habit formation parameter lies in the interval $h \in [0,1)$. The operator $\mathbb{E}_t$ denotes expectations conditional on the information set available to the household in period t, $CX_t(j)$ is a real consumption index, and $M_t(j)/P_t^{CX}$ denotes the end-of-period real money holdings of the household, where P_t^{CX} is the aggregate consumer price index defined below.

We assume that the household consumes a continuum of differentiated domestically produced goods, indexed by $j \in [0,1]$. In addition, the household consumes a total quantity of foreign goods denoted by $Z_t^C(j)$. Thus, in contrast to McCallum and Nelson (1999), imports are not only used in production but also in consumption. In our model, the quantity $Z_t^C(j)$ consists of two components: the first is oil consumption, $Z_t^O(j)$, and the second, $Z_t^R(j)$, comprises other imported goods. The second component could be viewed as a Dixit-Stiglitz aggregate. For simplicity, we assume that the household allocates its consumption imports between $Z_t^O(j)$ and $Z_t^R(j)$ according to the fixed ratio $g/(1-g)$, where $0<g<1$.

The total quantity consumed by the household in period t is given by the index $CX_t(j)$, with $CX_t(j) = w C_t(j)^a \, Z_t^C(j)^{1-a}$, where $w^{-1} \equiv a^a (1-a)^{1-a}$ and $a \in (0,1)$. The quantity of the domestically produced goods that the household consumes is defined in terms of the CES basket of goods $C_t(j) = [\int_0^1 C_t(z)^{(q-1)/q} \, dz]^{q/(q-1)}$, with $q > 1$.

The consumer price index (CPI), P_t^{CX}, is defined in terms of the minimum expenditure required to buy one unit of the consumption index $CX_t(j)$ and is thus defined as:

$$P_t^{CX} = (P_t^C)^a (P_t^{ZC})^{1-a}, \tag{3}$$

where P_t^{ZC} is the domestic currency price of consumption imports, Z_t^C. The price of imported consumption goods, P_t^{ZC}, is a weighted average of the oil price, P_t^{O*}, and the price of other domestically consumed foreign goods, P_t^{R*}, both expressed in domestic currency units:

$$P_t^{ZC} = [g P_t^{O*} + (1-g) P_t^{R*}] S_t. \tag{4}$$

We also assume that the law of one price holds for imported consumption goods, so that $P_t^{ZC} = P_t^{ZC*} S_t$, where P_t^{ZC*} denotes the foreign currency price of imported consumption goods.

The consumption-based deflator of the index of domestically produced differentiated goods, i.e., the gross output deflator, is given by:

$$P_t^C = [\int_0^1 P_t(j)^{1-q} dj]^{1/(1-q)}, \tag{5}$$

where $P_t(j)$ denotes the price of a differentiated domestically produced good. The consumption demand of domestic households for the foreign good is then given by:

$$Z_t^C = (1-a)(P_t^{ZC} / P_t^{CX})^{-1} CX_t. \tag{6}$$

The demand of domestic households for the composite differentiated good is given by:

$$C_t = a\,(P_t^C / P_t^{CX})^{-1} CX_t. \tag{7}$$

The domestic demand for each differentiated good can be expressed as:

$$C_t(z) = [P_t(z) / P_t^C]^{-q} C_t = [P_t(z) / P_t^C]^{-q} a [P_t^C / P_t^{CX}]^{-1} CX_t. \tag{8}$$

Foreigners' demand function for the household's exports is of a similar format (see McCallum and Nelson (1999)):

$$EX_t(j) = (P_t(j)/P_t^C)^{-q} EX_t = (P_t(j)/P_t^C)^{-q} [Q_t^h (Y_t^*)^b]. \tag{9}$$

where $h > 0$ and $b > 0$. Thus, aggregate exports (EX_t) are a positive function of the real exchange rate (Q_t) and of the exogenously given foreign income (Y_t^*). The real exchange rate is defined as $Q_t \equiv S_t P_t^{CX*} / P_t^{CX}$, where P_t^{CX*} denotes the foreign CPI defined as:

$$P_t^{CX*} \equiv (P_t^{R*})^d (P_t^{O*})^{1-d}, \tag{10}$$

with $d \in (0,1)$. In this index, P_t^{O*} denotes the foreign currency price of oil and P_t^{R*} denotes the foreign currency price of all other goods consumed by foreign households.

We further assume that the domestic household takes as given the aggregate consumer price index, P_t^{CX}, the gross output deflator, P_t^C, the nominal exchange rate, S_t, and the foreign variables. Because there are no impediments to trade in our model, the law of one price holds for each individual good. The household may not price discriminate, so the export price of the composite domestic good, P_t^X, is equal to P_t^C. The price of imported consumption goods in terms of domestic currency units, P_t^{ZC}, can be computed by taking $P_t^{ZC} = S_t P_t^{ZC*}$. Similarly, the domestic currency price of good j and its foreign currency counterpart are linked through the relation $P_t(j) = S_t P_t^*(j)$.

We next derive the period budget constraint facing a domestic household. To this end, we assume that the domestic household j is not only an employer of labor but is also endowed with one unit of potential work-time each period. The nominal wage paid for one unit of work effort is given by W_t. The domestic household supplies this potential work-time inelastically to the domestic labor market, implying international immobility of labor.

The domestic household holds three assets, domestic outside money, M_t, a domestic real one-period bond, B_t, and an internationally traded real one-period bond, B_t^*. Foreigners do not hold domestic bonds. The price of the domestic bond, paying off one unit of domestic output in period t, is $B_t/(1+r_t)$. The price paid by the domestic household for a foreign bond, paying off one unit of foreign output in period t, is $B_t^*/[(1+r_t^*)(1+k_t)]$. Here, r_t (r_t^*) denotes the real rate of return on holding domestic (foreign) bonds between $t-1$ and t. The stochastic shock term k_t captures the presence of a risk premium for foreign asset holdings incurred by domestic households. Given these assumptions, the period budget constraint facing household j reads:

$$[P_t(j)/P_t^{CX}]\,Y_t(j) - CX_t + [W_t/P_t^{CX}][N_t^S(j) - N_t(j)] + TR_t(j) - M_t(j)/P_t^{CX} + M_{t-1}(j)/P_t^{CX}$$

$$- B_{t+1}(j)(1+r_t)^{-1} + B_t - Q_t(P_t^{O*}/P_t^{CX*})Z_t^Y - Q_t B_{t+1}^*(1+k_t)^{-1}(1+r_t^*)^{-1} + Q_t B_t^* = 0, \qquad (11)$$

where $N_t^S(j)$ denotes the household's labor supply in period t and $Y_t(j) \equiv C_t(j) + EX_t(j)$ is total demand for the good produced by household j, consisting of domestic demand, $C_t(j)$, and export demand, $EX_t(j)$. The household pays the nominal wage W_t for the labor hired and receives real transfers, $TR_t(j)$, from the fiscal authorities. Fiscal authorities (domestic and foreign) do not issue bonds. Abstracting from government spending, the budget constraint of fiscal authorities implies that real transfers are financed by seignorage.

The first order conditions for the household's maximization problem with respect to CX_t, M_t / P_t^{CX}, B_{t+1}, B_{t+1}^*, N_t, and Z_t^Y can be expressed as:

$$(1/CX_{t-1}^{h})^{(s-1)/s} (CX_t)^{-1/s} - bh(CX_t)^{(h-sh-s)/s} \, \mathbb{E}[CX_{t+1}^{(s-1)/s}] = l_t \,, \qquad (12)$$

$$(M_t / P_t^{CX})^{-c} + l_t \, \mathbb{E}_t[(1+r_t)^{-1} P_t^{CX} / P_{t+1}^{CX} - 1] = 0 \,, \qquad (13)$$

$$b \, \mathbb{E}_t[l_{t+1}] = l_t / (1+r_t) \,, \qquad (14)$$

$$Q_t \, l_t = b \, \mathbb{E}_t[Q_{t+1} \, l_{t+1} (1+k_t)(1+r_t^*)] \,, \qquad (15)$$

$$[(l_t / x_t)(W_t / P_t^{CX})]^{1/(1-v_1)} = a_1^{1/(1-v_1)} A_t^{v_1/(1-v_1)} Y_t / N_t \,, \qquad (16)$$

$$[(l_t / x_t) Q_t (P_t^{O*} / P_t^{CX*})]^{1/(1-v_1)} = (1-a_1)^{1/(1-v_1)} Y_t / Z_t^Y \,, \qquad (17)$$

where l_t and x_t denote the Lagrange multipliers on constraints (11) and (1), respectively. In addition, the usual transversality condition and the bond market equilibrium condition $B_{t+1} = 0$ hold for all t.

The domestic (foreign) nominal interest rate obtains upon invoking the Fisher parity condition and is defined as $R_t = r_t + E_t \Delta p_{t+1}^{CX}$ ($R_t^* = r_t^* + E_t \Delta p_{t+1}^{CX*}$), where $p_t^{CX} \equiv \log P_t^{CX}$ ($p_t^{CX*} \equiv \log P_t^*$). Combing the first-order conditions (14) and (15) yields the uncovered interest parity (UIP) condition: $R_t = R_t^* + E_t \Delta s_{t+1} + k_t$, where $s_t \equiv \log S_t$.

3.1 Flexible Price Output

We next derive an expression for flexible price output, $\hat{Y}_t$, which we will use in the following to calculate an expression for the output gap. With flexible prices, the log-linear approximation to Eq. (1) can be used to compute $\hat{y}_t = (1-y)a_t + y\hat{z}_t^Y$, where a hat denotes the flexible price level of a variable and $y \equiv (1-a_1)(\bar{Z}^Y / \bar{Y})^{v_1}$. Here and in the following, lowercase letters denote natural logarithms and barred variables denote steady state values. The following expression for flexible price imports can be obtained by log linearizing Eq. (17) and neglecting constants:

$$\hat{z}_t^Y = \hat{y}_t - \tilde{h}(q_t - p_t^{O*} + p_t^{CX*}) = \hat{y}_t - \tilde{h}(p_t^O - p_t^{CX}), \qquad (18)$$

where $\tilde{h} \equiv 1/(1-v_1)$. Together, the expression for flexible price output and Eq. (18) imply:

$$\hat{y}_t = a_t - \tilde{w}(p_t^O - p_t^{CX}) \qquad (19)$$

where $\tilde{w} \equiv y(1-y)^{-1}(1-v_1)^{-1}$. Eq. (19) shows that flexible price output depends upon technology and is inversely related to the relative price of oil.

3.2 Price Setting

Since household j has monopoly power on the market for the differentiated good it produces, it treats the price it charges as a further choice variable. We therefore need to specify a price adjustment mechanism for $P_t(j)$. Once the price-setting rule is specified, the quantity produced by the household can be derived from the demand function for this product. We assume that households behave according to a price-adjustment mechanism similar to the one introduced by Fuhrer and Moore (1995), which assures an empirically reasonable degree of inertia in inflation dynamics. It stipulates that inflation, measured as the increase in the price index of the domestically produced goods, is a function of the output gap, $\tilde{y}_t \equiv y_t - \hat{y}_t$, and of the weighted arithmetic average of lagged and expected inflation:

$$dp_t^C = 0.5[dp_{t-1}^C + \mathbb{E}_t dp_{t+1}^C] + \Psi\tilde{y}_t + e_{P,t}\,, \qquad (20)$$

where Ψ is a positive constant and $e_{P,t}$ is a stochastic disturbance term.

3.3 The Price Indices

The various price indices arising in our model play a central role in the interplay between oil price shocks, monetary policy, and macroeconomic dynamics. The consumer price index, P_t^{CX}, and the gross output deflator, P_t^{C}, were already defined in Eqs. (3) and (5), respectively. We now use these price indices to derive an expression for the GDP deflator. In addition, we discuss how the price indices implied by our model differ from those presented in McCallum and Nelson (1999, 2000).

To derive the GDP deflator, we assume that the economy has settled in a symmetric equilibrium in which all domestic households are identical. We define gross output as $Y_t = C_t + EX_t$ and real GDP as $G_t = CX_t + X_t - Z_t$, where Z_t denotes total imports defined as the sum of consumption imports, Z_t^C, and input imports, Z_t^Y. Nominal GDP can then be expressed as $G_t P_t^{DEF} = CX_t P_t^{CX} + X_t P_t^C - Z_t S_t P_t^{Z*}$. Log-linearizing this equation yields the following expression for nominal GDP:

$$\overline{G}\,\overline{P}^{DEF}\left(g_t + p_t^{DEF}\right) = \overline{CX}\,\overline{P}^{CX}\left(cx_t + p_t^{CX}\right) + \overline{XP}^{C}\left(x_t + p_t^{C}\right) - \overline{ZSP}^{Z*}\left(z_t + s_t + p_t^{Z*}\right), \quad (21)$$

where we have dropped constants. Straightforward calculations show that the log-linearized versions of the consumer price index and the gross output deflator are given by:

$$p_t^{CX} = a\, p_t^{C} + (1-a)\, p_t^{ZC} = a\, p_t^{C} + (1-a)[s_t + p_t^{ZC*}], \quad (22)$$

$$p_t^{Y} = p_t^{C}, \quad (23)$$

where p_t^Y is the gross output deflator, which coincides with the core CPI.

Now we use the fact that the log-linear version of real GDP is given by $\overline{G}g_t = \overline{CX}cx_t + \overline{X}x_t - \overline{Z}z_t$. We further postulate that the trade balance is zero in the initial steady state, implying that $\overline{G} = \overline{CX}$. To derive steady state relations between the various price indices in our model, we also assume $\overline{P}^{R*} = \overline{P}^{O*}$. Then, it immediately follows that we also have $\overline{P}^{R*} = \overline{P}^{O*} = \overline{P}^{ZC*} = \overline{P}^{CX*}$. From this it can be deduced that the following equality holds: $\overline{P}^{ZC} = \overline{P}^{ZY} = \overline{P}^{Z} = \overline{P}^{CX*}\overline{S} = \overline{P}^{CX}$. From the definition of the domestic CPI it follows that $\overline{P}^{C} = \overline{P}^{ZC} = \overline{P}^{CX} = \overline{SP}^{*}$ and thus $\overline{P}^{DEF} = \overline{P}^{CX}$. Combining these results, the GDP deflator can be formally expressed as:

$$p_t^{DEF} = (1/w_1)[w_1 p_t^{CX} + w_2\, a\, p_t^C - w_2\, a\, (s_t + p_t^{Z*})], \tag{24}$$

with $w_1 \equiv \overline{C}/\overline{Y}$ and $w_2 \equiv \overline{X}/\overline{Y}$. Thus, in our model, the GDP deflator is a function of the consumer price index, of the gross output deflator, and of the domestic currency price of the imported goods.

— Insert Table 1 about here —

Table 1 summarizes the log linearized versions of the price indices implied by our model. These price indices can be compared with the price indices arising in the model developed by McCallum and Nelson (1999, 2000). In their model, the imported good is exclusively used as an input good in the production of the domestic good. In our model, in contrast, imported goods serve both as an input factor in domestic production and as a final consumption good. Thus, the McCallum-Nelson model is a special case of our extended model. Our model degenerates to their model when we invoke the assumption that $a = 1$. Under this assumption, the CPI only comprises the prices of domestically produced goods. This, in turn, implies that the CPI is equal to the gross output deflator. Moreover, under the assumption that $a = 1$, an oil price shock exerts no direct effect on the consumption-based price indices. Only the GDP deflator, which can be expressed as $p_t^{DEF} = (1/w_1)[p_t^C - w_2(s_t + p_t^{Z*})]$ in the McCallum-Nelson version of our model, is directly affected by the shock hitting the price of the imported good. In our model, in contrast, an oil price shock exerts a direct effect on both the CPI and the GDP deflator. Whereas the impact of an oil price shock on the GDP deflator under the assumption that $a = 1$ is unambiguously negative, the sign of the impact of an oil price shock on this deflator in our model depends on the relative magnitude of the coefficients a and w_1, i.e. on the share of imported consumption goods in total consumption and on the steady-state share of total consumption in gross output, respectively.

3.4 Model Solution

The equations of the log linearized model include Eqs. (18) - (20), the price indices summarized in Table 1, the UIP condition, and the log linear versions of the real exchange rate, the output gap, and exports (Eq. (9)). In addition, we need the national income identity

$$y_t = w_1 c_t + w_2 ex_t \,, \tag{25}$$

where w_1 and w_2 denote the steady state shares of consumption and exports in gross output, respectively. Finally, log linearizing Eqs. (12) and (14), we obtain:

$$\log l_t = [(bsh^2 + bsh - bh^2 - 1)/(s(1-bh))]cx_t + (1-bh)^{-1}(1-bhr_v)v_t - h[(s-1)/(s(1-bh))]cx_{t-1} - bh[(s-1)/(s(1-bh))]\mathbb{E}_t cx_{t+1}, \tag{26}$$

$$\log l_t = \mathbb{E}_t \log l_{t+1} + R_t - \mathbb{E}_t \log p_{t+1}^{CX}. \tag{27}$$

To solve the model we use the algorithm developed by Klein (2000). The calibration of the model is given in Table 2 and closely follows McCallum and Nelson (1999, 2000). In comparison with them, we have to specify some additional parameters. First, we have to specify the share of imported goods in total consumption, $1-a$. We assume that this share takes on the value 0, 0.1 or 0.2, respectively. In the McCallum-Nelson model, this share is zero. Second, we assume that the share of oil imports in total consumption imports, g, is equal to 0.5. For the case $1-a = 0.1$ this means that the share of oil in total consumption is equal to 5 percent. Third, we assume a weight of $1-d = 0.05$ for oil in the foreign CPI. Finally, we have to specify the parameters describing the dynamics of the oil price, p_t^{O*}. We assume that the dynamics of the oil price are captured by an autoregressive process of order one. Following Kim and Loungani (1992), we set the persistence parameter of this process equal to 0.9.

— Insert Table 2 about here —

4 Model Properties

In this section, we present impulse responses and simulation results in order to explore the dynamic properties of the model. To this end, we also have to specify a monetary policy reaction function. We use a standard Taylor type monetary policy rule:

$$R_t = m_0 + (1 - m_3)[dp_t^i + m_1(dp_t^i - \bar{p}) + m_2\tilde{y}_t] + m_3 R_{t-1} + e_{R,t}\,, \tag{28}$$

where $\bar{p}$ denotes the inflation target of the central bank, $e_{R,t}$ is a stochastic shock term, and m_1 and m_2 are parameters that capture the reaction of the central bank to deviations of the inflation rate from its target level and to the output gap. All variables are measured at quarterly frequency. The interest rate smoothing objective of central banks (Goodfriend (1991)) is reflected in the parameter m_3.

The key new element of the monetary policy rule given in Eq. (28) is the inflation term, dp_t^i, which allows three alternative cases to be discussed. We separately analyze monetary policy regimes in which the central bank reacts either to the change in the gross output deflator (core inflation), or to the change in the consumer price index (CPI inflation), or to the change in the GDP deflator. Accordingly, we set $i \in \{C, CX, DEF\}$ in Eq. (28).

4.1 Impulse Response Analysis

To analyze the dynamic properties of the model, we have to specify the numerical values of the parameters in the monetary policy rule given in Eq. (28). We assume that the parameters m_1 and m_2 take on the numerical value 0.5 and 0.25, respectively. To compute the impulse responses given in Figures 1 and 2, we further set m_3 equal to 0.8.

Figure 3 shows the response of changes in the GDP deflator, CPI inflation, and core inflation to an oil price shock for different numerical parameter values assigned to the share of consumed imports in total consumption. In the first panel of the Figure, we set $a = 1$, which means that oil is solely used as an input in domestic production. In the second and third panel, we set $a = 0.9$ and $a = 0.8$, respectively. In these cases, oil is also used as a final consumption good. To compute the impulse responses plotted in the figure, we set $i = C$ in Eq. (28), that is, the central bank responds to deviations of core inflation from its target level.[3]

The first panel of the figure depicts the inflation dynamics that obtain when imports are not used as a consumption good. In this case core inflation and CPI inflation are the same. It can be seen in the figure that the GDP deflator decreases in the period the oil price shock hits the economy. This is in sharp contrast to CPI inflation, which remains roughly unchanged. The changes in the GDP deflator and the CPI start to resemble each other beginning in the period following the oil price shock. Clearly, the observation that core and CPI inflation coincide is at variance with the stylized facts presented in Section 2.

As can be seen in the second panel of Figure 3, these stylized facts are nicely captured by the modified model suggested in this paper. The graph shows that, while core inflation increases only moderately in the aftermath of an oil price shock, CPI inflation increases on impact. The GDP deflator again declines immediately after the shock, but the extent is smaller than in the upper panel. The reason is that, even for a

[3] The results for the price indices are qualitatively similar if the central bank responds to the consumer price index or the gross domestic output deflator instead.

relatively small share of oil in total consumption, the CPI is driven up by the oil price shock, which, in turn, implies that the impact of the oil price shock on the GDP deflator is dampened.

The consequences of increasing the share of oil in consumption to 10 percent can be seen in the third panel of Figure 3. In this panel, the GDP deflator remains roughly constant in the period when the oil price shock occurs. This is due to the fact that the CPI strongly increases at the same time. This compensates the increase in import prices that ceteris paribus exerts a dampening effect on the GDP deflator.

— Insert Figure 3 about here —

Figure 4 gives the impulse responses of the nominal interest rate, potential output, the output gap, consumption, and the real exchange rate to an oil price shock under alternative Taylor-rule specifications. The first column of the figure graphs impulse responses obtained by using a Taylor rule with dp_t^C (Taylor rule 1). The second column of the figure, in contrast, gives impulse responses for a model in which the central bank targets CPI inflation, dp_t^{CX} (Taylor rule 2). The third column of the figure shows impulse responses for a model in which the change in the GDP deflator, dp_t^{DEF}, enters the monetary policy rule given in Eq. (28) (Taylor rule 3).

— Insert Figure 4 about here —

The figure shows that the dynamics of the plotted variables in the aftermath of an oil price shock depend on the inflation rate the central bank targets and on the numerical value assumed by the share of oil in total consumption. This share is set to 0 percent (solid lines) and 10 percent (dashed lines), respectively.

As can be seen in the figure, the central bank increases the interest rate in response to an oil price shock if it targets CPI inflation whereas it decreases the interest rate if it targets the change in the GDP deflator. If it targets core inflation the central bank leaves the nominal interest rate roughly unchanged.

The model also has clear-cut implications for the dynamics of the real exchange rate in the aftermath of an oil price shock. The dynamics of the real exchange rate are driven by the responses of the domestic CPI and of the nominal interest rate. If the share of oil in total consumption amounts to 10 percent, the real exchange rate unambiguously appreciates. The real appreciation is strongest for CPI targeting because the central bank noticeably increases the nominal interest rate in this case. If, in contrast, oil is not a consumption good ($a = 1.0$) and the central bank targets the change in the GDP deflator, the real exchange rate strongly depreciates in response to an oil price shock. This is due to the pronounced decrease in the nominal interest rate, which leads to a depreciation of the nominal and, because of sticky prices, of the real exchange rate.

The dynamics of the nominal interest rate and, thus, of the exchange rate strongly influence the response of potential output, the output gap, and consumption to an oil price shock. The response of potential output is exclusively determined by the relative price of oil (see Eq. (19)), which in turn depends on the real exchange rate. A real depreciation of the exchange rate or a rise in the oil price increase the cost of imported inputs and lead to a decline in potential output. The decline in potential output, thus, is largest if the central bank targets the change in the GDP deflator.

The response of output is less clear-cut. On the one hand, private consumption declines because of the loss in purchasing power. On the other hand, export demand is stimulated if the real exchange rate depreciates. Output increases in the immediate aftermath of the shock if the rise in export demand overcompensates the decline in private consumption. This is the case if the central bank targets the change in the GDP deflator and if oil is not a consumption good. In all other cases output declines. However, the output gap increases in all these cases because the decline in potential output is always larger than the decline in output.

4.2 Simulation of the Model

We now use stochastic simulations to analyze the dynamic properties of the model under alternative monetary policy rules. The set of monetary policy rules we analyze includes the three Taylor rules discussed in the previous section and nominal income targeting as studied by McCallum and Nelson (1999). We follow them and define nominal income growth as $dx_t \equiv dy_t + dp_t^C$. The performance of these four rules is evaluated along three dimensions. First, we vary the parameters of the monetary policy rules. Second, we study the influence of varying the share of oil in total consumption on the relative performance of these rules. Third, we investigate whether the central bank should react differently to oil price shocks than to other shocks hitting the economy.

To code up the simulations, we generated 100 times series of the endogenous variables of the model, each time series consisting of 200 observations. We repeated this procedure 100 times. For each simulation run, we calculated the standard deviation of the output gap, the three inflation rates, and the nominal interest rate. This gave us 100 standard deviations for these variables. Finally, we computed the arithmetic average and the standard deviations for these series. The performance of the rules is summarized by the arithmetic averages. The standard deviations of the latter are used to assess the significance of the differences between the rules. Tables 3-5 summarize the simulation results.

Table 3 gives the simulation results for a benchmark parameterization of the four monetary policy rules. In the benchmark simulation, we assume that the parameter m_1 governing the reaction of monetary policy to deviations of the inflation rate from the target is equal to 0.5. The parameter m_2 governing the reaction of monetary policy to the output gap is equal to 0.25. Finally, we set the interest rate smoothing parameter equal to 0.8. The table contains standard deviations of the five endogenous variables mentioned above for the cases of oil price shocks and all other shocks but oil (preference shock, monetary policy shock, UIP shock, technology shock, shock to income abroad, and price setting shock). We report results for the case in which the share of oil in total consumption is 5 percent $(a = 0.9)$ and 10 percent $(a = 0.8)$, respectively.[4]

To assess the robustness of our results, we also present simulation results for two alternative parameterizations of the monetary policy rules. Table 4 gives results for the case in which the central bank does not respond to the output gap (strict inflation targeting). In comparison with our benchmark simulation we set the parameter m_2 equal to zero. Table 5 depicts simulation results for the case in which the central bank strongly responds to the deviations of the inflation rate from the target $(m_1 = 2.0)$. In additional simulations (not reported) we also investigated whether our results depend on

[4] The main results reported in the remainder of this section are qualitatively the same if we set $a = 1.0$, which means that oil is not a consumption good. Note, however, that in this case one cannot distinguish between CPI inflation and core inflation.

the parameter m_3, which summarizes the extent to which the central bank smoothes the interest rate. The general impression that emerged from these simulations was that our results are robust even when we assume that the central bank does not smooth interest rates at all ($m_3 = 0$).

— Insert Tables 3-5 about here —

It can be seen in Table 3 that in the case of oil price shocks the reported standard deviations are largest if the central bank targets the change in the GDP deflator. The differences between the remaining three monetary policy rules are rather small. However, targeting core inflation is a good strategy as compared to nominal income targeting. Targeting CPI inflation yields the best results in terms of output gap and CPI inflation stabilization, yet comes at the cost of higher core inflation and interest rate volatility. Considering all other shocks, the results further show that there are almost no significant differences between the analyzed monetary policy rules, regardless of the share of oil in total consumption. Nominal income targeting and CPI inflation targeting dominate the other strategies with regard to CPI inflation volatility.

A similar picture emerges from Table 4, which reports results for strict inflation targeting. If only oil price shocks hit the economy, a central bank targeting the change in the GDP deflator provokes a large volatility of the output gap and inflation. The differences between the other rules are not large, although core inflation targeting seems to be a good strategy because it yields good stabilization results with regard to all variables. Targeting CPI inflation is again the best strategy with regard to the output gap and CPI inflation, but not for the other variables. If one considers all shocks but oil price shocks in the simulations of the model, there are again almost no differences between the monetary policy rules. Yet, there seems to be a trade off between stabilizing core inflation and stabilizing CPI inflation.

If the central bank strongly responds to deviations of inflation from its target (Table 5), the performance of a monetary policy rule based on the GDP deflator is once more by far the worst in the case of oil price shocks. Core inflation targeting again seems to be the preferable strategy as compared with nominal income targeting. As in the benchmark simulation, the differences between the monetary policy rules are rather small if all shocks but oil price shocks are used to simulate the model. Yet, core inflation targeting is always the dominant strategy in comparison with GDP deflator targeting.

Taken together, the tables also suggest that the larger the degree of openness in consumption $(1-a)$ the higher is the standard deviation of CPI inflation and the lower is the standard deviation of the output gap and of changes in the GDP deflator. As concerns the different parameterizations underlying Tables 3-5 it can be seen that on average a policy of strict inflation targeting delivers worse results than either the benchmark policy rule or the one relying on a strong inflation response. This latter result is largely unaffected by variations in the degree of openness in consumption.

5 Conclusions

In this paper we have analyzed the relative performance of alternative monetary policy rules in the presence of oil price shocks. The existing literature so far has implicitly assumed that all prices move in the same direction and to the same extent when an oil price shock hits the economy. Our impulse response analysis indicates that it is important to distinguish between alternative price indices when modeling the dynamic effects of oil price increases on the economy. This has important implications for monetary policy as the central bank has to choose which inflation rate to target. In terms of policy conclusions, our simulation results suggest that targeting the change in the GDP deflator is an inferior monetary policy strategy in the presence of oil price shocks. In general, our model suggests that core inflation targeting seems to be a good strategy.

Our results may also have important implications for empirical work. They cast doubt on the practice of numerous studies estimating monetary policy rules using the GDP deflator as an explanatory variable, especially if the deviations of actual monetary policy from the estimated rule are used to judge the monetary policy stance. Whereas the distinction between changes in the GDP deflator and other measures of inflation is not especially important in ‘normal’ times, it becomes crucial when oil price shocks hit the economy.

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Figure 1: U.S. price indices 1959:1-2001:3 (percentage change over previous year)

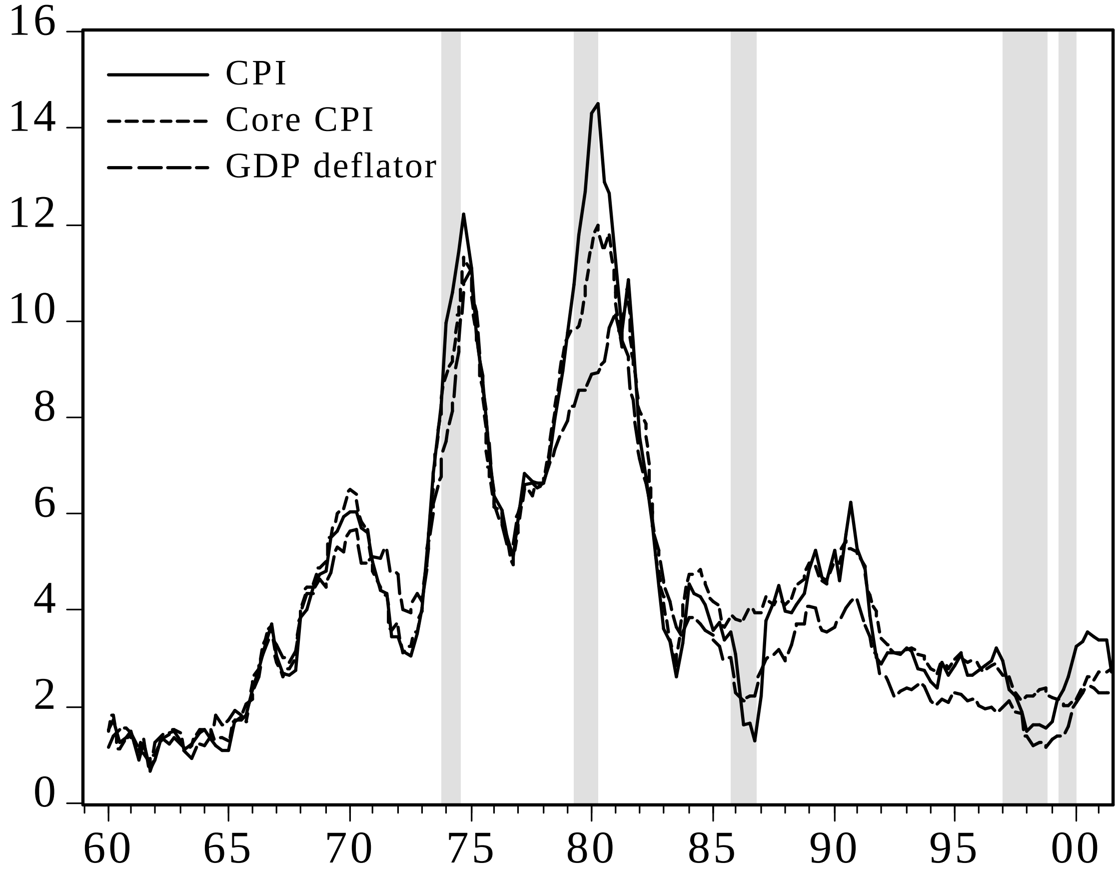


Figure 2: Taylor rules for the U.S. with alternative inflation target variables (percent)

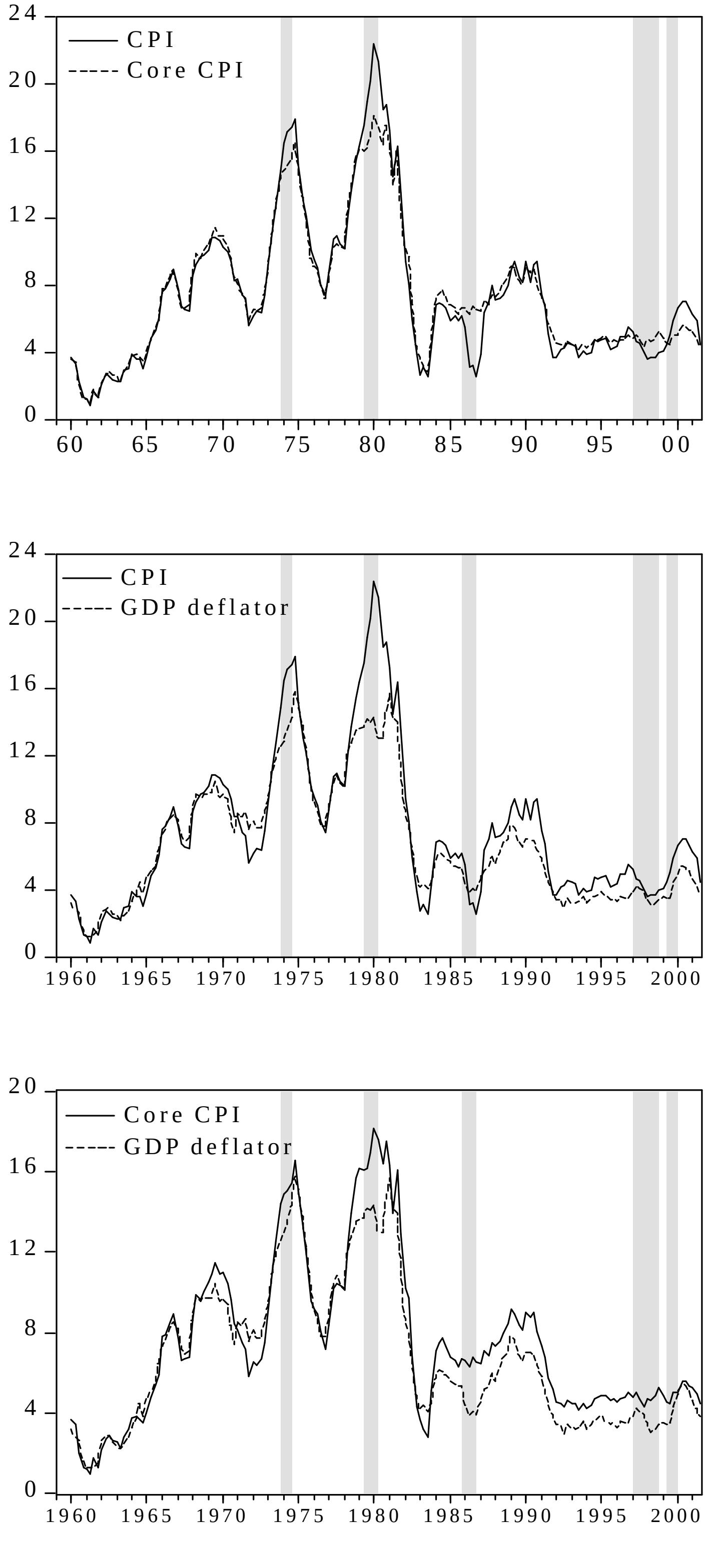
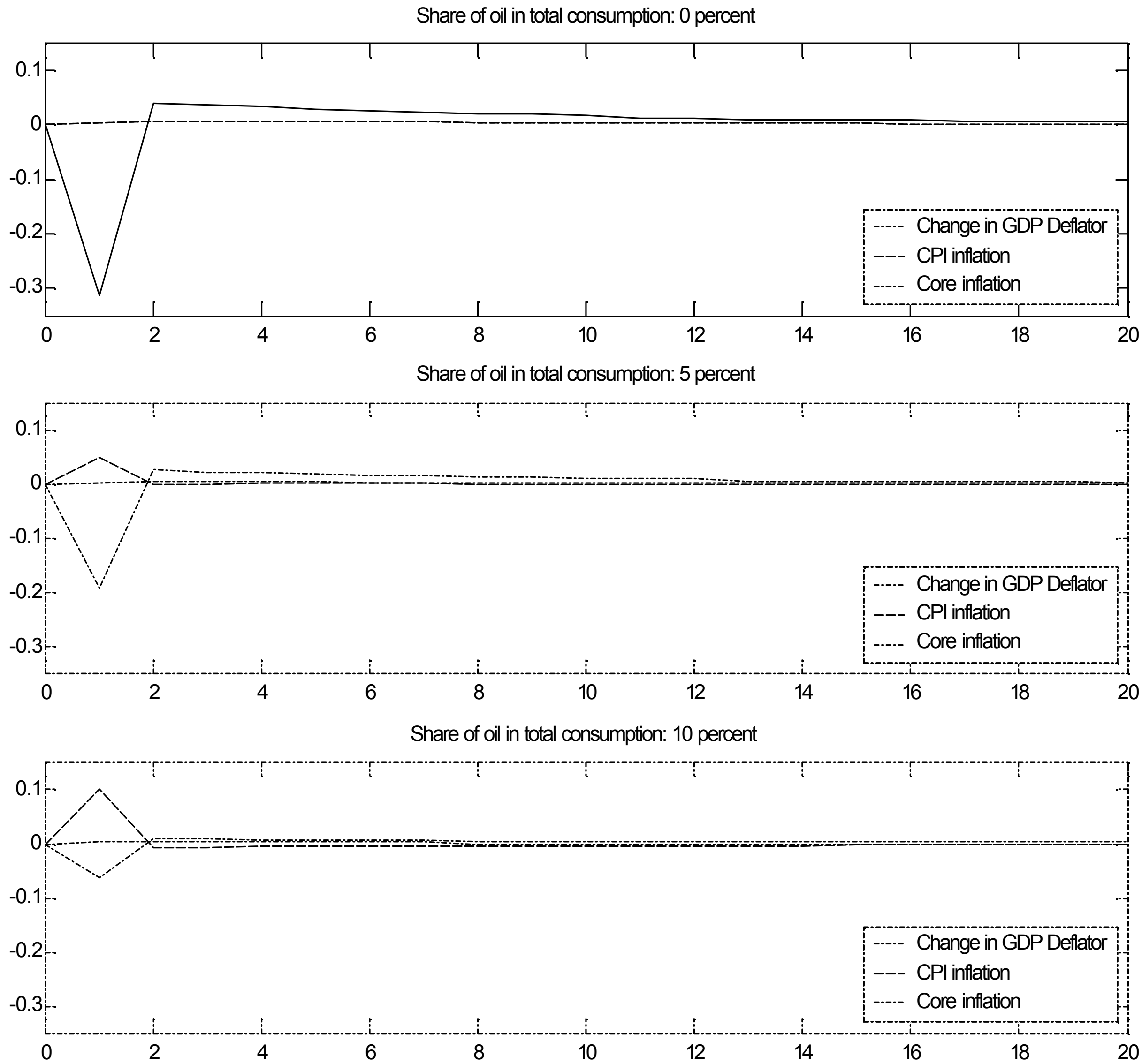
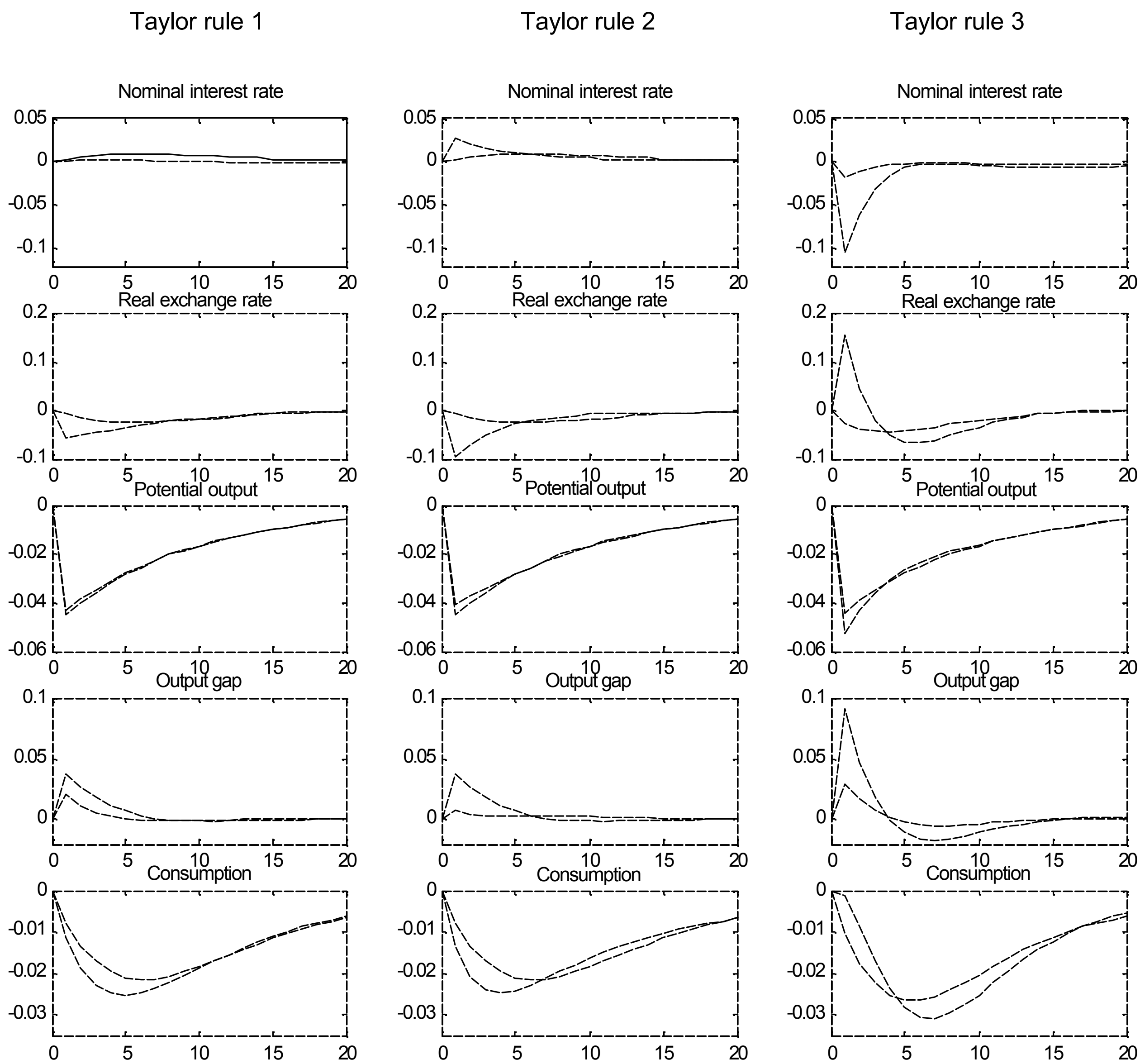


Figure 3: Responses of inflation rates to a unit shock in the oil price



Notes: The figure depicts impulse responses (deviations from steady state in percent) for the Taylor rule $R_t = (1-0.8)[dp_t^C + 0.5dp_t^C + 0.25\tilde{y}_t] + 0.8R_{t-1} + e_{R,t}$ and for alternative shares, $1-a$, of imports in total consumption.

Figure 4: Impulse responses of selected variables to a unit shock in the oil price



Notes: Dashed lines obtain when setting $a = 0.8$ and solid lines obtain when setting $a = 1.0$. The figure gives impulse responses (deviations from steady state in percent) for the Taylor rule $R_t = (1-0.8)[dp_t^i + 0.5\,dp_t^i + 0.25\tilde{y}_t] + 0.8R_{t-1} + e_{R,t}$. In the first column, the central bank targets core inflation ($i = C$). In the second column, the central bank targets CPI inflation ($i = CX$). In the third column, the central bank targets the change in the GDP deflator ($i = DEF$).

Table 1: Price indices (deviations from steady state)

Index	$a < 1$	$a = 1$
CPI	$p_t^{CX} = a\ p_t^{C} + (1-a) p_t^{ZC}$	$p_t = p_t^{C} = p_t^{X}$
Core CPI	$p_t^{C} = p_t^{X}$	$p_t = p_t^{C} = p_t^{X}$
Gross output deflator	$p_t^{Y} = p_t^{C} = p_t^{X}$	$p_t^{Y} = p_t^{C} = p_t^{X} = p_t$
GDP deflator	$p_t^{DEF} = \frac{1}{w_1}\left[w_1 p_t^{CX} + w_2 a\ p_t^{C} - w_2 a\ p_t^{Z}\right]$	$p_t^{DEF} = \frac{1}{w_1}\left[p_t - w_2 p_t^{Z}\right]$
Foreign CPI	$p_t^{CX*} = (1-d) p_t^{O*}$	$p_t^{CX*} = (1-d) p_t^{O*}$
Domestic currency price of imported consumption goods	$p_t^{ZC} = s_t + g\ p_t^{O*}$	--
Domestic currency price of imported inputs	$p_t^{ZY} = s_t + p_t^{O*}$	$p_t^{ZY} = s_t + p_t^{O*}$
Import deflator	$p_t^{Z} = \frac{1-a}{a} \frac{w_1}{w_2}(p_t^{ZC} - p_t^{ZY}) + p_t^{ZY}$	$p_t^{Z} = p_t^{ZY}$

Note: $w_1 \equiv \overline{C}/\overline{Y}$ and $w_2 \equiv \overline{X}/\overline{Y}$.

Table 2: The calibrated parameters

Parameter	Value	Description
		Structural parameters
w_1	0.75	Steady-state share of consumption in gross output
w_2	0.25	Steady-state share of exports in gross output
$\tilde{w}$	0.048	Negative of the real-exchange-rate elasticity of potential output
g	0.5	Share of oil in total imports
b	1.0	Elasticity of exports with respect to foreign income
h	1.0	Real-exchange-rate elasticity of exports
$\tilde{h}$	1.0	Negative of the real-exchange-rate elasticity of imported inputs
$1-d$	0.05	Share of oil in foreign CPI
b	0.99	Subjective discount factor
h	0.8	Habit persistence parameter
s	1/6	Intertemporal elasticity of substitution
Ψ	0.02	Output-gap coefficient in price-setting equation
		Stochastic processes
r_a	1	AR(1) parameter of the technology shock
s_a	0.0035	Standard deviation of the technology shock
r_u	0	AR(1) parameter of the preference shock
s_u	0.01	Standard deviation of the preference shock
r_{e_R}	0	AR(1) parameter of the monetary policy shock
s_{e_R}	0.002	Standard deviation of the monetary policy shock
r_k	0.5	AR(1) parameter of the risk premium shock
s_k	0.04	Standard deviation of the risk premium shock
r_{y^*}	1	AR(1) parameter of the shock to foreign income
s_{y^*}	0.02	Standard deviation of the shock to foreign income
$r_{p^{O*}}$	0.9	AR(1) parameter of the oil price shock
$s_{p^{O*}}$	0.14	Standard deviation of the oil price shock
r_{e_p}	0	AR(1) parameter of the price-setting shock
s_{e_p}	0.002	Standard deviation of the price-setting shock

Table 3: Simulation Results for Benchmark Monetary Policy Rules

Rule	a	$s_{\tilde{y}}$	Std. Dev.	s_{dp^c}	Std. Dev.	$s_{dP^{CX}}$	Std. Dev.	$s_{dP^{DEF}}$	Std. Dev.	s_R	Std. Dev.
		Oil price shocks									
NIT	0.9	**0.648**	0.005	**0.566**	0.007	**2.899**	0.015	**11.238**	0.056	**0.339**	0.005
Taylor rule 1		**0.527**	0.004	**0.524**	0.007	**2.740**	0.013	**11.110**	0.056	**0.840**	0.014
Taylor rule 2		**0.429**	0.004	**0.892**	0.016	**2.624**	0.015	**10.930**	0.061	**1.716**	0.024
Taylor rule 3		**1.017**	0.007	**1.706**	0.033	**3.975**	0.025	**12.129**	0.064	**4.198**	0.033
NIT	0.8	**0.457**	0.004	**0.547**	0.009	**6.022**	0.033	**3.792**	0.021	**0.504**	0.010
Taylor rule 1		**0.341**	0.002	**0.191**	0.002	**5.708**	0.027	**3.758**	0.018	**0.322**	0.004
Taylor rule 2		**0.158**	0.002	**0.994**	0.020	**5.004**	0.025	**3.870**	0.020	**2.390**	0.025
Taylor rule 3		**0.505**	0.004	**0.761**	0.013	**6.284**	0.032	**3.853**	0.020	**1.379**	0.014
		All other shocks									
NIT	0.9	**2.144**	0.013	**2.202**	0.018	**3.942**	0.020	**7.269**	0.036	**2.970**	0.021
Taylor rule 1		**2.131**	0.013	**2.084**	0.018	**4.064**	0.021	**7.484**	0.038	**2.193**	0.024
Taylor rule 2		**2.126**	0.014	**2.119**	0.017	**3.964**	0.021	**7.336**	0.038	**2.478**	0.025
Taylor rule 3		**2.157**	0.012	**2.078**	0.017	**4.282**	0.022	**7.819**	0.038	**2.896**	0.022
NIT	0.8	**1.907**	0.012	**2.165**	0.020	**7.187**	0.043	**3.265**	0.020	**2.707**	0.021
Taylor rule 1		**1.894**	0.011	**2.077**	0.019	**7.464**	0.037	**3.240**	0.017	**2.126**	0.025
Taylor rule 2		**1.897**	0.012	**2.176**	0.022	**7.034**	0.033	**3.258**	0.022	**3.001**	0.026
Taylor rule 3		**1.901**	0.011	**2.076**	0.018	**7.624**	0.039	**3.261**	0.016	**2.200**	0.021

Bold figures are standard deviations (percent per annum) of the output gap ($s_{\tilde{y}}$), core inflation (s_{dp^c}), CPI inflation ($s_{dP^{CX}}$), the change in the GDP deflator ($s_{dP^{DEF}}$), and the nominal interest rate (s_R), respectively. Figures in the columns labeled "Std. Dev." give the standard deviation for the corresponding bold figure.

The monetary policy rules are (dropping constants):

– NIT (nominal income targeting): $R_t = (1-0.8)[1.5dx_t + 0.25\tilde{y}_t] + 0.8R_{t-1} + e_{R,t}$,

– Taylor rule 1 (dp^C targeting): $R_t = (1-0.8)[1.5dp_t^C + 0.25\tilde{y}_t] + 0.8R_{t-1} + e_{R,t}$,

– Taylor rule 2 (dp^{CX} targeting): $R_t = (1-0.8)[1.5dp_t^{CX} + 0.25\tilde{y}_t] + 0.8R_{t-1} + e_{R,t}$,

– Taylor rule 3 (dp^{DEF} targeting): $R_t = (1-0.8)[1.5dp_t^{DEF} + 0.25\tilde{y}_t] + 0.8R_{t-1} + e_{R,t}$.

Table 4: Simulation Results for Strict Inflation Targeting

Rule	a	$s_{\tilde{y}}$	Std. Dev.	s_{dp^c}	Std. Dev.	$s_{dP^{CX}}$	Std. Dev.	$s_{dP^{DEF}}$	Std. Dev.	s_R	Std. Dev.
		Oil price shocks									
NIT	0.9	**0.760**	0.006	**0.703**	0.008	**3.005**	0.013	**11.406**	0.052	**0.248**	0.003
Taylor rule 1	0.9	**0.619**	0.004	**0.625**	0.007	**2.831**	0.014	**11.248**	0.056	**0.724**	0.012
Taylor rule 2	0.9	**0.527**	0.005	**1.009**	0.017	**2.727**	0.014	**11.077**	0.056	**1.613**	0.023
Taylor rule 3	0.9	**1.101**	0.010	**1.766**	0.034	**4.083**	0.026	**12.290**	0.068	**4.564**	0.039
NIT	0.8	**0.507**	0.003	**0.577**	0.008	**6.119**	0.027	**3.822**	0.018	**0.605**	0.010
Taylor rule 1	0.8	**0.379**	0.003	**0.224**	0.003	**5.785**	0.032	**3.781**	0.021	**0.214**	0.003
Taylor rule 2	0.8	**0.201**	0.003	**1.066**	0.024	**5.069**	0.027	**3.910**	0.022	**2.392**	0.027
Taylor rule 3	0.8	**0.544**	0.004	**0.785**	0.013	**6.369**	0.035	**3.875**	0.022	**1.536**	0.015
		All other shocks									
NIT	0.9	**2.438**	0.018	**2.248**	0.021	**4.064**	0.020	**7.752**	0.037	**2.605**	0.015
Taylor rule 1	0.9	**2.374**	0.014	**1.976**	0.016	**4.127**	0.023	**7.889**	0.040	**1.955**	0.022
Taylor rule 2	0.9	**2.392**	0.017	**2.059**	0.018	**4.047**	0.022	**7.774**	0.041	**2.107**	0.017
Taylor rule 3	0.9	**2.368**	0.013	**1.927**	0.018	**4.347**	0.023	**8.198**	0.044	**3.129**	0.020
NIT	0.8	**2.145**	0.014	**2.147**	0.020	**7.455**	0.037	**3.395**	0.019	**2.385**	0.016
Taylor rule 1	0.8	**2.096**	0.013	**1.954**	0.019	**7.726**	0.035	**3.297**	0.018	**1.957**	0.024
Taylor rule 2	0.8	**2.140**	0.015	**2.145**	0.020	**7.288**	0.039	**3.379**	0.020	**2.694**	0.022
Taylor rule 3	0.8	**2.091**	0.012	**1.934**	0.018	**7.877**	0.045	**3.302**	0.016	**2.176**	0.022

Bold figures are standard deviations (percent per annum) of the output gap ($s_{\tilde{y}}$), core inflation (s_{dp^c}), CPI inflation ($s_{dP^{CX}}$), the change in the GDP deflator ($s_{dP^{DEF}}$), and the nominal interest rate (s_R), respectively. Figures in the columns labeled "Std. Dev." give the standard deviation for the corresponding bold figure.

The monetary policy rules are (dropping constants):

– NIT (nominal income targeting): $R_t = (1-0.8)[1.5\,dx_t + 0.0\,\tilde{y}_t] + 0.8R_{t-1} + e_{R,t}$

– Taylor rule 1 (dp^C targeting): $R_t = (1-0.8)[1.5\,dp_t^C + 0.0\tilde{y}_t] + 0.8R_{t-1} + e_{R,t}$

– Taylor rule 2 (dp^{CX} targeting): $R_t = (1-0.8)[1.5\,dp_t^{CX} + 0.0\tilde{y}_t] + 0.8R_{t-1} + e_{R,t}$

– Taylor rule 3 (dp^{DEF} targeting): $R_t = (1-0.8)[1.5\,dp_t^{DEF} + 0.0\tilde{y}_t] + 0.8R_{t-1} + e_{R,t}$

Table 5: Simulation Results for Monetary Policy Rules with Strong Inflation Response

Rule	a	$s_{\tilde{y}}$	Std. Dev.	s_{dp^c}	Std. Dev.	$s_{dP^{CX}}$	Std. Dev.	$s_{dP^{DEF}}$	Std. Dev.	s_R	Std. Dev.
					Oil price shocks						
NIT	0.9	**0.750**	0.006	**0.633**	0.008	**3.002**	0.014	**11.403**	0.054	**0.335**	0.004
Taylor rule 1		**0.477**	0.003	**0.337**	0.004	**2.699**	0.013	**11.000**	0.051	**0.733**	0.011
Taylor rule 2		**0.182**	0.002	**0.487**	0.011	**2.315**	0.012	**10.428**	0.055	**2.216**	0.027
Taylor rule 3		**1.762**	0.012	**1.459**	0.020	**4.773**	0.023	**14.063**	0.069	**9.569**	0.062
NIT	0.8	**0.600**	0.005	**0.510**	0.006	**6.268**	0.032	**3.896**	0.020	**0.690**	0.008
Taylor rule 1		**0.341**	0.002	**0.171**	0.002	**5.705**	0.031	**3.761**	0.021	**0.316**	0.004
Taylor rule 2		**0.308**	0.003	**0.710**	0.013	**4.142**	0.021	**3.549**	0.019	**3.704**	0.033
Taylor rule 3		**0.755**	0.005	**0.600**	0.008	**6.905**	0.033	**4.049**	0.020	**2.913**	0.020
					All other shocks						
NIT	0.9	**2.043**	0.013	**1.917**	0.018	**3.523**	0.018	**6.727**	0.035	**4.467**	0.032
Taylor rule 1		**2.133**	0.012	**1.718**	0.014	**3.779**	0.017	**7.293**	0.033	**2.834**	0.030
Taylor rule 2		**2.083**	0.014	**1.760**	0.014	**3.573**	0.018	**6.932**	0.036	**3.417**	0.033
Taylor rule 3		**2.269**	0.012	**1.725**	0.013	**4.267**	0.022	**8.140**	0.047	**5.086**	0.030
NIT	0.8	**1.859**	0.013	**1.881**	0.013	**6.612**	0.034	**3.003**	0.016	**4.072**	0.024
Taylor rule 1		**1.927**	0.012	**1.718**	0.015	**7.215**	0.038	**3.033**	0.015	**2.794**	0.036
Taylor rule 2		**1.845**	0.012	**1.850**	0.016	**6.305**	0.035	**2.950**	0.015	**4.576**	0.026
Taylor rule 3		**1.960**	0.011	**1.717**	0.014	**7.555**	0.036	**3.098**	0.013	**3.127**	0.028

Bold figures are standard deviations (percent per annum) of the output gap ($s_{\tilde{y}}$), core inflation (s_{dp^c}), CPI inflation ($s_{dP^{CX}}$), the change in the GDP deflator ($s_{dP^{DEF}}$), and the nominal interest rate (s_R), respectively. Figures in the columns labeled "Std. Dev." give the standard deviation for the corresponding bold figure.

The monetary policy rules are (dropping constants):

– NIT (nominal income targeting): $R_t = (1-0.8)[3.0\,dx_t + 0.25\tilde{y}_t] + 0.8R_{t-1} + e_{R,t}$

– Taylor rule 1 (dp^C targeting): $R_t = (1-0.8)[3.0\,dp_t^C + 0.25\tilde{y}_t] + 0.8R_{t-1} + e_{R,t}$

– Taylor rule 2 (dp^{CX} targeting): $R_t = (1-0.8)[3.0\,dp_t^{CX} + 0.25\tilde{y}_t] + 0.8R_{t-1} + e_{R,t}$

– Taylor rule 3 (dp^{DEF} targeting): $R_t = (1-0.8)[3.0\,dp_t^{DEF} + 0.25\tilde{y}_t] + 0.8R_{t-1} + e_{R,t}$