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Working Paper

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NBB Working Paper, No. 277

Provided in Cooperation with:
National Bank of Belgium, Brussels

Suggested Citation: Stevens, Arnoud (2015) : Optimal monetary policy response to endogenous oil price fluctuations, NBB Working Paper, No. 277, National Bank of Belgium, Brussels

This Version is available at:
https://hdl.handle.net/10419/144489

Optimal monetary policy response to endogenous oil price fluctuations

Working Paper Research

by Arnoud Stevens

January 2015 No 277

National Bank OF BELGIUM
Eurosystem

Editorial Director
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ISSN: 1375-680X (print)
ISSN: 1784-2476 (online)

Abstract

Should the central bank seek to identify the underlying causes of oil price hikes in determining appropriate policy responses to them? Most likely not. Within a calibrated new-Keynesian model of Oil-Importing and Oil-Producing Countries, I derive the Ramsey policy and analyze optimal monetary policy responses to different sources of oil price fluctuations. I find that oil-specific demand and supply shocks call for similar policy responses, given the low substitutability of oil in production and the incompleteness of international asset markets.

JEL classification: E52, E61, Q43
Keywords: Oil Prices, Optimal Monetary Policy, Ramsey Approach,Welfare Analysis.

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I acknowledge the financial support from the Flemish Fund for Scientific Research (FWO). Part of the research was undertaken while I was a PhD researcher at the Department of Financial Economics, Ghent University, Belgium and a dissertation intern at the National Bank of Belgium (Research Department). I would like to thank Julio Carrillo, Vivien Lewis and Rafael Wouters for helpful discussions. I also thank seminar participants at the ISNE-2011 conference in Dublin for comments. All remaining errors are mine.

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1 Introduction

An emerging literature explores the implications of treating oil price shocks as endogenous with sources that could include both demand and supply. One important finding of this line of research is that the economic effects of an oil price change critically depend on the cause of the price change (see, e.g., Kilian 2009, Peersman and Van Robays 2009, Unalmis et al. 2009, Elekdag et al. 2008, Nakov and Pescatori 2010a, Balke et al. 2010, Bodenstein and Guerrieri 2011 and Peersman and Stevens 2013). This finding suggests that distinguishing between the causes of oil price shocks might be important in determining the appropriate policy responses to address them. However, the extent to which the design of optimal monetary policy should depend on the different origins of oil price fluctuations remains an unresolved question. Does the optimal monetary policy response to an oil price increase hinge on the underlying driving force? If so, how important are the differences in policy behavior?

In this paper, I seek to shed light on these questions by deriving the optimal Ramsey-type monetary policy for an oil-dependent economy that operates within an environment of endogenous oil price fluctuations. More specifically, I analyze the dynamic effects of different types of oil shocks and assess the differences in the optimal monetary policy response to these shocks. Furthermore, I compare the dynamics of the Ramsey economy with the dynamics of the model in which monetary policy follows a simple empirical Taylor-type rule to set interest rates. Doing so allows us to evaluate whether actual monetary policy, as captured by the empirical policy rule, either amplifies or dampens the recessionary effects of oil price hikes compared to what is optimal from a welfare point of view.

The framework I employ is based on the two-country dynamic stochastic general equilibrium (DSGE) model of Oil-Importing and Oil-Producing Countries proposed by Peersman and Stevens (2013). This model introduces an oil market in an otherwise standard medium-scale model based on those presented in Christiano et al. (2005) and Smets and Wouters (2007). Relative to Peersman and Stevens (2013), I simplify the model along two dimensions. First, I abstract from oil consumption by households and assume that the oil-importing country uses oil simply and solely as a production input. Second, I model the oil-exporting country in a more stylized way by assuming that oil productive capacity is exogenously given, i.e., the capital stock of oil producers is fixed. Although restrictive, these simplifications are intended to facilitate the interpretation of the results. Moreover, the paper aims to provide initial insights into the optimal monetary policy response to endogenous oil price fluctuations. Therefore, further refinements of the model are left for

future research. Optimal monetary policy is studied applying the Ramsey approach, as in, e.g., Schmitt-Grohé and Uribe (2004a, 2005) and Levin et al. (2005). The alternative would be to employ the linear quadratic approach, first introduced by Rotemberg and Woodford (1997) and expanded by Woodford (2003) and Benigno and Woodford (2005). However, the disadvantage of this latter approach is that it relies on a quadratic welfare approximation before solving the policy problem and therefore potentially omits the effects of non-linearities.

This paper is not the first to investigate the relationship between oil price shocks and monetary policy. However, to my knowledge, it is the first to analyze the Ramsey optimal monetary policy response to different sources of oil price fluctuations. A first strand of the literature has focused on the role of monetary policy in the recessionary consequences of oil price hikes, treating oil prices as exogenous supply disturbances. Bernanke et al. (1997, 2004), Hamilton and Herrera (2004) and Dvir and Rogoff (2006) rely on counterfactual policy experiments within vector autoregressive (VAR) models to disentangle the direct effects of oil shocks from those that are due to the systematic monetary policy response. However, because VAR models are non-structural, these policy exercises suffer from a Lucas Critique Problem. Taking this critique seriously, Leduc and Sill (2004), Medina and Soto (2005) and Carlstrom and Fuerst (2006) conduct the same type of counterfactual analyses in microfounded DSGE models. All three contributions find that monetary policy plays an important role in shaping the recessionary effects of oil price hikes. Moreover, they show that the best policy for mitigating the economic downturn is one that stabilizes inflation.

Policies that focus on minimizing output fluctuations are not necessarily optimal from a welfare point of view. Therefore, a second strand of the literature has begun to investigate the optimal monetary policy response in the face of exogenous oil price changes. Wohltmann and Winkler (2008) compare the welfare effects of unanticipated and anticipated oil price shocks. They find that anticipated oil shocks lead to higher welfare losses than unanticipated shocks. Montoro (2012) and Natal (2012) show that when oil has low substitutability in production, exogenous oil price shocks generate an endogenous policy trade-off between inflation and output stabilization. Finally, Winkler (2009) and Kormilitsina (2011) derive the optimal policy response to exogenous oil price shocks and contrast optimal with actual monetary policy. They report conflicting results: Winkler (2009) finds that optimal policy requires a larger output drop than what is observed under a traditional Taylor rule, whereas according to Kormilitsina (2011), optimal policy dampens output fluctuations relative to the actual monetary policy behavior.

Importantly, the above-mentioned contributions on optimal policy behavior ascribe

all variations in oil prices to a unique supply shock and hence do not take into account the deeper sources of these fluctuations. However, Bodenstein et al. (2012) argue that policy responses to oil price fluctuations without regard to the origins of these fluctuations are misguided. Within a two-country DSGE model featuring endogenous oil prices, they derive the optimal coefficients of a simple interest rate rule, i.e., the policy coefficient values that maximize welfare, and show that no two shocks induce the same policy response.[1] Although instructive, the approach of optimizing simple rules to study optimal policy behavior poses some problems. First, the coefficients of simple policy rules are invariant to the underlying sources of shocks and are dictated by those shocks that contribute the most to macroeconomic volatility. Therefore, if oil-specific shocks are only of minor importance in driving aggregate variability, the optimized simple rule is most likely not the optimal one to address these shocks. Second, a simple policy rule may be too simple, in that it neglects some important target variables. If this is the case, the optimized instrument rule could be quite different from the fully optimal policy. In this paper, I overcome these issues by deriving the globally optimal Ramsey monetary policy under commitment.

As a second contribution of the paper, I consider different channels through which oil price hikes generate a trade-off for policy makers between stabilizing inflation and output and assess their implications for the conduct of optimal monetary policy. More specifically, I investigate three sources of monetary policy trade-offs. The first source of trade-off is the traditional one in the new-Keynesian literature that arises from the simultaneous presence of price and wage stickiness, as explained by Erceg et al. (2000). The other two sources of policy trade-offs relate to two specific characteristics of the oil market, namely, the low substitutability of oil in production and the fact that oil is traded in an international environment of incomplete asset markets. Drawing on the insights of Montoro (2012), if oil is difficult to substitute, oil price fluctuations generate a time varying wedge between the natural and efficient levels of output. As shown by Corsetti et al. (2010, 2011), incomplete markets induce an additional policy trade-off, in that the central bank aims to counteract wealth-shifting effects across borders, in addition to stabilizing output and inflation.

The central result of this paper is that shocks that are specific to the oil market, such as oil supply disturbances and shifts in oil efficiency, call for rather similar policy responses once we acknowledge that oil is difficult to substitute in production and that international asset markets are incomplete. This suggests that monetary policy that neglects to identify

[1] A similar type of analysis is conducted by De Fiori et al. (2006). Using an open-economy framework that endogenizes the oil market, these authors analyze the performance of optimized simple rules. Their main finding is that the optimal interest rate rule reacts strongly to headline inflation but accommodates increases in oil price inflation.

the causes of oil price fluctuations is not significantly misguided. Intuitively, in a case with low substitutability of oil and incomplete markets, oil-specific demand and supply shocks induce similar welfare effects that call for similar policy responses. More specifically, when oil is difficult to substitute, oil price hikes generate a negative wedge between the natural and the efficient levels of output. Under incomplete markets, oil price hikes induce a shift in wealth from the oil-importing to oil-producing country. Together, both effects optimally require a severe—but short-lived—monetary policy tightening in response to unfavorable oil price increases; the tightening, in fact, deepening the recession in the short-run compared to what is observed under actual monetary policy.

The paper proceeds as follows. In Section 2, I present the model. Section 3 outlines the calibration. Section 4 derives the optimal policy and assesses the differences in the policy responses to various oil shocks. In Section 5, I analyze the robustness of the results to alternative parameterizations of the price-elasticity of oil supply. Finally, Section 6 draws the main conclusion.

2 The Model

The model I present in this paper is closely related to the two-country model of Oil-Importing and Oil-Producing Countries described in Peersman and Stevens (2013). The oil-importing (domestic) country uses oil as production input. It produces differentiated manufactured goods and sells them on both local and foreign markets. The oil-producing (foreign) country only produces oil. Manufactured goods for consumption are entirely imported from the domestic economy. Conceptualizing the oil-importing country as the US, the oil-producing country maintains a currency peg against the dollar.[2] As a result, the foreign economy needs to adopt the US monetary policy.

The model includes real and nominal frictions standard in the recent generation of new-Keynesian models as proposed by Christiano et al. (2005) and Smets and Wouters (2007). Domestic labor and goods markets are characterized by monopolistic competition and nominal rigidities as in Calvo (1983). Oil producers also operate in a monopolistic market, but can set prices optimally at each point in time. Consumption decisions are subject to external habit formations, and investment adjustments are costly. I assume perfect risk sharing within each country but allow for incomplete international markets.

Following the convention in the optimal monetary policy literature, I assume that fiscal policy offsets distortions resulting from the monopolistic competition in labor and product

[2] The main oil-producing countries do, indeed, peg their currencies to the dollar.

markets. More specifically, production and labor income subsidies are set to restore the Pareto-optimality of the steady state. Therefore, the sole task of monetary policy is to stabilize the business cycle.

The rest of this section outlines the model's equilibrium conditions.[3] Unless otherwise noted, foreign region parameters and variables are denoted by the superscript '*'. Variables without a time subscript refer to the steady-state level. Given that the dollar is the common currency, I use the US Consumer Price Index (CPI) as the numeraire price index for each region.

2.1 Oil-Importing (Domestic) Country

Domestic Firms The domestic economy produces a fixed range of differentiated (non-oil) goods of measure 1, indexed by $i \in (0,1)$. A competitive firm bundles the intermediate goods Y_t^i into an aggregate final good $\widetilde{Y}_t$ according to the constant elasticity of substitution (CES) technology $\widetilde{Y}_t = \left(\int_0^1 Y_t^{i\,\frac{\varepsilon_p-1}{\varepsilon_p}} di\right)^{\frac{\varepsilon_p}{\varepsilon_p-1}}$, where $\varepsilon_p > 1$ is the elasticity of substitution across goods. The demand for each individual good is $Y_t^i = \left(\frac{P_t^i}{P_t}\right)^{-\varepsilon_p} \widetilde{Y}_t$, where P_t^i is the price of intermediate good i. The aggregate price index reads as $P_t = \left(\int_0^1 \left(P_t^i\right)^{1-\varepsilon_p} di\right)^{\frac{1}{1-\varepsilon_p}}$.

Each differentiated good Y_t^i is produced by a single firm, which, therefore, operates in a regime of monopolistic competition. The production of intermediate goods is modeled in the spirit of Rotemberg and Woodford (1996). First, the value added output VA_t^i (i.e., GDP) is produced under a Cobb-Douglas production function with labor $\widetilde{L}_t^i$ and capital services $K_t^{S,i}$, weighted by θ and $1-\theta$, respectively; i.e., $VA_t^i = \eta_t^a \left(\widetilde{L}_t^i\right)^{\theta} \left(K_t^{S,i}\right)^{1-\theta}$. Total factor productivity (TFP) η_t^a is assumed to follow an exogenous process. Second, value added is aggregated with oil O_t^i by means of a CES technology to produce gross output Y_t^i; i.e., $Y_t^i = \left(\eta^{\frac{1}{\alpha}} \left(VA_t^i\right)^{\frac{\alpha-1}{\alpha}} + (1-\eta)^{\frac{1}{\alpha}} \left(\eta_t^{oe} O_t^i\right)^{\frac{\alpha-1}{\alpha}}\right)^{\frac{\alpha}{\alpha-1}} - \Phi$, where $\alpha > 0$ defines the elasticity of substitution between value added and oil in production, η is the share of GDP in gross output and Φ denotes fixed costs. The term η_t^{oe} represents an exogenous shock that affects the relative efficiency of oil usage (henceforth, 'oil efficiency shock').

[3] An appendix containing detailed model derivations is available upon request.

Cost minimization implies the following demand curves for labor and oil:

$$\widetilde{L}_t^i = \frac{\theta}{1-\theta}\frac{r_t^k}{w_t}K_t^{S,i}, \tag{1}$$

$$O_t^i = \left(\frac{s_t}{p_t^o}\right)^{\alpha}\frac{1-\eta}{\eta}VA_t^i\left(\eta_t^{oe}\right)^{\alpha-1}, \tag{2}$$

with,

$$s_t \equiv \left(\frac{r_t^k}{1-\theta}\right)^{1-\theta}\left(\frac{w_t}{\theta}\right)^{\theta}\frac{1}{\eta_t^a}, \tag{3}$$

where p_t^o denotes the real oil price, w_t represents the real wage rate and r_t^k is the rental rate of capital. The auxiliary variable s_t captures the GDP-deflator expressed in real terms of units of consumption. Real marginal costs are equal across firms and given by

$$mc_t = \left(\eta\left(s_t\right)^{1-\alpha} + \left(1-\eta\right)\left(\frac{p_t^o}{\eta_t^{oe}}\right)^{1-\alpha}\right)^{\frac{1}{1-\alpha}}. \tag{4}$$

Price decisions are subject to Calvo (1983)-staggering. Non-adjusted prices are indexed to lagged inflation. If $\xi_p \in (0,1)$ is the Calvo price stickiness parameter, $\gamma_p \in (0,1)$ denotes the degree of price indexation and $\beta \in (0,1)$ represents the discount factor, then the first-order condition of a firm that is able to re-optimize its price $\overline{P}_t^i$ is given by

$$\left(1+\tau_p\right)\frac{\overline{P}_t^i}{P_t} = \left(1+\lambda_p\right)\frac{\Psi_t^p}{\Phi_t^p}. \tag{5}$$

λ_p is the steady-state (net) price markup, which equals $\lambda_p = \frac{\varepsilon_p}{\varepsilon_p - 1} - 1$. The parameter τ_p captures production subsidies. Following Schmitt-Grohé and Uribe (2004b) the variables Ψ_t^p and Φ_t^p are defined recursively as

$$\Psi_t^p = mc_t\tilde{Y}_t + \beta\xi_p E_t\left[\left(\frac{U_{c,t+1}}{U_{c,t}}\right)\left(\frac{\pi_{t+1}^p}{\left(\pi_t^p\right)^{\gamma_p}}\right)^{\varepsilon_p}\Psi_{t+1}^p\right], \tag{6}$$

$$\Phi_t^p = \tilde{Y}_t + \beta\xi_p E_t\left[\left(\frac{U_{c,t+1}}{U_{c,t}}\right)\left(\frac{\pi_{t+1}^p}{\left(\pi_t^p\right)^{\gamma_p}}\right)^{\varepsilon_p-1}\Phi_{t+1}^p\right], \tag{7}$$

where π_t^p denotes the gross price inflation rate, i.e., $\pi_t^p = P_t/P_{t-1}$, and E_t is the expectations operator conditional on the information set at the beginning of period t. The variable $\beta\frac{U_{c,t+1}}{U_{c,t}}$ represents the one-period stochastic discount factor, which depends on the households' marginal utility of consumption $U_{c,t}$ (discussed below). If prices are perfectly flexible, i.e., $\xi_p \to 0$, the optimality condition (5) simplifies to $\left(1+\tau_p\right)\overline{P}_t^i = \left(1+\lambda_p\right)P_t mc_t$. The monopolistic supplier of good i then sets its price $\bar{P}_t^i$ as a constant markup $\frac{(1+\lambda_p)}{(1+\tau_p)}$ over marginal costs. I assume that firm output is subsidized to eliminate the monopolistic distortion associated with a positive markup, i.e., $\tau_p = \lambda_p$.

Domestic Households The domestic economy is made up of a continuum of differentiated households, indexed by $\tau \in (0,1)$, which seek to maximize lifetime utility $E_0 \sum_{t=0}^{\infty} \beta^t U_t^\tau$. Period utility is a positive function of consumption C_t^τ and a negative function of hours worked L_t^τ, $U_t^\tau = \frac{1}{1-\sigma_c}\left(C_t^\tau - hC_{t-1}\right)^{1-\sigma_c} - \frac{1}{1+\sigma_l}\left(L_t^\tau\right)^{1+\sigma_l}$, where $\sigma_c > 0$ is the degree of risk aversion, $h \in (0,1)$ captures external habit formation in consumption and $\sigma_l > 0$ is the inverse Frisch elasticity of labor supply. The marginal utilities of consumption and labor are, respectively,[4]

$$U_{C,t} = \left(C_t - hC_{t-1}\right)^{-\sigma_c}, \tag{8}$$

$$U_{L,t} = -\left(L_t\right)^{\sigma_l}. \tag{9}$$

Households have access to several types of assets to facilitate the inter-temporal transfer of wealth. First, they can purchase domestic risk-free bonds, for which the gross nominal interest rate is given by R_t. The optimal choice of bonds yields the usual consumption Euler equation,

$$U_{c,t} = E_t\left(\beta \frac{R_t}{\pi_{t+1}^p} U_{c,t+1}\right). \tag{10}$$

Second, households hold international securities. I contrast the complete- and incomplete-market cases. Under complete markets, a full set of state-contingent claims is traded internationally, such that risk is equally shared across borders. Given that the foreign economy pegs its currency to the domestic currency, the international equilibrium risk-sharing condition reads as

$$U_{c,t} = U_{c,t}^*, \tag{11a}$$

where $U_{c,t}^*$ denotes the foreign households' marginal utility of consumption. Therefore, in the case of complete international capital markets, marginal consumption utilities are equal in both countries. Conversely, when markets are incomplete, only one non-state-contingent bond can be traded internationally. Then, the optimal choice of foreign bond holdings leads to the uncovered interest parity (UIP) condition,

$$R_t^* = R_t\left(1 + \kappa\left(\frac{NFA_t - NFA}{Y}\right)\right), \tag{11b}$$

which replaces the risk-sharing condition (11a) observed in the complete-market case. The non-state-contingent international bond pays interest R_t^*, which equals the domestic rate

[4] I assume the existence of complete domestic markets that insure the households against variations in household specific labor income, i.e., the marginal utility of wealth is identical across different types of households. Each household then chooses the same level of consumption and investment. Therefore, we can suppress the household specific index τ in the first order conditions reported below.

R_t, corrected for a default risk premium. This risk premium depends positively on the net foreign asset position NFA_t, with $\kappa > 0$, and acts as a stationarity-inducing device.[5]

In addition to accumulating financial wealth, households can invest I_t in the physical capital stock K_t. Capital services K_t^S are related to the physical stock of capital through $K_t^S = z_t K_{t-1}$, where z_t is the capital utilization rate set by the households. Variations in the capital utilization rate entail a cost in units of consumption, denoted by the increasing convex function $\chi(z_t)$.[6] The optimal condition for the utilization rate equates the rental price of capital with the marginal cost of higher capital utilization,

$$r_t^k = \chi'(z_t). \tag{12}$$

Accumulation of physical capital takes the form

$$K_t = (1 - \delta_K)K_{t-1} + \left(1 - S\left(\frac{I_t}{I_{t-1}}\right)\right) I_t, \tag{13}$$

where $\delta_K \in (0, 1)$ represents the depreciation rate of capital. Following Christiano et al. (2005), investment changes are assumed to be costly, measured by the investment adjustment cost function $S\left(I_t/I_{t-1}\right)$.[7] The optimal choice of physical capital gives rise to the usual Tobin's Q equation,

$$Q_t = E_t\left[\frac{\pi_{t+1}^p}{R_t}\left[\left(r_{t+1}^k z_{t+1} - \chi(z_{t+1})\right) + Q_{t+1}(1 - \delta_K)\right]\right], \tag{14}$$

which equates the real return on bond holdings to the real return on capital accumulation. Investment adjustment costs imply that current investment is a function of its lagged and expected future value, as well as the current value of capital,

$$\begin{aligned} 1 \;=\; & Q_t\left\{1 - S\left(\frac{I_t}{I_{t-1}}\right)\right\} - Q_t I_t\left\{S'\left(\frac{I_t}{I_{t-1}}\right)\right\}\frac{1}{I_{t-1}} \\ & + E_t\left[\frac{\pi_{t+1}^p}{R_t} Q_{t+1} I_{t+1}\left\{S'\left(\frac{I_{t+1}}{I_t}\right)\right\}\left(\frac{I_{t+1}}{{I_t}^2}\right)\right]. \end{aligned} \tag{15}$$

Following Erceg et al. (2000), households are monopolistic suppliers of differentiated labor types l_t^τ and set wages in a Calvo (1983)-staggered manner. In addition, I stipulate

[5] See Benigno (2009) for details of the non-stationarity problem, and how to resolve it, in open-economy models with incomplete financial markets.

[6] As in Christiano et al. (2005), I impose that in steady state $z = 1$, $\chi(z) = 0$ and $\chi \equiv \frac{\chi''(z)}{\chi'(z)} \geqslant 0$. In Section 3, I discuss the functional form for $\chi(u_t)$ in greater detail.

[7] Following Christiano et al. (2005), I assume that the adjustment cost function $S(.)$ has the following steady-state properties: $S(1) = S'(1) = 0$ and $S''(1) > 0$. The specific functional form ascribed to $S(.)$ is presented in Section 3.

that non-adjusted wages are indexed to lagged price inflation. Analogously to final goods producers, a competitive labor bundler buys the differentiated labor types and aggregates them to $\widetilde{L}_t = \left(\int_0^1 l_t^{\tau} \frac{\varepsilon_w - 1}{\varepsilon_w} d\tau\right)^{\frac{\varepsilon_w}{\varepsilon_w - 1}}$, with $\varepsilon_w > 1$ denoting the elasticity of substitution between different labor types. Demand for labor is given by $l_t^{\tau} = \left(\frac{W_t^{\tau}}{W_t}\right)^{-\varepsilon_w} \widetilde{L}_t$, where W_t^{τ} is the price of labor type τ and W_t is the aggregate wage index, which reads as $W_t = \left(\int_0^1 W_t^{\tau\ 1-\varepsilon_w} d\tau\right)^{\frac{1}{1-\varepsilon_w}}$. A household τ that is able to re-optimize its nominal wage will set $\overline{W}_t^{\tau}$ such that

$$(1+\tau_w)\left(\frac{\overline{W}_t^{\tau}}{W_t}\right)^{1+\varepsilon_w\sigma_l} = (1+\lambda_w)\frac{\Psi_t^w}{\Phi_t^w}, \tag{16}$$

where λ_w is the steady-state (net) wage markup, which equals $\lambda_w = \frac{\varepsilon_w}{\varepsilon_w - 1} - 1$, and τ_w are subsidies to labor income. Ψ_t^w and Φ_t^w are auxiliary variables, which according to Schmitt-Grohé and Uribe (2004b), can be expressed in recursive form as

$$\Psi_t^w = \left(\widetilde{L}_t\right)^{1+\sigma_l} + \beta\xi_w E_t\left[\left(\frac{1}{(\pi_t^p)^{\gamma_w}}\right)^{\varepsilon_w(1+\sigma_l)} \left(\pi_{t+1}^w\right)^{\varepsilon_w(1+\sigma_l)} \Psi_{t+1}^w\right], \tag{17}$$

$$\Phi_t^w = U_{c,t}^{\tau} w_t \widetilde{L}_t + \beta\xi_w E_t\left[\left(\frac{1}{(\pi_t^p)^{\gamma_w}}\right)^{\varepsilon_w - 1} \left(\pi_{t+1}^w\right)^{\varepsilon_w - 1} \Phi_{t+1}^w\right], \tag{18}$$

where $\xi_w \in (0,1)$ is the Calvo parameter for nominal wage stickiness, $\gamma_w \in (0,1)$ denotes the degree of wage indexation and π_t^w is the gross wage inflation rate. Wage subsidies τ_w are set equal to λ_w to eliminate the distortion resulting from monopolistic competition and to restore the efficiency of the steady state. As a result, if wages are perfectly flexible, i.e., $\xi_w \to 0$, the marginal rate of substitution between leisure and consumption equals the real wage, i.e., $w_t = -\frac{U_{l,t}}{U_{c,t}}$.

2.2 Oil-Exporting (Foreign) Country

Oil Producers Analogously to the (non-oil) goods producers in the oil-importing country, crude oil producers operate in a regime of monopolistic competition.[8] There is a continuum of oil producers, indexed by $j \in (0,1)$, with each producing one particular type of oil $O_t^{*,j}$. Oil production is described by an AK-technology, $O_t^{*,j} = \eta_t^{oc} D_t^{S,j}$, where $D_t^{S,j}$ represents capital services and η_t^{oc} is the exogenous oil production technology. The physical capital stock D_t^j should be interpreted as a combination of exploitable oil fields

[8] Because oil producing firms are situated all around the world, each produces a type of oil that is differentiated from the other oil producers' output in terms of geographical distance.

and the installed machinery on these fields. Given the small oil depletion rate and the substantial time required to develop new exploitable oil fields, I assume, for simplicity, that this physical capital stock is fixed, i.e., $D_t^j = \overline{D}$. Short-term fluctuations in capital services are captured by the variable utilization rate u_t, implying $D_t^{S,j} = u_t \bar{D}$. Oil production occurs at normal capacity, denoted $OCAP_t^*$, if $u_t = 1$; therefore, $OCAP_t^* = \eta_t^{oc} \bar{D}$. Accordingly, I refer to exogenous disturbances of the oil sector's TFP η_t^{oc} as 'oil capacity shocks'. Military conflicts or natural disasters that destroy oil productive capacity are examples of such exogenous oil supply events.

The real marginal costs of oil-producers mc_t^* equal the rental rate of capital services r_t^d divided by TFP,

$$mc_t^* = r_t^d \frac{1}{\eta_t^{oc}}. \tag{19}$$

Given the monopolistic competitive market structure, oil prices P_t^o are set as a markup $(1 + \lambda_{o,t})$ over marginal costs,[9]

$$(1 + \tau_o) P_t^o = (1 + \lambda_{o,t}) P_t mc_t^*, \tag{20}$$

where τ_o are production subsidies. In contrast to domestic goods prices, oil prices are perfectly flexible. Therefore, variations in the oil markup $\lambda_{o,t}$ are ascribed entirely to exogenous sources, denoted η_t^o, i.e., $\lambda_{o,t} = \eta_t^o$, that represent shifts in the market power of oil producers (henceforth, 'oil markup shocks').[10] Similar to the domestic economy, the government offsets the steady-state effect of monopolistic distortions in the oil sector by enacting the appropriate magnitude of production subsidies τ_o.

Foreign Households The representative foreign household seeks to maximize expected lifetime utility $E_0 \sum_{t=0}^{\infty} \beta^t U_t^*$. In contrast to domestic households, period t utility only depends on consumption C_t^*. In particular, I assume that $U_t^* = \frac{1}{1-\sigma_c^*} \left(C_t^* - h^* C_{t-1}^*\right)^{1-\sigma_c^*}$, where $\sigma_c^* > 0$ is the degree of risk aversion and $h^* \in (0, 1)$ is the degree of external habit formation. Note that consumption goods C_t^* are entirely imported from the domestic economy. The optimal consumption path is determined by the familiar Euler equation,

$$U_{c,t}^* = E_t \left(\beta \frac{R_t^*}{\pi_{t+1}^p} U_{c,t+1}^* \right), \quad \text{where} \quad U_{c,t}^* = \left(C_t^* - h^* C_{t-1}^*\right)^{-\sigma_c^*}. \tag{21}$$

[9] Because oil prices are perfectly flexible, each intermediate oil producer optimally chooses the same price, i.e., $P_t^{o,j} = P_t^o$, and produces the same oil amount, i.e., $O_t^{*,j} = O_t^*$. Therefore, we can drop the index j from the oil producers' first order conditions.

[10] Modeling OPEC as a cartel would induce behavioral equations for oil producers that, up to the first order, are observationally equivalent to those obtained in my model. In that case, we could interpret oil markup shocks as shifts in the degree to which cartel agreements are observed by its members.

When there is a complete set of state-contingent claims in the international capital market, risk is equally shared across borders and $U^*_{c,t} = U_{c,t}$, see condition (11a).

Foreign households also choose the utilization rate of the oil capital stock, of which a level of u_t induces a utilization cost of $\vartheta(u_t)$ units of consumption goods. The first-order condition for this utilization rate is

$$r^d_t = \vartheta'(u_t). \tag{22}$$

Given the installed oil capital stock $\overline{D}$, the household increases the utilization rate up to the point where the marginal revenue equals the marginal cost of additional oil exploitation.

Oil Supply Curve By combining the aggregate oil production function, i.e., $O^*_t = \eta^{oc}_t D^S_t$, with equations (19), (20), and (22), we obtain the oil supply curve, the log-linearized form of which is

$$\widehat{O}^*_t = \hat{\eta}^{oc}_t + \frac{1}{\vartheta}\left(\widehat{p}^o_t\right) - \frac{1}{\vartheta}\left(\frac{1}{1+\lambda_o}\hat{\eta}^o_t - \hat{\eta}^{oc}_t\right), \tag{23}$$

where $\vartheta \equiv \frac{\vartheta''(u)u}{\vartheta'(u)}$ and variables in their log deviations around the deterministic steady state are denoted by the superscript '$\hat{}$', i.e., $\widehat{X}_t = \log\left(\frac{X_t}{X}\right)$. Note that the price-elasticity of the supply of oil equals the inverse of the elasticity of marginal utilization costs with respect to the utilization rate, i.e., $\frac{dO_t/O_t}{dp^o_t/p^o_t} = \frac{1}{\vartheta}$. Remarkably, both unfavorable oil capacity shocks and oil markup shocks cause an increase in oil prices for a given level of output; however, the resulting oil price increases operate through different transmission channels. Therefore, each category of oil supply shock produces a different effect on the oil capacity utilization rate. It is through these differing effects that these shocks can be identified. If oil producers increase their market power, they impose a higher price without affecting the oil capacity utilization rate, holding all other factors constant. Conversely, following an exogenous decline in oil productive capacity, oil fields must be utilized more intensively to maintain a given level of production. This effect generates upward pressure on the rental rate of oil fields, which increases marginal costs and oil prices.

2.3 Aggregation and Market Clearing

Labor market clearing implies

$$L_t = s^w_t \widetilde{L}_t, \tag{24}$$

where $\widetilde{L}_t = \int_0^1 \widetilde{L}^i_t di$ and $L_t = \int_0^1 L^\tau_t d\tau$ denote aggregate labor demand and aggregate labor supply, respectively. The term $s^w_t = \left(\int_0^1 \left(\frac{W^\tau_t}{W_t}\right)^{-\varepsilon_w} d\tau\right) \geqslant 1$ is a measure of wage

dispersion, which according to Schmitt-Grohé and Uribe (2004b), can be rewritten to obtain

$$s_t^w = (1-\xi_w)\left(\frac{\overline{W}_t^{\tau}}{W_t}\right)^{-\varepsilon_w} + \xi_w\left(\left(\pi_{t-1}^p\right)^{\gamma_w}\right)^{-\varepsilon_w}\left(\frac{1}{\pi_t^w}\right)^{-\varepsilon_w} s_{t-1}^w. \tag{25}$$

The goods market clearing condition is given by

$$Y_t = s_t^p \widetilde{Y}_t, \tag{26}$$

where $\widetilde{Y}_t$ equals the aggregate demand for final goods, $Y_t = \int_0^1 Y_t^i di$ denotes the aggregate production of intermediate goods and $s_t^p = \left(\int_0^1 \left(\frac{P_t^i}{P_t}\right)^{-\varepsilon_p} di\right) \geqslant 1$ is a measure of price dispersion. Similar to the wage dispersion measure, price dispersion can be expressed recursively as

$$s_t^p = (1-\xi_p)\left(\frac{\overline{P}_t^i}{P_t}\right)^{-\varepsilon_p} + \xi_p\left(\left(\pi_{t-1}^p\right)^{\gamma_p}\right)^{-\varepsilon_p}\left(\frac{1}{\pi_t^p}\right)^{-\varepsilon_p} s_{t-1}^p. \tag{27}$$

Because oil prices are flexible, aggregate oil demand $O_t = \int_0^1 O_t^i di$ equals aggregate oil supply $O_t^* = \int_0^1 O_t^{*,j} dj$, i.e.,

$$O_t = O_t^*. \tag{28}$$

By integrating the budget constraints of all domestic households τ, we obtain, after some manipulations, the national income account of the domestic economy,[11]

$$\begin{aligned} \tilde{Y}_t &= C_t + I_t + \chi(z_t)K_{t-1} + p_t^o O_t + \eta_t^g \\ &\quad + \left(NFA_t - \frac{R_{t-1}^*}{\pi_t^p} NFA_{t-1}\right) + \frac{\kappa}{2}\frac{1}{Y}\left(NFA_t - \overline{NFA}\right)^2, \end{aligned} \tag{29}$$

where η_t^g denotes exogenous government consumption. Finally, the foreign income account (30) reads as

$$p_t^o O_t^* = C_t^* + \vartheta(u_t)\bar{D} - \left(NFA_t - \frac{R_{t-1}^*}{\pi_t^p} NFA_{t-1}\right). \tag{30}$$

2.4 Monetary Policy

The oil-exporting country adopts the domestic country's monetary policy because it pegs its currency to the dollar. With respect to the oil-importing country, I consider two

[11] One of the manipulations requires substituting out taxes using the government budget constraint. The government collects lump-sum taxes T_t^r from households to finance price and wage subsidies and its exogenously given consumption η_t^g, i.e., $T_t^r = \tau_p P_t \widetilde{Y}_t + \tau_w P_t w_t \widetilde{L}_t + \eta_t^g$.

different monetary policy regimes. First, I derive the optimal monetary policy under commitment. Second, I assume that the monetary authority commits itself to a simple instrument rule. I discuss these two policy regimes in turn. First, however, recall the inclusion in the analysis of fiscal subsidies that offset the steady-state monopolistic distortions of production and employment. As a result, the central bank plays no role in offsetting the effects of steady-state distortions and focuses exclusively on stabilizing the business cycle.

Optimal Policy Optimal monetary policy is studied using the Ramsey approach; i.e., the monetary authority maximizes conditional expected social welfare V_0, given the non-linear constraints of the competitive economy, where welfare V_0 equals the expected discounted sum of lifetime utilities of all domestic agents,

$$V_0 = E_0 \sum_{t=0}^{\infty} \beta^t U_t^{\tau}. \tag{31}$$

In solving the optimization problem, I assume that ex-ante commitment is feasible. Moreover, I focus on the optimal policy from a time-invariant monetary policy perspective, as proposed by Woodford (2003).[12] The alternative method of analyzing optimal monetary policy would be to employ the linear quadratic approach. In contrast to the Ramsey approach, this method relies on a quadratic welfare approximation prior to solving the policy problem. Specifically, in this case, optimal policy behavior is derived from maximizing the linear quadratic approximation of the welfare objective (31), subject to the first-order (or linear) approximations of the structural equations. The disadvantage of this approach is that it may neglect the effects of non-linearities in the model, due to its approximate nature.

To compute the Ramsey-optimal policy under timeless-perspective commitment, I formulate an infinite-horizon Lagrangian problem, in which the central bank maximizes conditional expected social welfare (31), subject to the full set of non-linear constraints implied by the private sector's behavioral equations and the market-clearing conditions of the model economy. The first-order conditions for this problem describe the Ramsey-optimal conduct of monetary policy. I employ the symbolic Matlab procedures developed by Levin and Lopez-Salido (2004) to derive the central bank's first-order conditions in practice. Under these procedures, the Lagrangian is first differentiated with respect to each endogenous variable, with the derivatives subsequently set to zero. Then, we obtain the model

[12] The time-invariant optimal monetary policy approach assumes that by the initial period, $t = 0$, the economy has been operating for an infinite number of periods. As a result, the planner's optimal rule at time $t = 0$ can be substituted for the optimal policy conditions derived for any arbitrary period $t > 0$.

economy under optimal policy by combining the optimal policy conditions with the private sector's behavioral equations and the market-clearing conditions.

Taylor-type Policy The second policy regime that I consider is one in which the monetary authority follows a simple Taylor-type rule with interest rate smoothing,

$$R_t = R^{1-\tau_R} \left(R_{t-1}\right)^{\tau_R} \left(x_t\right)^{\tau_y(1-\tau_R)} \left(\frac{\pi_t^p}{\pi^p}\right)^{\tau_\pi(1-\tau_R)} \left(x_t/x_{t-1}\right)^{\tau_{dy}} . \tag{32}$$

Under this regime, the interest rate is adjusted in response to the level and growth rate of the output gap, price inflation, and the lagged interest rate. The corresponding feedback coefficients are, τ_y, τ_{dy}, τ_π, and τ_R, respectively. Throughout the paper, the output gap x_t is defined as the deviation of actual value added VA_t from potential value added VA_t^p, where the latter is the value added that would prevail under flexible prices and wages in the absence of the oil markup shock, i.e., $x_t = \frac{VA_t}{VA_t^p}$. Note the difference between the potential and natural level of output. The latter is the level of output that would prevail under flexible prices and wages but with markup shocks present. Therefore, in the analysis discussed below, the potential level of output differs from the natural level of output only following oil markup shocks. The values of the policy parameters are drawn from Peersman and Stevens (2013), who obtain estimates of the policy rule (32) in a full-fledged DSGE model of the US and oil-producing countries. Therefore, under the assumed calibration (outlined in Section 3), the simple Taylor-type rule can be viewed as describing the conduct of actual monetary policy.

3 Calibration

Functional Forms Before discussing the calibration, I first specify the functional forms of the investment adjustment cost $S\left(I_t/I_{t-1}\right)$ and the capacity utilization costs $\chi(z_t)$ and $\vartheta(u_t)$.

The investment adjustment cost function, taken from Levin et al. (2005), is

$$S\left(\frac{I_t}{I_{t-1}}\right) = \varsigma \frac{1}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 . \tag{33}$$

Note that in steady state, adjustment costs are zero, i.e., $S\left(1\right) = 0$, and of only second order, i.e., $S'\left(1\right) = 0$ and $S''\left(1\right) = \varsigma > 0$.

Again, following Levin et al. (2005), I define the capacity utilization cost $\chi(z_t)$ incurred by domestic households as a CES function of its capacity utilization rate z_t, i.e.,

$$\chi(z_t) = a\frac{(z_t)^{1+\chi} - 1}{1+\chi}, \tag{34}$$

where $\chi \geqslant 0$ is the elasticity of marginal utilization costs with respect to the utilization rate. The parameter $a > 0$ is selected such that steady-state utilization costs are zero. The same specification is used for the foreign capacity utilization cost function $\vartheta(u_t)$, where the inverse of the elasticity of the marginal utilization cost corresponds to the price-elasticity of oil supply, i.e., $1/\vartheta = \frac{dO_t/O_t}{dp_t^o/p_t^o}$ (see equation (23)).

Calibration Table 1 displays the calibration of the model. Unless otherwise noted, parameter values are drawn from Peersman and Stevens (2013), who estimate an extended version of the model using a full-information Bayesian approach. Before turning to the parameters that are specific to the oil market, I first comment on the standard parameters.

[insert Table 1 here]

In brief, most of the estimates of the standard parameters, reported in the companion paper, are in line with the literature. Considering a quarterly calibration of the model, the discount factor is set to $\beta = 0.99$. Physical capital depreciates at an annual rate of 10%, i.e., $\delta_K = 0.025$. The labor cost share of value added at steady state is calibrated as $\theta = 0.76$. Approximately one fifth of all manufactured goods are consumed by the government, $\eta^g/\widetilde{Y} = 0.21$. I assume that the utility parameters are symmetric across the two economies. More specifically, in both countries, the coefficient of habit formation is set at $h = h^* = 0.48$, and the degree of relative risk aversion is $\sigma_c = \sigma_c^* = 1.80$. Consistent with studies including nominal wage rigidities, the inverse Frisch elasticity of labor supply is given a relatively high value of $\sigma_l = 2.8$.[13] The elasticity of the cost of changing investments ς and the elasticity of utilization costs with respect to utilization χ are both set to six. I calibrate the Calvo price and wage adjustment cost parameters as $\xi_p = 0.8$ and $\xi_w = 0.75$, respectively, which implies an average contract duration of approximately five quarters for prices and four quarters for wages. The degree of indexation to past inflation is $\gamma_p = 0.25$ for prices and $\gamma_w = 0.45$ for wages. The long-run price markup is calibrated as $\lambda_p = 0.39$, whereas the wage markup takes a relatively lower value of $\lambda_w = 0.2$. Under the Taylor-type policy, the monetary policy rule exhibits a high degree of interest rate smoothing, with τ_R calibrated at 0.87, whereas the coefficients on inflation,

[13] See, e.g., Rabanal and Rubio-Ramirez (2005) for a comparison of estimates of the Frisch elasticity $1/\sigma_l$, obtained in flexible wage new-Keynesian models, with those observed in sticky wage environments.

the size of the output gap, and changes in the output gap are set at $\tau_\pi = 1.5$, $\tau_y = 0.05$ and $\tau_{dy} = 0.3$, respectively. In the case of incomplete international capital markets, we must consider a non-zero cost in acquiring net foreign assets to restore the stationarity of the model. Following Jacob and Peersman (2013), I assume that the elasticity of the cost of accumulating foreign debt is low, with $\kappa = 0.001$.

Turning to the parameters that are specific to the oil market, first note that I normalize the real steady-state oil price to one. The long-run oil price markup is calibrated as $\lambda_o = 0.75$.[14] I set $\eta = 0.95$, implying a share of oil in gross output of 5%. The degree of oil substitutability is considered to be low, with $\alpha = 0.03$. Note that the substitution elasticity coefficient equals the short-run oil demand elasticity (see equation (2)). Therefore, the calibrated value for α is consistent with reduced-form evidence on the steepness of the oil demand curve reported in, e.g., Dahl and Sterner (1991), Krichene (2002), Cooper (2003), and Atkins and Jazayeri (2004). In particular, all of these studies estimate the price-elasticity as lying between 0 and 0.11. The elasticity of the utilization cost of capital in the oil sector ϑ is selected to obtain a price-elasticity of oil supply of approximately 0.1, i.e., $\vartheta = 10$. This baseline calibration is based on evidence provided in Peersman and Stevens (2013). However, other recent empirical studies by Krichene (2002) and Baumeister and Peersman (2013) suggest that the oil supply elasticity coefficient is significantly positive but smaller than 0.1. Therefore, in Section 5, I investigate the sensitivity of the results to alternative parameterizations of ϑ. Finally, I assume that all stochastic disturbances follow $AR(1)$ processes in logarithmic terms, with a persistence parameter of 0.8.

4 Optimal Monetary Policy Response to Different Oil Shocks

I now investigate the extent to which the optimal monetary policy response to oil price fluctuations depends on the underlying source of the fluctuations. In doing so, I aim to assess the importance of different sources of the policy trade-off between stabilizing output and stabilizing inflation in driving the results. The most common explanation for this trade-off is that both prices and wages are sticky (see Erceg et al., 2000). In addition to this traditional explanation, the model features two other sources for the policy trade-off that relate to specific characteristics of the oil market. The first additional channel

[14] The literature provides little guidance on the size of the oil price markup λ_o. However, in an additional robustness check available upon request, I demonstrate that the results are robust to alternative specifications of λ_o. For instance, the results hold when we impose the relatively lower value of $\lambda_o = 0.36$, which corresponds to the size of the oil markup derived from the structural oil model of Nakov and Pescatori (2010a).

through which oil price increases generate a policy trade-off arises from the fact that oil is difficult to substitute in production, i.e., $\alpha < 1$. As shown by Montoro (2012), when oil is a gross complement to the domestic factors in production, real marginal costs are a convex function of the real oil price. Oil price fluctuations then generate non-linear distortions in the wedge between the natural and efficient levels of output, distortions that increase the tension between the objectives of stabilizing inflation and stabilizing economic activity. The second additional source of the trade-off relates to the fact that oil trade occurs in an environment of incomplete international asset markets. Corsetti et al. (2010, 2011) demonstrate that relative to the case of complete markets, the central bank's loss function in the incomplete-market case includes a welfare relevant measure of cross-country demand imbalances. Consequently, incomplete markets induce an additional policy trade-off, in that the central bank aims to counteract wealth-shifting effects across borders, in addition to stabilizing output and inflation. In the following, I first consider the more realistic environment in which oil has few substitutes and international asset markets are incomplete. Subsequently, I remove the assumptions of low substitutability of oil and incomplete international risk sharing one at the time to evaluate their respective implications for the conduct of optimal monetary policy.

4.1 Baseline Model Economy

Figures 1a and 1b depict the first-order dynamics of the Ramsey economy when international capital markets are incomplete and the elasticity of substitution between oil and value added is low, with $\alpha = 0.03$. To evaluate the contribution of actual monetary policy to the recessionary effects of oil price hikes, I also plot the impulse responses for the model under the Taylor-rule policy (32). I distinguish three types of oil shocks. First, oil capacity shocks η_t^{oc} and oil markup shocks η_t^{o} represent 'oil supply shocks'. Second, the oil efficiency shock constitutes an 'oil-specific demand shock'. Finally, domestic TFP and government spending shocks are classified as 'macro-economic (ME)-driven oil demand shocks', which affect oil demand indirectly through changes in domestic economic activity. I mainly focus on the dynamics of the oil supply and oil-specific demand shocks because these factors have been shown to be the main driving forces of oil price fluctuations.[15]

[15] There is considerable disagreement in the literature regarding the relative importance of oil supply and demand shocks in driving oil prices. For instance, Hamilton (1983, 2009), Nakov and Pescatori (2010b), and Peersman and Stevens (2013) find that variations in oil prices are mainly driven by oil supply disruptions. Conversely, Kilian (2009), Balke et al. (2010) and Bodenstein and Guerrieri (2011) argue that shocks to oil demand have driven oil prices historically. However, despite these different results, there is consensus in these studies that ME-driven oil demand shocks play only a minor role in determining oil prices, i.e.,

Note that to facilitate the comparison, all shocks have been normalized to produce a 10% maximum increase in the real oil price under the Taylor-type policy. Before assessing the differences in the policy responses to the various types of oil shocks, I first briefly discuss the key transmission channels of each of these shocks, assuming the monetary authority follows the Taylor-type rule.

[insert Figures 1a and 1b here]

Key Dynamics The first two panels of Figure 1a depict the impulse responses of selected variables to the two types of oil supply shock.[16] Unfavorable movements in both shocks, i.e., positive oil markup shocks and negative oil capacity shocks, lower oil production. The resulting rise in real oil prices entails a negative income effect on domestic output. Due to staggered price contracts, this negative effect is partially counteracted by an endogenous decrease in the price markup, reflected by the higher inflation rate. Furthermore, intermediate goods producers hire additional domestic input factors to substitute for the more expensive oil. Following an exogenous decline in oil productive capacity, this positive substitution effect dominates the negative income effect in the very short run (three quarters or less). Therefore, on impact, labor demand, the value-added output of domestic productive factors (not shown), and gross output increase. After approximately 2.5 quarters, employment and output fall below steady-state levels. In contrast, in response to a negative oil markup shock, the income effect prevails over the substitution effect over all horizons, such that employment, value added, and gross output immediately fall. These different effects on labor demand and output derive from the different trade dynamics that both shocks trigger. In the case of a negative oil capacity shock, oil fields must be utilized more intensively to maintain production at its pre-shock levels. This occurrence raises the oil capacity utilization costs, expressed in terms of forgone consumption. As a result, exports of manufactured goods from the oil-importing to oil-producing country rise, which weakens the negative income effect triggered by the oil price increase. In the case of a positive oil markup shock, oil producers impose a higher price for a given productive capacity. The resulting decline in oil demand lowers the oil capacity utilization rate. Therefore, domestic exports of manufactured goods fall, which strengthens the negative income effect on domestic output induced by the oil price increase.[17] Remarkably, despite their differential effects on labor demand, both types of oil supply shock entail a decline

oil prices are mainly driven by shocks that are specific to the oil market.

[16] Additional impulse responses of other variables not presented in Figures 1a and 1b are reported in the Appendix (available upon request).

[17] Note that after approximately 2.5 years, both types of oil supply shock cause employment and output to increase before turning back to their long-run steady-state levels because unfavorable movements in

in the real wage rate over the entire transition period. This result is due to the decline in consumption, which increases labor supply and depresses wages. Finally, applying the Taylor-type rule, monetary policy makers raise the interest rate—following both types of supply shock—in an attempt to curb inflation.

The third panel of Figure 1a illustrates that the dynamics induced by a negative oil efficiency shock are similar to those produced by an unfavorable oil capacity shock. A decline in oil efficiency leads to an increase in oil demand and oil prices. This oil price increase in turn raises marginal production costs and inflation while putting downward pressure on gross output and employment. However, both output and employment rise on impact. Similar to the case of an oil capacity shock, this result is due to an increase in the oil capacity utilization rate, which increases the domestic exports of manufactured goods.

One important policy objective is to close output gaps. Therefore, it is instructive to note the differences in the output-gap dynamics produced by the different types of oil shocks. An exogenous increase in the oil markup does not affect the potential level of output and therefore produces a negative output gap. In contrast, unfavorable shifts in oil productive capacity and oil efficiency produce a positive output gap on impact. These shocks induce an oil price increase that works like a negative technology shock to generate contraction in the domestic economy. More specifically, the rise in oil prices lowers output and raises marginal production costs. Due to price stickiness, prices do not fully adjust, such that markups decline and inflation increases. These markup dynamics mitigate the recessionary consequences of the oil price hike, implying a positive gap between actual and potential output.

The responses to TFP and government spending shocks (displayed in Figure 1b) are well described in the literature. Following a positive productivity shock, output, consumption, investment, and real wages rise, whereas employment falls. Inflation also falls due to the depressing effects of the technological improvements on marginal costs. The overall increase in domestic economic activity raises oil demand and oil prices. Under the Taylor-rule policy, nominal and real interest rates fall but not to an extent that prevents an output gap from opening up or a fall in inflation. Turning to the public spending shock, an exogenous increase in government consumption raises output and puts upward pressure on real factor prices, including oil prices, and inflation. To stem these inflationary pressures, real interest rates rise. As is standard in the DSGE literature, government spending shocks entail a strong crowding-out effect on both private consumption and investment.

oil supply induce a transfer of wealth from the oil-importing to oil-producing country, driving up foreign consumption and domestic exports.

Ramsey Policy In the following, I investigate the optimal monetary policy responses to the different types of oil shocks. The results are presented in Figures 1a and 1b along with the dynamics for the model under the Taylor-type rule. To facilitate the interpretation of the results, I also plot the dynamic responses of the potential level of output that would prevail under flexible prices and wages in the absence of markup shocks. In the canonical new-Keynesian model, the potential output level corresponds to the efficient output level, provided that fiscal instruments are used to address inefficiencies in the steady state. The benevolent central banker aims to replicate the Pareto-optimal equilibrium. However, this policy objective conflicts with the objective of stabilizing inflation.[18] Investigations of this policy trade-off typically conclude that policies that keep output close to potential are nearly optimal (e.g., Levin et al. 2005). Moreover, Bodenstein et al. (2008) show that this conclusion carries over to model environments with exogenous energy price shocks. Therefore, the standard optimal policy prescriptions in the new-Keynesian tradition suggest that the Ramsey policy tends to close the gap between actual and potential output.

A comparison of oil supply and oil-specific demand shocks in Figure 1a reveals that shocks that are specific to the oil market optimally require similar policy responses. More specifically, in response to unfavorable oil supply and oil efficiency shocks, the Ramsey policy calls for a steep but short-lived increase in the real interest rate. Compared to the Taylor-type rule, this approach amplifies the recessionary consequences of the oil price hike on impact. However, after approximately one year, the Ramsey economy experiences smaller drops in output, consumption, and hours worked. Remarkably, in contrast to what we may expect from the standard new-Keynesian policy prescriptions, the optimal output gap is strongly negative within the first year following adverse oil supply and oil-specific demand shocks. In the following subsections, I investigate this anomaly in greater detail.

Turning to the TFP shock presented in Figure 1b, optimal policy tends to close the negative output gap and reduces the deflationary effects on prices. This expansionary policy puts upward pressure on oil demand and therefore raises oil prices above their baseline levels. Similarly, the Ramsey response to government spending shocks yields an output path that closely resembles that of the flexible economy (see panel 2 in Figure 1b). However, in contrast to technology shocks, demand shocks induce a positive output gap. As a result, relative to the policy under the Taylor-type rule, the Ramsey policy reduces output and mitigates the increase in oil demand and prices.

[18] Under Calvo staggering, variations in prices and wages entail negative welfare effects, as these variations generate cross-sectional dispersion in labor supply and goods production. As shown by Erceg et al. (2000), when both prices and wages are sticky, monetary policy can stabilize the output gap only at the expense of higher price and wage inflation rates.

In summary, if international capital markets are incomplete and oil cannot easily be substituted for other factors of production, the model predicts that shocks that are specific to the oil market call for rather similar policy responses. More specifically, in response to unfavorable shifts in oil supply or oil efficiency, the optimal policy is highly restrictive and exacerbates the recession compared to actual monetary policy. Because the literature indicates that oil-specific demand and supply shocks are of primary importance in the determination of oil prices, this result suggests that monetary policy that neglects to identify the causes of oil price fluctuations is not significantly misguided. Importantly, these conclusions contrast with the standard predictions of the new-Keynesian tradition. To close output gaps, we may expect optimal policy to be restrictive following adverse oil capacity and oil efficiency shocks while being accommodative in response to adverse oil markup shocks. As I demonstrate below, the finding that typical oil price shocks, in contrast to the standard new-Keynesian prescriptions, call for similar policy responses results from the observations that the degree of substitutability between oil and other factors of production is low and that oil is traded in an international environment of incomplete asset markets. Intuitively, given low substitutability of oil and incomplete asset markets, oil-specific demand and supply shocks induce similar welfare effects that should call for similar policy responses. Specifically, when oil is difficult to substitute in production, oil price hikes generate a negative wedge between the natural and efficient levels of output. Furthermore, under incomplete markets, oil price hikes induce a shift in wealth from the oil-importing to oil-producing country. In the following two subsections, I demonstrate these statements in greater detail. I remove the assumptions of incomplete international risk sharing and low oil substitutability one at a time and contrast the Ramsey policy derived under these alternative model specifications with the policy behavior observed in the baseline case.

4.2 The Role of the Degree of International Risk Sharing

I first investigate the importance of incomplete risk sharing between the oil-importing and oil-producing countries in shaping policy behavior. As shown by Corsetti et al. (2010, 2011), asset market imperfections result in inefficient capital flows and global demand imbalances, which in turn induce a policy trade-off between internal and external objectives. More specifically, relative to the case of complete markets, the central bank's loss function in the incomplete-markets case depends not only on inflation rates and the output gap but also on the wedge D_t between the cross-country marginal utility differentials $\frac{U^*_{c,t}}{U_{c,t}}$ and

real exchange rate Q_t. In logarithmic terms, wedge D_t is given by

$$\ln\left(D_t\right) = \ln\left(\frac{U^*_{c,t}}{U_{c,t}}\right) - \ln\left(Q_t\right), \tag{35}$$

where $Q_t = S_t \frac{P^*_t}{P_t}$ and S_t is the nominal exchange rate expressed as the home currency price of foreign currency. Corsetti et al. (2011) define this wedge as the 'relative demand gap'. In the efficient equilibrium, households across different countries are equally well off, implying that the relative demand gap (35) is constant and equal to zero; i.e., $\frac{U^*_{c,t}}{U_{c,t}} = Q_t$. Complete markets provide full insurance against country-specific risk and therefore replicate the optimality condition of zero cross-country demand imbalances. In contrast, incomplete markets induce inefficient international capital flows that lead to endogenous fluctuations in the relative demand gap. Monetary policy then faces an additional trade-off in that it aims to counteract wealth-shifting effects across borders, in addition to seeking to stabilize both output and inflation. Note that because the oil-producing country pegs its currency to the US dollar, the real exchange rate Q_t is constant and equal to one in our model. Therefore, the relative demand gap simplifies to the cross-country differences in marginal consumption utilities, i.e., $D_t = \frac{U^*_{c,t}}{U_{c,t}}$.

To assess the role of the degree of international risk sharing in the conduct of optimal monetary policy, I derive the Ramsey policy under complete markets and contrast it with the policy behavior observed under incomplete markets. Figures 2a and 2b display the impulse responses predicted by the simplified model in which international financial markets are complete. Again, all shocks have been normalized to produce a 10% maximum increase in the real oil price under the Taylor-type policy.

[insert Figures 2a and 2b here]

Comparing the complete-market case to the incomplete-market case, we first observe that the optimal policy responses to ME-driven oil demand shocks are similar under both market structures. Therefore, the remainder of this section is devoted to the analysis of the oil-specific demand shock and the two types of oil supply shock. Figure 2a illustrates that in the case of complete markets and unfavorable shifts in oil supply or oil efficiency, the optimal response of the interest rate to oil price shocks depends strongly on the underlying cause of the oil price increase. More specifically, Ramsey policy is restrictive and raises the real interest rate following oil capacity and oil efficiency shocks, whereas it is accommodative and lowers the real interest rate in response to oil markup shocks. Despite these differences in the optimal monetary policy stance, the Ramsey policy aligns the recessionary consequences of all three shocks in that it reduces the output slump compared to the Taylor-type rule. In particular, output, consumption, investment, and

employment all contract by less, at the expense of slightly higher price and wage inflation rates. Note that in response to oil capacity and oil efficiency shocks, the real interest rate rises on impact more under the Ramsey policy than under the Taylor-type rule. Therefore, for these shocks, the result that the Ramsey policy is looser than the Taylor-type policy may seem counterintuitive, as rising interest rates typically indicate monetary policy tightening. However, compared to the Taylor-type rule, the increase in the Ramsey real interest rate is less persistent. Given the forward-looking behavior of households, consumption and investment are affected by the short-run rates only if these rates bring about variations in the long-run real rate of interest, i.e., if the rise in short-run rates is persistent.

Importantly, the finding that relative to the Taylor-type rule, Ramsey policy, under complete markets, mitigates the recessionary consequences of oil-specific demand and supply shocks contrasts with the outcome observed under incomplete markets. In the latter case, optimal policy worsens the economic downturn in the short run. The contrasting results stem from dissimilarity in the risk-sharing conditions between the two market structures. First, note that contractionary oil supply and oil efficiency shocks raise the oil-exporting country's oil revenues (not shown). If international asset markets are frictionless, trade in state-contingent claims provide efficient insurance against country-specific risk. As a result, part of the increased oil revenue returns to the domestic country until the two countries achieve equal consumption levels. In the case of incomplete markets, the higher oil revenues are partially absorbed by increased foreign consumption, i.e., there is a transfer of wealth from the oil-importing to oil-producing country. To curb this wealth-shifting effect, the benevolent central banker puts the economy into a severe but short-lived recession, as such a recession mitigates the increase in oil prices and revenues. Relative to the Taylor-type rule, real oil prices fall by approximately 1.5 percentage points (see Figure 1a).

The above analysis provides an explanation of why, under incomplete markets, oil supply and oil-specific demand shocks call for similar policy responses and generate optimal output dynamics that differ considerably from potential output. In particular, the focus on external objectives reduces the benevolent central banker's concern about internal objectives, such as stabilizing the output gap. Because the different types of oil-specific demand and supply shocks produce similar cross-country wealth-shifting effects, this approach aligns the optimal policy responses across these shocks. Note, however, from Figure 2a, that although the assumption of complete markets reverses the sign of the optimal output gap relative to the incomplete-market case, this alternative environment still implies a significant wedge between optimal and potential output in the wake of oil capacity and

oil efficiency shocks. Specifically, the optimal output gap is positive and larger than the gap observed under a Taylor-type policy. This finding contrasts with the standard new-Keynesian policy prescription that optimal policy should seek to replicate the potential equilibrium. In the following subsection, I demonstrate that the friction that drives this result stems from the observation that oil has low substitutability in production.

4.3 The Role of the Degree of Oil Substitutability

Montoro (2012) demonstrates that when oil is a gross complement to domestic production factors, i.e., $\alpha < 1$, oil price fluctuations induce a time-varying wedge between the natural and efficient levels of output. This result creates an additional source of the policy trade-off between stabilizing inflation and stabilizing economic activity, one that may have important implications for the welfare analysis of monetary policy. Therefore, in this section, I wish to analyze the role of the degree of oil substitutability in determining the optimal monetary policy response to oil price shocks. To this end, I assess the robustness of the baseline results to an alternative environment in which oil enters the production function with unit elasticity of substitution, i.e., $\alpha = 1$, and production takes the Cobb-Douglas form.[19] I first conduct this robustness assessment for the case of complete international capital markets. This approach allows us to analyze the implications of the frictions induced by the low substitutability of oil in isolation from the welfare effects implied by the incompleteness of international risk sharing. Subsequently, I demonstrate that the main conclusions carry over to a more realistic environment in which international asset markets are incomplete. The results are presented in Figures 3-5. Before discussing these results, I provide intuitive support for the policy trade-off induced by CES production technology.

Sources of the Additional Policy Trade-off The time-varying gap between the natural and efficient levels of output, which arises when it is difficult to substitute other factors of production for oil, results from the dynamic behavior of marginal production costs. To demonstrate this effect, I derive the log-quadratic (Taylor-series) approximation of the domestic real marginal cost equation (4). In doing so, recall that variables that are presented as log deviations from the deterministic steady-state are denoted by the superscript '$\hat{}$'. If we define the effective real oil price $\widetilde{p}_t^o$ as the ratio of the actual real oil price p_t^o to the relative oil efficiency η_t^{oe}, i.e., $\widetilde{p}_t^o \equiv \frac{p_t^o}{\eta_t^{oe}}$, then the second-order approximation

[19] In an additional exercise, I consider lower values, within the range $\alpha \in (0.03, 1)$, for the degree of oil substitutability. See the next subsections.

of real marginal costs is given by

$$\widehat{mc}_t = \tilde{\eta}\hat{s}_t + (1-\tilde{\eta})\,\widehat{\tilde{p}}^o_t + \frac{1}{2}(1-\alpha)\,\tilde{\eta}\,(1-\tilde{\eta})\left[\hat{s}_t - \widehat{\tilde{p}}^o_t\right]^2 + \Xi, \tag{36}$$

where $\tilde{\eta} \equiv \eta\left(\frac{s}{mc}\right)^{1-\alpha}$ is the share of the value added output in total costs in steady state, $(1-\tilde{\eta}) \equiv (1-\eta)\left(\frac{\tilde{p}^o}{mc}\right)^{1-\alpha}$ is the steady-state share of oil in total costs and Ξ denotes the error incurred in approximating the marginal cost function. The equations for the GDP-deflator s_t and the effective real oil price $\widetilde{p}^o_t$ have the following second-order expansion:

$$\hat{s}_t = (1-\theta)\,\hat{r}^k_t + \theta\hat{w}_t - d\hat{\eta}^a_t, \tag{37}$$

$$\widehat{\tilde{p}}^o_t = \widehat{p}^o_t - \widehat{\eta}^{oe}_t. \tag{38}$$

Note that equations (37) and (38) are exact expressions rather than approximations.

From equation (36), we can see that CES production with an elasticity of substitution less than one, i.e., $\alpha < 1$, entails two sources of inefficient marginal cost dynamics.[20] First, as stressed by Natal (2012), the coefficients of the first-order terms, i.e., $\tilde{\eta}$ and $(1-\tilde{\eta})$, depend on the degree of monopolistic distortion in the goods market unless $\alpha = 1$, as in the Cobb-Douglas case. To see this result, note that according to equation (5), the steady-state real marginal cost equals the ratio of production subsidies to the gross price markup, i.e., $mc = \frac{1+\tau_p}{1+\lambda_p}$. Consider an exogenous rise in real oil prices. As the economy becomes less competitive, i.e., λ_p increases, the oil cost share $(1-\tilde{\eta})$ increases and real marginal costs become more sensitive to increases in oil prices. As perfect price stability entails constant real marginal costs, i.e., $\widehat{mc}_t = 0$ to a first-order approximation, the drop in domestic factor prices required to compensate for the higher oil price becomes larger as the economy's steady state becomes more distorted. Therefore, natural output falls more than efficient output, which creates an endogenous monetary policy trade-off between output and inflation stabilization.

Second, as shown by Montoro (2012), in contrast to the Cobb-Douglas case, where $\alpha = 1$, the Taylor expansion of real marginal costs in the CES case contains non-zero quadratic terms. More specifically, when oil has low substitutability in production, real marginal costs become a convex function of the real oil price. An exogenous increase in oil prices then raises marginal production costs above their linear counterpart; the latter,

[20] In the Appendix, I replicate Montoro's (2012) solution to the equilibrium real marginal cost, which provides further insights into the policy trade-off induced by CES production technology. In brief, under several simplifying assumptions, the second order approximation of real marginal costs (36) can be expressed as a function of the gap between the actual and natural levels of output. Within this setup, it can then be shown that inflation stabilization does not automatically stabilize the welfare relevant output gap (see Section 2.5 of the Appendix for details).

given by $\tilde{\eta}\widehat{s}_t + (1-\tilde{\eta})\widehat{\tilde{p}}^o_t$. If firms can adjust their prices to maintain markups, i.e., if the economy is in equilibrium at its natural level and prices are flexible, real marginal costs decline to a first-order approximation. As a result, price markups increase up to the first order, which produces a negative gap between the natural and efficient levels of output; i.e., efficient output is less responsive to oil price fluctuations than natural output.

Two remarks are in order. First, in the case of a Cobb-Douglas production function, the elasticity of substitution between value added and oil is unity, i.e., $\alpha = 1$. In this case, the Taylor expansion of real marginal costs depends only on the first-order terms, with coefficients that are independent of the degree of monopolistic distortion, i.e., $\widehat{mc}_t = \eta\widehat{s}_t + (1-\eta)\widehat{\tilde{p}}^o_t$. Then, the gap between the natural and efficient levels of output is constant over time. Second, as shown by Montoro (2012), eliminating the distortions in the steady state—as I do in my analysis—reduces but does not eliminate the inefficient fluctuations in natural output. More specifically, when setting the production subsidies equal to the steady-state net price markup, i.e., $\tau_p = \lambda_p$, the oil cost share no longer depends on the steady-state distortions. However, because of the convexity of marginal costs, oil price fluctuations still induce a time-varying wedge between the natural and efficient levels of output. Thus, in the analysis below, inefficient fluctuations in natural output only arise from the convexity of marginal costs inherent in CES production technology.

Results Under Complete Markets Figures 3a and 3b depict how the substitutability of oil influences the propagation of oil shocks and the conduct of optimal monetary policy in the model variant that features complete markets.

[insert Figures 3a and 3b here]

Several observations stand out. First, when production is characterized by a unit elasticity of substitution between oil and value added, the substitution effect gains in importance in the dynamic responses to a temporary oil price increase. Relative to the case of CES production, this effect augments the differences between the dynamic effects of oil capacity, oil markup and oil efficiency shocks on factor markets. More specifically, whereas the substitution effect dominates and employment increases following unfavorable movements in oil productive capacity and oil efficiency, the income effect prevails and employment falls in response to an increase in the oil markup. Similarly, if the underlying technology of production is Cobb-Douglas instead of CES, firms tend to substitute domestic productive factors for oil in response to an exogenous rise in TFP. As a result, in contrast to the case of CES production, positive TFP shocks lower oil demand and prices on impact. After only approximately five quarters, the overall increase in domestic economic activity

dominates the substitution effect, leading to an increase in oil demand and prices. Additionally, note that the dynamic responses to oil demand shocks are far stronger in the Cobb-Douglas case than in the CES case. The high substitutability of oil inherent in the Cobb-Douglas production technology implies that oil demand is highly responsive to price changes. Therefore, to achieve a 10% increase in oil prices as a result of demand-side disturbances, we must consider relatively large shocks that induce relatively large effects on the domestic economy. In the case of TFP and government spending shocks, the implied shock sizes are unrealistically high, generating output increases of 20-30%.

Second, the optimal monetary policy response to oil supply and oil-specific demand shocks critically depends on the degree of substitutability of oil. First, consider unfavorable oil capacity and oil efficiency shocks. Figure 3a reveals that, similar to the case of CES production, Ramsey policy in the Cobb-Douglas case raises the real interest rate in response to both shocks. However, in contrast to the CES case, the optimal monetary policy stance is tighter than suggested by the Taylor-type rule; Ramsey policy augments the recessionary consequences of the oil price hike. The different results observed in the CES and Cobb-Douglas cases arise from the different welfare effects inherent in the different degrees of oil substitutability in production. Under Cobb-Douglas production technology, the elasticity of substitution between value added and oil is unity and the natural (or potential) output level corresponds to the efficient output level. The benevolent central banker aims to replicate the efficient equilibrium. Therefore, in this model variant, Ramsey policy acts to close the gap between actual and natural output. Compared to the Taylor-type rule, optimal policy then amplifies the output slump and reduces price inflation. As noted above, under CES production technology, low substitutability of oil induces an additional policy trade-off in that efficient output becomes less responsive than natural output to oil price fluctuations. As a result, in the CES case, adverse oil capacity and oil efficiency shocks drive a negative wedge between the natural and efficient levels of output. Then, under the Taylor-type rule, the central bank primarily focuses on inflation and attempts to bring the economy near the natural output level. In contrast, the Ramsey policy aims to replicate the efficient level of output and is therefore not as tight as the Taylor-type rule.

With respect to the oil markup shock, we note that optimal policy keeps the real interest rate nearly constant in the case of a unit oil elasticity of substitution (see Figure 3a), whereas it lowers real interest rates if oil is difficult to substitute (see Figure 2a). Recall that an exogenous increase in the oil markup drives a negative wedge between the actual and potential levels of output. This effect magnifies the trade-off between stabilizing output and stabilizing price and wage inflation. Specifically, monetary policy should lower

the real interest rate to close the output gap, whereas it should raise the real interest rate to curb price and wage inflation. Panel 2 of Figure 3a reveals that in the case of Cobb-Douglas production, optimal policy puts equal weights on both targets by holding the real interest rate nearly constant. Therefore, in this model variant, in contrast to oil capacity and oil efficiency shocks, the Taylor-rule based monetary policy response to an oil markup shock closely mimics the optimal response; the Ramsey policy dampens the recession compared to the Taylor-type rule but only to a minor extent. Conversely, under the CES production technology (see panel 2 of Figure 2a), the low substitutability of oil further widens the negative output gap. Therefore, relative to the Cobb-Douglas case, the optimal policy is more concerned with output gap stabilization and thus entails a reduction in the real interest rate. Similar to the cases of oil capacity and oil efficiency shocks, the Ramsey policy then reduces the recessionary consequences of the oil markup shock compared to the actual monetary policy response.

Finally, comparing Figures 2b and 3b, we observe that the degree of oil substitutability in production does not significantly influence the optimal monetary policy response to ME-driven oil demand shocks. Expansionary TFP and government spending shocks only raise oil prices indirectly, i.e., through increased economic activity that drives up oil demand. Because of this indirect transmission channel, the expansion of the gap between natural and efficient output observed under CES production technology is small and of minor concern to the benevolent central banker. As a result, in both the CES and Cobb-Douglas cases, Ramsey policy tends to close the gap between the actual and natural levels of output.

Concerning oil supply and oil-specific demand shocks, we conclude that the welfare effects induced by the low substitutability of oil align the optimal output responses to different sources of oil price fluctuations; specifically, Ramsey policy mitigates the recession relative to actual policy. Importantly, if oil and other factors of production were perfect substitutes, then the optimal monetary policy response to oil shocks would strongly depend on the underlying cause of the oil price increase. In particular, in accordance with the standard new-Keynesian policy prescription to close output gaps, optimal policy would be restrictive following oil capacity and oil efficiency shocks, while it would be accommodative in response to oil markup shocks.

Sensitivity Analysis Thus far, I have assumed that the true oil substitution elasticity is low, with $\alpha = 0.03$. Although this calibrated value is similar to many reduced-form estimates of the price-elasticity of oil demand, it is considerably lower than more recent estimates derived from structural models of the oil market. For instance, Baumeister and

Peersman (2013), Kilian and Murphy (2010), and Bodenstein and Guerrieri (2011) all report oil demand elasticity estimates centered around 0.5. Therefore, as a robustness check, I contrast the optimal policy with the baseline Taylor-type rule for different degrees of oil substitutability in production, i.e., $\alpha \in (0.03, 0.25, 0.5, 0.75, 1)$. Figure 4 summarizes the respective output responses in this exercise to unfavorable oil capacity, oil markup, and oil efficiency shocks.

[insert Figure 4 here]

We notice that the impact of monetary policy on output in the aftermath of a typical oil price shock depends crucially on the degree of oil substitutability α. Specifically, the actual monetary policy, as determined by the Taylor-type rule, is more likely to amplify the recessionary effects of the oil price hike relative to what is optimal from a welfare perspective when the value of α is lower. Importantly, only near the Leontief-case, i.e., α close to zero, does optimal policy cause smaller output declines during the entire transition period. This result might explain the contradictory conclusions reported in Winkler (2009) and Kormilitsina (2011) regarding the contribution of monetary policy to recessions generated by exogenous oil price increases. Both authors derive the Ramsey-optimal conduct of monetary policy and compare it to actual policy. However, they consider different price elasticities of oil demand. In a calibration exercise, Winkler (2009) fixes the oil elasticity of substitution at $\alpha = 0.5$ and finds that optimal policy calls for a stronger and more prolonged recession compared to the standard Taylor rule. Applying impulse response matching techniques, Kormilitsina (2011) finds that the elasticity of substitution between production factors is not significantly different from zero and that optimal policy dampens the recession relative to the actual monetary policy response.

Results Under Incomplete Markets In Section 4.2, we concluded that the cross-country wealth-shifting effects induced by asset market imperfections align the optimal policy responses to oil-specific demand and supply shocks. Note that this conclusion is contingent on the observation that oil is a gross complement of domestic factors of production. In an additional robustness check, I derive the Ramsey policy under incomplete markets in the model featuring Cobb-Douglas production (see Figure 5) and contrast it with the policy behavior observed under complete markets (see Figure 3a).

[insert Figure 5 here]

We find that in the case of Cobb-Douglas production, the welfare implications of incomplete international risk sharing do not importantly affect the optimal monetary policy response to oil price hikes. Specifically, when production takes the Cobb-Douglas form,

the impulse responses observed under incomplete markets (See Figure 5) resemble those observed under complete markets (see Figure 3a), implying that the optimal monetary policy response to oil price fluctuations critically depends on the underlying driving source. Intuitively, when the elasticity of substitution between oil and value added is high, at $\alpha = 1$, the oil price increase induces a strong negative substitution effect on oil demand. This effect dampens the rise in oil revenues and the related shift in wealth observed under incomplete markets. As a result, relative to the model with CES production, the benevolent central banker is less aggressive in combating global demand imbalances and, similar to the complete-markets case, tends to replicate the natural equilibrium.

5 On the Importance of the Oil Supply Elasticity

The two most important parameters characterizing the oil market are the price-elasticity coefficients of oil demand and oil supply. In the preceding analysis, I analyzed the role of the degree of oil substitutability α and the implied steepness of the oil demand curve in shaping policy responses to oil price fluctuations. In this section, I focus on the sensitivity of the results to alternative parameterizations of the oil supply elasticity $1/\vartheta$.[21] The baseline calibration of $1/\vartheta = 0.1$ is based on evidence reported in Peersman and Stevens (2013). However, structural analyses of the oil market typically consider a very steep oil supply curve with a price-elasticity close to zero. Therefore, as a first alternative calibration, I set $1/\vartheta = 0.025$. This value is based on the work of Kilian and Murphy (2010), who impose an upper bound of approximately 0.025 on the impact oil supply elasticity. For completeness, I also consider a value for $1/\vartheta$ above its baseline calibration, specifically, $1/\vartheta = 0.2$. For each of these calibrations, I contrast the Ramsey policy with the Taylor-type rule. The respective output responses in this sensitivity analysis to unfavorable oil capacity, oil markup, and oil efficiency shocks are presented in Figure 6.[22] Similar to the main analysis, I consider three model environments, namely, the baseline case with incomplete markets and CES production technology (see panel A), the model variant with complete markets (see panel B), and the environment that also assumes that

[21] The main conclusion that typical oil price shocks call for similar policy responses under incomplete international risk sharing is also robust to other model specifications that I do not present here. For example, the results hold when we abstract from variable capital utilization (i.e., $\chi \to \infty$) and remove investment adjustment costs (i.e., $\varsigma = 0$). Detailed impulse responses pertaining to these additional specifications are reported in the Appendix (available upon request).

[22] Other impulse responses pertaining to this robustness assessment are reported in the Appendix (available upon request).

the production function is Cobb-Douglas (see panel C).

[insert Figure 6 here]

Two conclusions stand out. First, consider the case of complete markets. Comparing panels B and C of Figure 6 reveals that the benevolent central banker's concern about the opening of the gap between natural and efficient output induced by the low substitutability of oil is not affected by the magnitude of the oil supply elasticity. Similar to the baseline calibration, where $1/\vartheta = 0.1$, if oil has low substitutability in production, the optimal monetary policy stance in the aftermath of a typical oil price shock is looser than the Taylor-type rule suggests in cases of lower or higher values of $1/\vartheta$. As a result, the conclusion that the Ramsey policy aligns the recessionary consequences of the various oil supply and oil efficiency shocks under complete markets is robust to alternative specifications of the price-elasticity of oil supply.

Second, turning to panel C of Figure 6, we observe that the weight that optimal policy places on counteracting the cross-border wealth-shifting effects induced by incomplete international risk sharing depends heavily on the oil supply elasticity coefficient $1/\vartheta$. Specifically, for lower values of $1/\vartheta$, the benevolent central banker is more concerned with stabilizing global demand imbalances and the Ramsey policy is more likely to amplify the recessionary consequences of an oil price shock compared to the Taylor-type rule. When the oil supply curve is steep, small declines in oil demand produce relatively large declines in oil prices. Therefore, relative to an environment with a more elastic oil supply curve, policy makers can, by provoking a recession and reducing oil demand, more easily mitigate oil price hikes and the associated shift of wealth across borders. As a result, because it is easier to combat cross-country wealth-shifting effects, policy makers will also pay more attention to this issue. Importantly, when the oil supply elasticity is high, at $1/\vartheta = 0.2$, the optimal weight on stabilizing global demand imbalances is so low that, similar to the case of complete markets, optimal policy dampens the recession relative to actual monetary policy. However, note that estimates of the price-elasticity of oil supply are typically low between 0 and 0.1 (e.g., Krichene 2002 and Baumeister and Peersman 2013). Therefore, to the extent that the baseline calibration of $1/\vartheta = 0.1$ is at the high end of the estimates reported in the literature, my main analysis may understate the importance of global demand imbalances in shaping optimal policy. This observation strengthens the conclusion that oil-specific demand and supply shocks call for similar policy responses, given that international asset markets are incomplete.

6 Conclusion

This paper studies optimal Ramsey-type monetary policy in the presence of endogenous oil price fluctuations. More specifically, I investigate the extent to which the optimal monetary policy response to an oil price increase depends on the underlying driving force of the price increase. Making up the key result of the paper, I demonstrate that the types of shock identified in the literature as the main drivers of oil price fluctuations, i.e., oil supply and oil-specific demand shocks, call for similar policy responses, given the low substitutability of oil in production and the incompleteness of international asset markets. This approach suggests that monetary policy that fails to identify the causes of oil price fluctuations is not significantly misguided. Intuitively, if oil is a gross complement of domestic factors of production, real marginal costs are a convex function of the real oil price. Independent of their underlying cause, oil price hikes then induce a negative wedge between the natural and efficient levels of output. By aiming to close this gap, the Ramsey policy aligns the recessionary consequences of the various oil supply and oil efficiency shocks. If, additionally, international financial markets are incomplete, unfavorable oil supply and oil-specific demand shocks both induce a shift in wealth from the oil-importing to oil-producing country. To curb this wealth-shifting effect, optimal policy calls for a large but short-lived increase in the real interest rate, as this increase reduces oil demand and mitigates the oil price increase.

Needless to say, the model used in this paper could be refined along several lines. I highlight three possible shortcomings. First, I abstract from oil consumption by households. Treating oil as an input in consumption causes the responses of core and headline inflation to oil price increases to diverge. Because oil prices are viewed as flexible, the direct effects of oil prices on the CPI are not expected to complicate monetary policy analysis. Aoki (2001) demonstrates that monetary policy should seek to stabilize only those components of the price index that are sticky, i.e., the core price index. Despite this prescription, the inclusion of oil in the consumption basket may affect policy analysis to the extent that under this approach, the second-round effects of oil price shocks on core inflation are intensified. Stronger second-round effects increase the central bank's concern about inflation stabilization relative to output stabilization. However, studying exogenous energy price fluctuations in an environment that includes distinct core and headline inflation rates, Bodenstein et al. (2008) find that rules that target the output gap are nearly optimal. Although caution is warranted, this result suggests that my main conclusions are robust to the inclusion of oil in consumption. Second, in the present model specification, the oil-importing country is treated as a relatively closed economy that only

engages in trade with oil-producing countries. This assumption may be too simplifying, as it ignores the open-economy aspects of the transmission of oil price shocks, e.g., changes in the nominal exchange rate and in the terms of trade. Opening up the economy by including a second oil-importing country would greatly complicate the Ramsey analysis of optimal monetary policy, as this consideration entails strategic interactions between the independent policy makers of both countries. Thus, for now, I leave this issue as an interesting topic for further research. Third, the model neglects investments in oil inventories through which expectations of future oil prices affect the current price of oil. Examples of models that include oil in the investment portfolio can be found in Unalmis et al. (2009) and Peersman and Stevens (2013). However, these contributions rely on a reduced-form approach rather than on microfoundations to model inventory behavior. Although this approach can be justified for positive analysis, it cannot be applied in normative work. Overcoming these problems is another fruitful area for future research.

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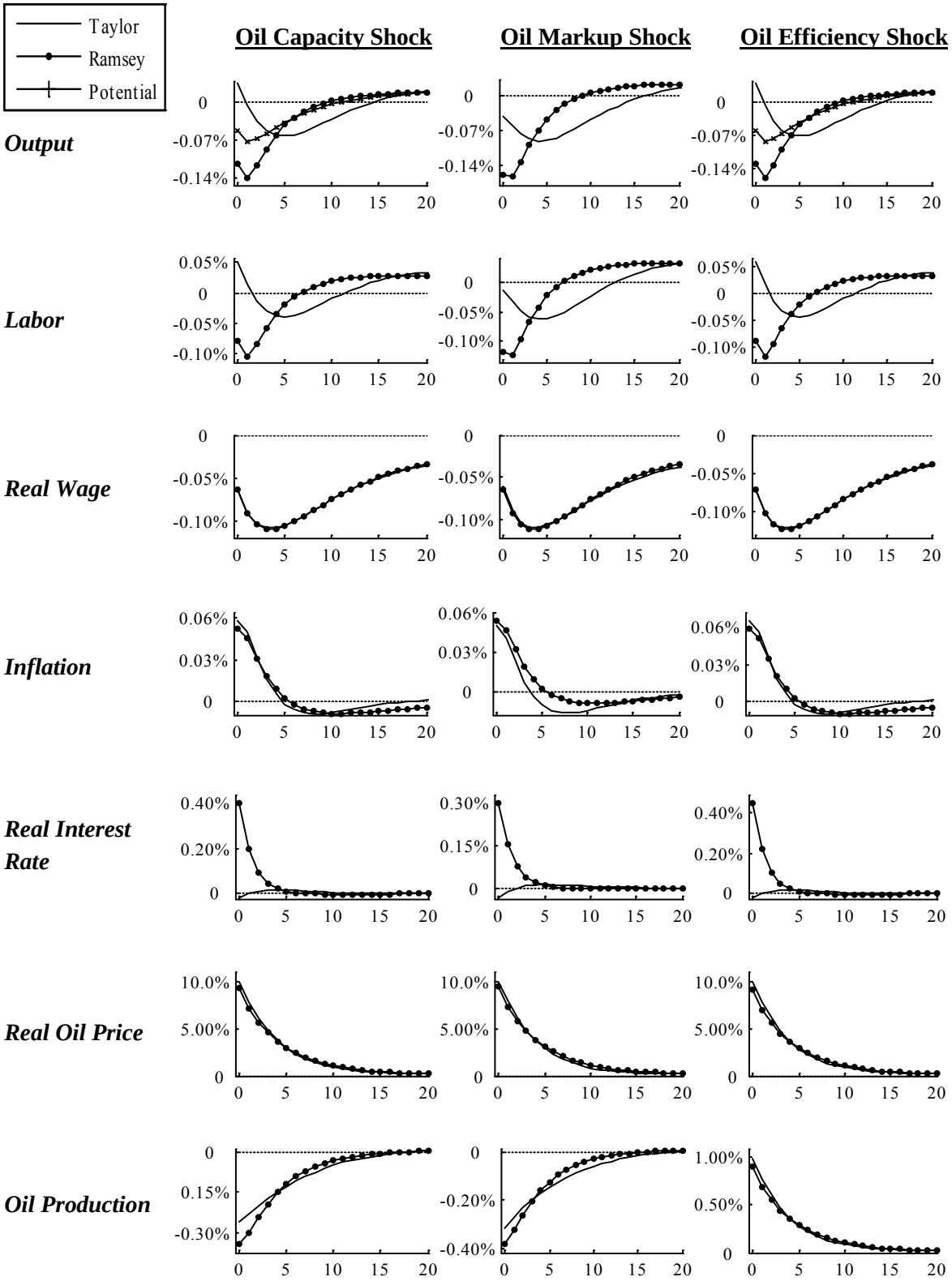
Table 1: Calibrated parameter values

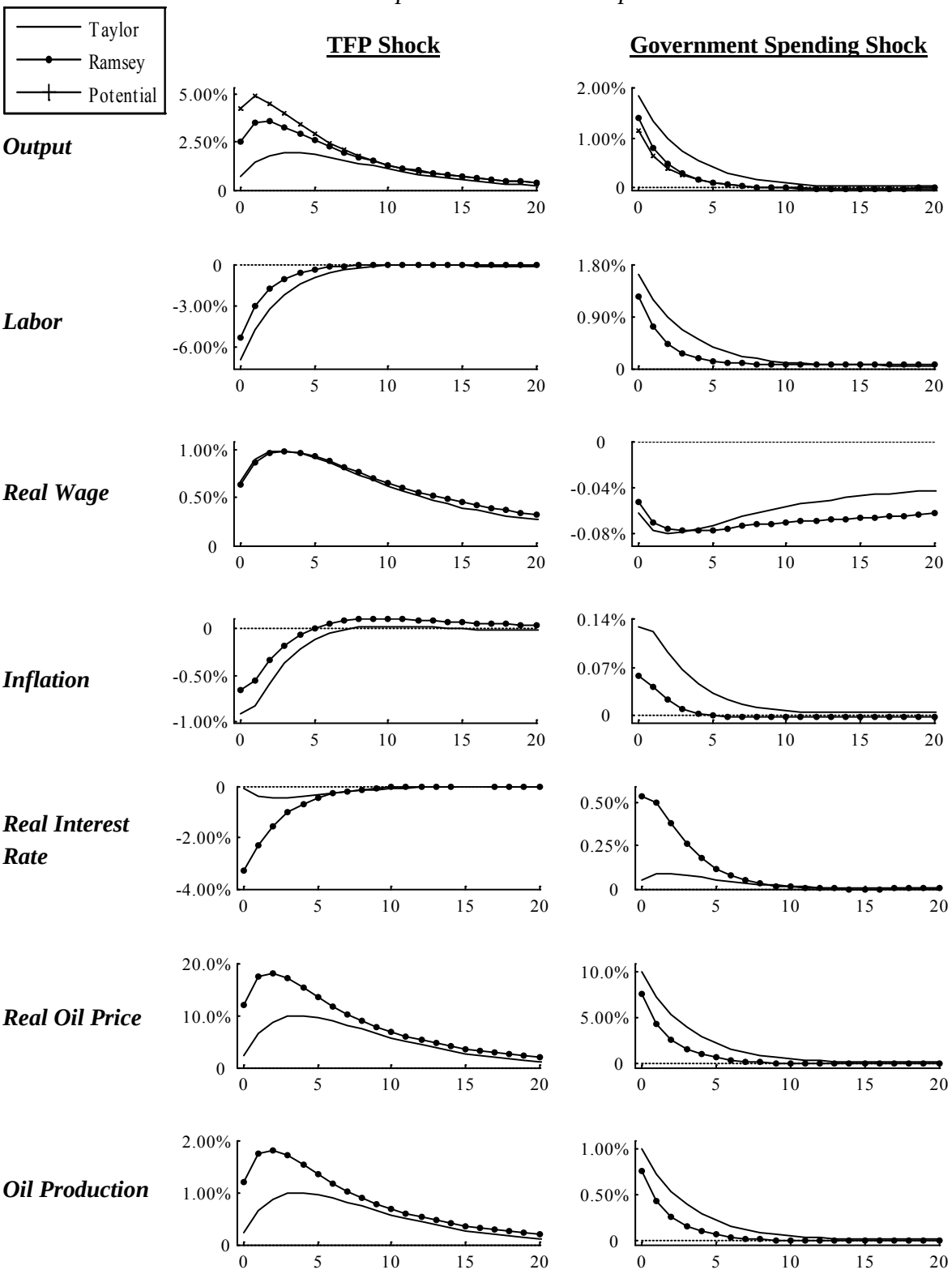
SYMBOL	DESCRIPTION	VALUE	
Standard Parameters			
β	Subjective discount factor	0.99	
θ	Labor share in production	0.76	
$\eta^g/\tilde{Y}$	Government spending share	0.21	
ϕ/Y	Share of fixed costs in production	0.44	
h	Consumption habit (home & foreign)	0.48	
σ_c	Risk aversion (home & foreign)	1.80	
σ_l	Labor utility	2.80	
δ_K	Capital depreciation rate	0.025	
ς	Investment adjustment costs	6.00	
χ	Capacity utilization cost - goods sector	6.00	
ξ_p	Price rigidity	0.80	
γ_p	Price indexation	0.25	
λ_p	Price markup	0.44	
ξ_w	Wage rigidity	0.75	
γ_w	Wage indexation	0.45	
λ_w	Wage markup	0.20	
τ_R	Interest rate smoothing	0.87	
τ_π	Interest rate response to inflation	1.50	
τ_y	Interest rate response to outputgap	0.05	
τ_{dy}	Interest rate response to Δ outputgap	0.30	
Parameters Specific to the Oil Market			
$1-\eta$	Share of oil in gross output	0.05	
λ_o	Oil price markup	0.75	
ϑ	Capacity utilization cost - oil sector	10	
α	Oil elasticity of substitution	CES	Cobb Douglas
		0.03	1
Additional Parameters in the Model with Incomplete Markets			
κ	Cost of adjusting foreign assets	0.001	

Figure 1a: Impulse responses to oil supply and oil-specific demand shocks
incomplete markets – CES production



Note: Impulse responses (IRFs) are measured in percentage deviations from steady state. Solid lines present IRFs under the Taylor rule. Solid lines with point markers depict the Ramsey economy. Solid lines with crosses denote IRFs of potential output. All shocks have been normalized to produce a 10% increase in real oil prices under Taylor-type policy.

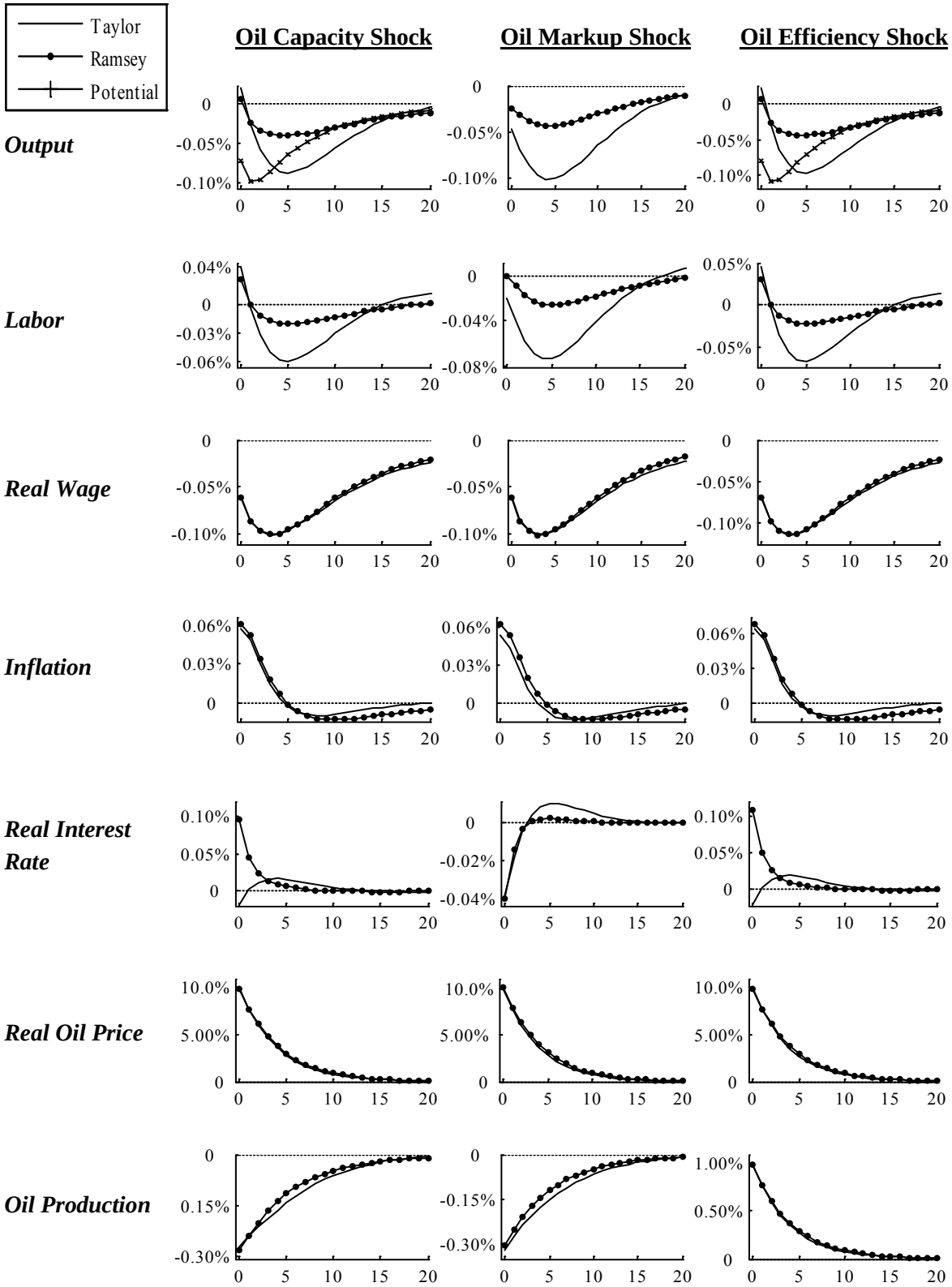
Figure 1b: Impulse responses to ME-driven oil demand shocks
in*complete markets ─ CES production*



Note: Impulse responses (IRFs) are measured in percentage deviations from steady state. Solid lines present IRFs under the Taylor rule. Solid lines with point markers depict the Ramsey economy. Solid lines with crosses denote IRFs of potential output. All shocks have been normalized to produce a 10% increase in real oil prices under Taylor-type policy.

Figure 2a: Impulse responses to oil supply and oil-specific demand shocks

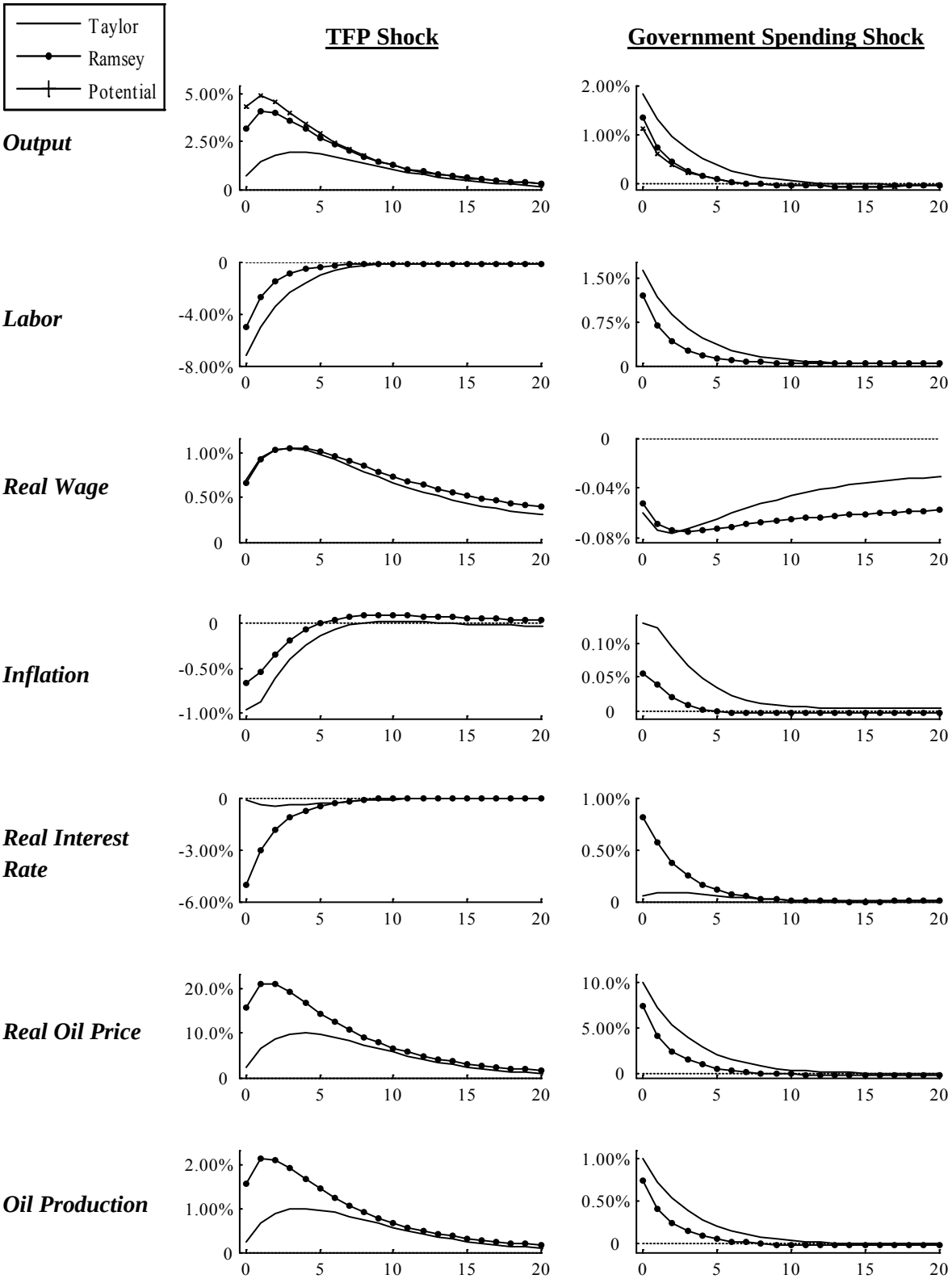
complete markets ─ CES production



Note: Impulse responses (IRFs) are measured in percentage deviations from steady state. Solid lines present IRFs under the Taylor rule. Solid lines with point markers depict the Ramsey economy. Solid lines with crosses denote IRFs of potential output. All shocks have been normalized to produce a 10% increase in real oil prices under Taylor-type policy.

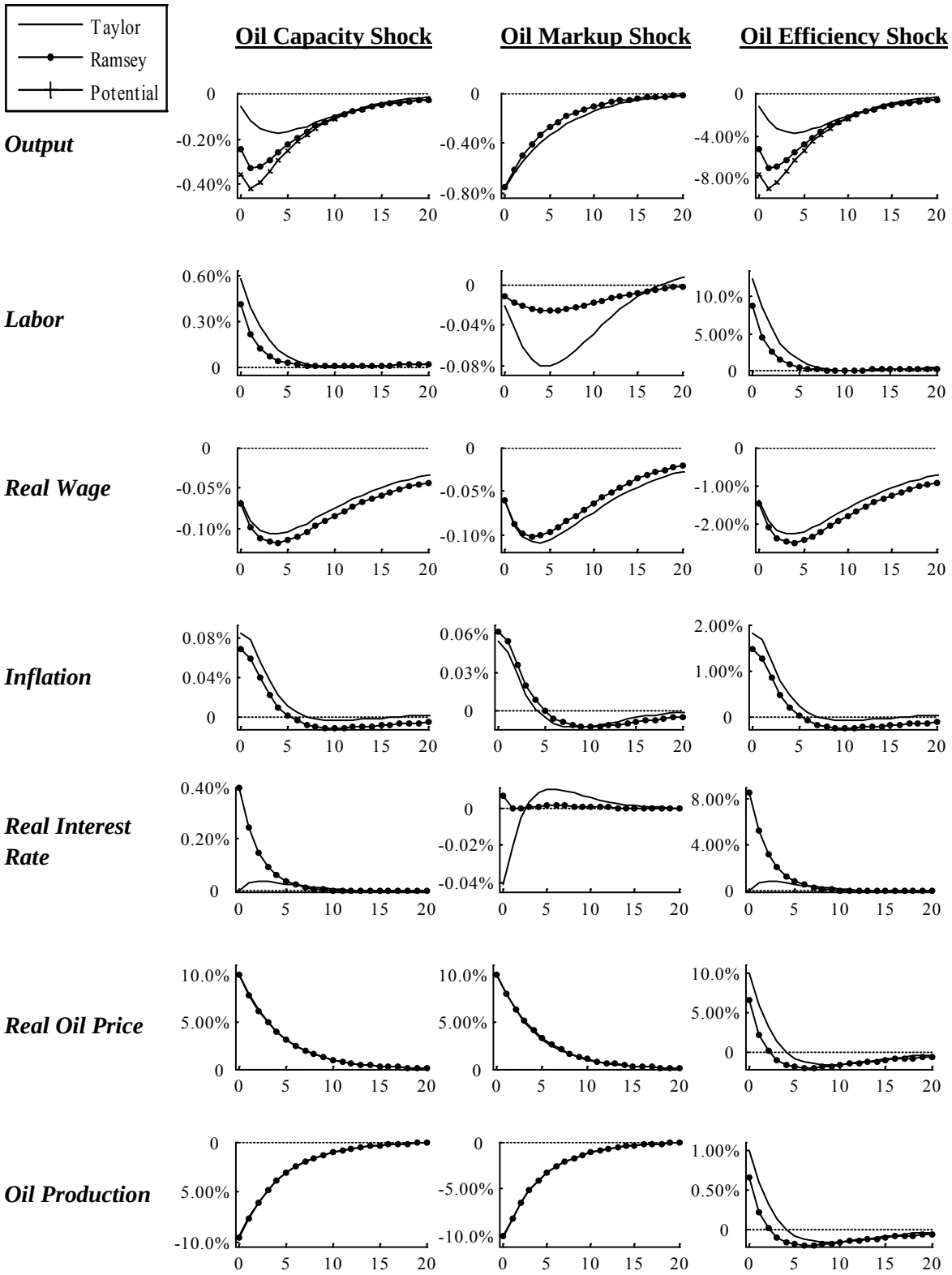
Figure 2b: Impulse responses to ME-driven oil demand shocks

complete markets ─ CES production



Note: Impulse responses (IRFs) are measured in percentage deviations from steady state. Solid lines present IRFs under the Taylor rule. Solid lines with point markers depict the Ramsey economy. Solid lines with crosses denote IRFs of potential output. All shocks have been normalized to produce a 10% increase in real oil prices under Taylor-type policy.

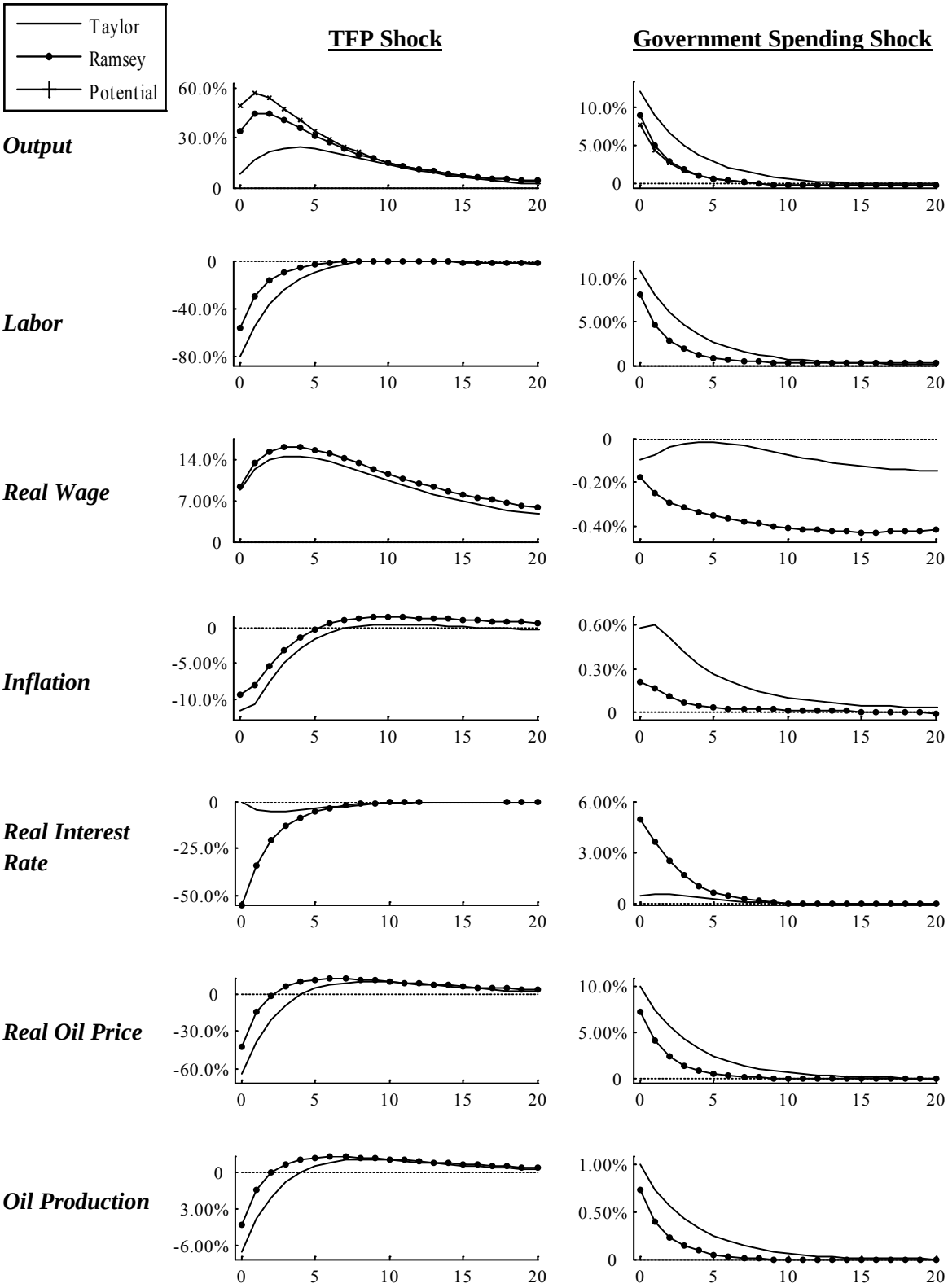
Figure 3a: Impulse responses to oil supply and oil-specific demand shocks
complete markets ─ Cobb Douglas production



Note: Impulse responses (IRFs) are measured in percentage deviations from steady state. Solid lines present IRFs under the Taylor rule. Solid lines with point markers depict the Ramsey economy. Solid lines with crosses denote IRFs of potential output. All shocks have been normalized to produce a 10% increase in real oil prices under Taylor-type policy.

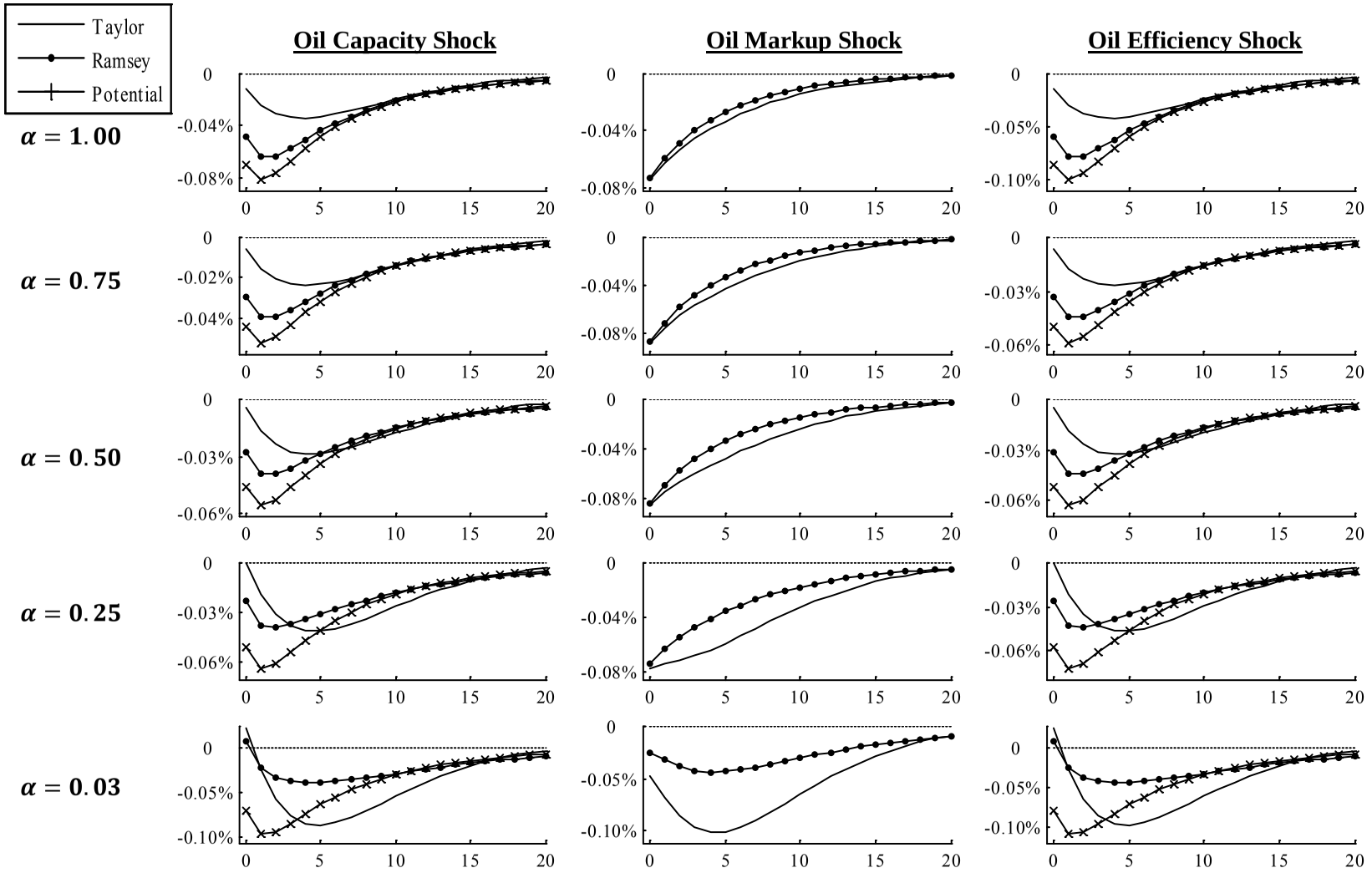
Figure 3b: Impulse responses to ME-driven oil demand shocks

complete markets ─ Cobb Douglas production



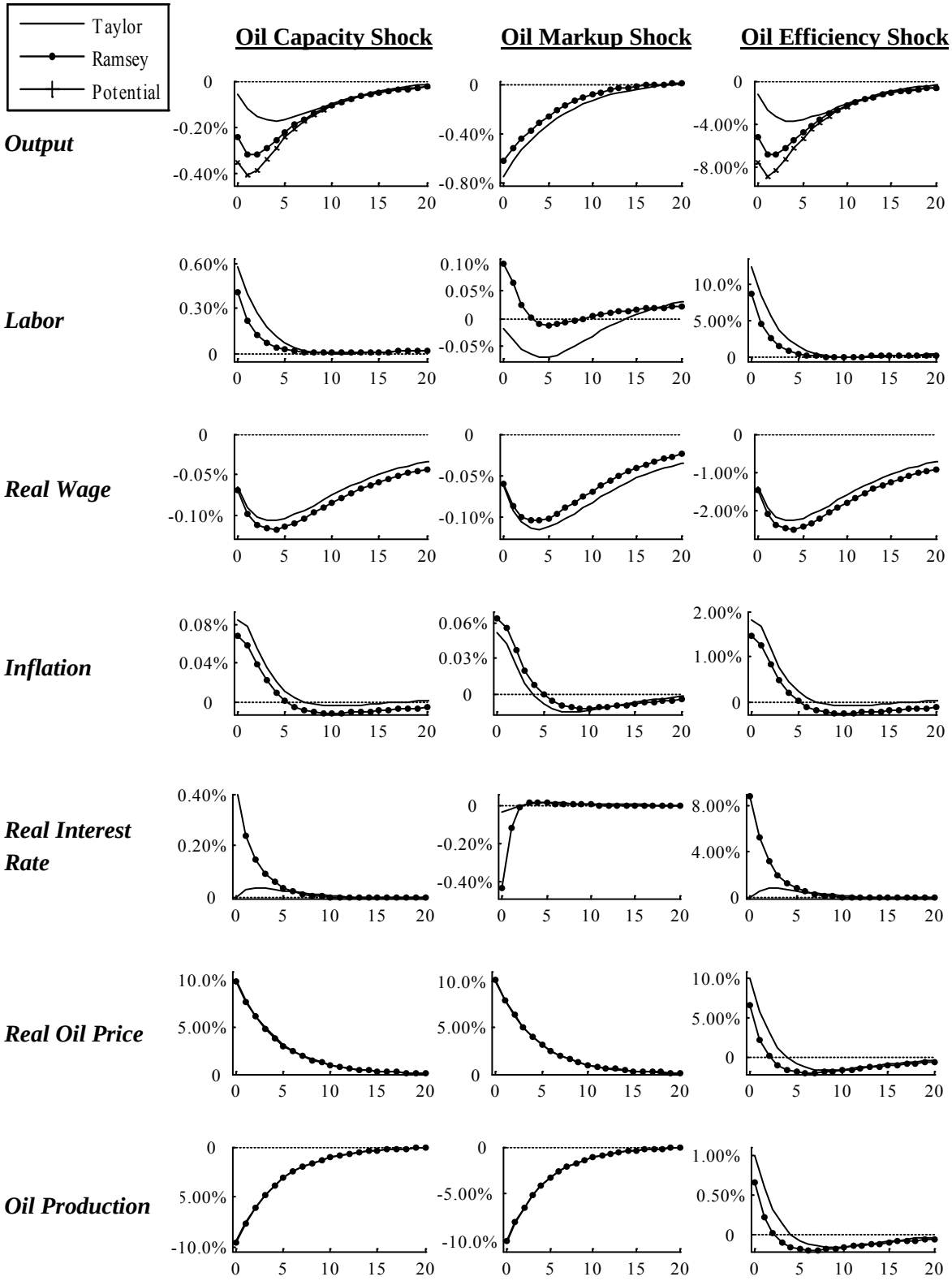
Note: Impulse responses (IRFs) are measured in percentage deviations from steady state. Solid lines present IRFs under the Taylor rule. Solid lines with point markers depict the Ramsey economy. Solid lines with crosses denote IRFs of potential output. All shocks have been normalized to produce a 10% increase in real oil prices under Taylor-type policy.

Figure 4: Output responses to oil supply and oil-specific demand shocks for different degrees of oil substitutability α (*complete markets*)



Note: Impulse responses (IRFs) are measured in percentage deviations from steady state. Solid lines present output responses under the Taylor rule. Solid lines with point markers depict the Ramsey economy. Solid lines with crosses denote IRFs of potential output. All shocks have been normalized to produce a 10% increase in real oil prices in case the substitutability of oil is low at α = 0.03 and monetary policy follows the Taylor-type rule.

Figure 5: Impulse responses to oil supply and oil-specific demand shocks
incomplete markets ─ Cobb Douglas production



Note: Impulse responses (IRFs) are measured in percentage deviations from steady state. Solid lines present IRFs under the Taylor rule. Solid lines with point markers depict the Ramsey economy. Solid lines with crosses denote IRFs of potential output. All shocks have been normalized to produce a 10% increase in real oil prices under Taylor-type policy.

Figure 6: Sensitivity of output responses to alternative values of the oil supply elasticity $1/\vartheta$

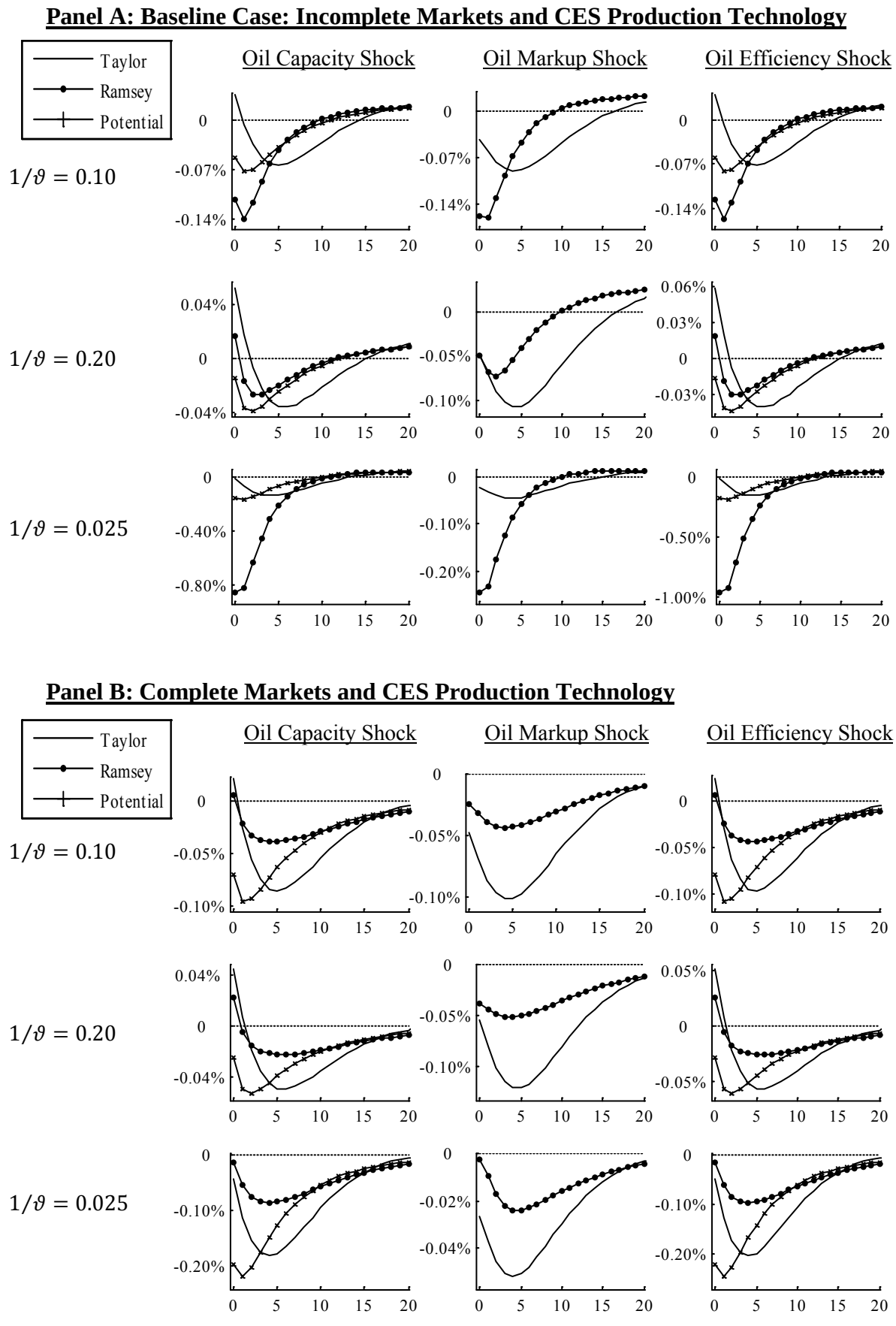
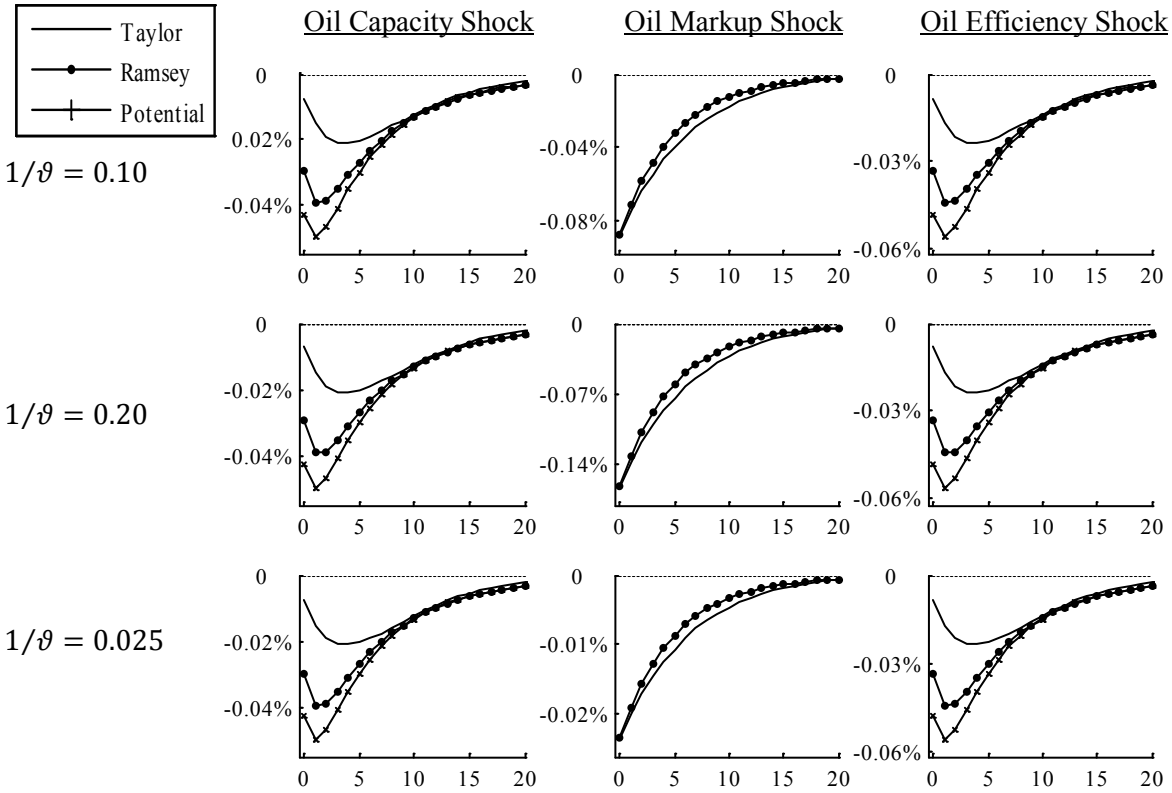


Figure 6 (Contd): Sensitivity of output responses to alternative values of the oil supply elasticity $1/\vartheta$

Panel C: Complete Markets and Cobb-Douglas Production Technology



Note: Impulse responses (IRFs) are measured in percentage deviations from steady state. Solid lines present output responses under the Taylor rule. Solid lines with point markers depict the Ramsey economy. Solid lines with crosses denote IRFs of potential output. All shocks have been normalized to produce a 10% increase in real oil prices in case the price-elasticity of oil supply equals $1/\vartheta = 0.1$ and monetary policy follows the Taylor-type rule.

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Layout: Analysis and Research Group
Cover: NBB AG – Prepress & Image

Published in January 2015