Jump-Starting the Euro Area Recovery: Would a Rise in Core Fiscal Spending Help the Periphery?*

Olivier Blanchard
International Monetary Fund

Christopher J. Erceg**
Federal Reserve Board

Jesper Lindé
Federal Reserve Board

June 30, 2014

Abstract

We show that a fiscal expansion by the core economies of the euro area would have a large and positive impact on the periphery economies given that policy rates are expected to remain low for a prolonged period. Under our preferred model specification, a one percent of GDP expansion in core fiscal spending would boost periphery GDP around 0.4 percent in a liquidity trap lasting 12 quarters, about half as large as the effect on core GDP. Our analysis suggests that the core might well benefit from some fiscal expansion insofar as it would narrow the core output gap while boosting inflation. However, given that the core would bear the cost of paying for the stimulus but has less resource slack than the periphery, the core has an incentive to provide considerably less stimulus than would be desirable from a euro area perspective (about half as much under an illustrative calibration).

JEL Classification: E52, E58

Keywords: Monetary Policy, Fiscal Policy, Liquidity Trap, Zero Bound Constraint, DSGE Model, Currency Union.

*We thank Mazi Kazemi and Sher Singh for providing excellent research assistance. The views expressed in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the IMF or the Board of Governors of the Federal Reserve System or of any other person associated with the Federal Reserve System.

E-mail addresses: oblanchard@imf.org, christopher.erceg@frb.gov and jesper.l.linde@frb.gov.

1. Introduction

There are many calls for Europe's core economies to expand fiscal spending to help the periphery. The hope is that such a policy would help boost the GDP of periphery economies, improve their external positions, and make them less vulnerable to swings in confidence.

But would fiscal expansion in the core in fact be likely to raise periphery output? And, if so, would the effects be regarded as desirable by both the core and periphery?

One channel through which higher core spending would affect the periphery is through aggregate effects on the euro area, including through the reaction of monetary policy. Higher core spending would boost euro area output and inflation. Outside of a liquidity trap, the ECB would raise interest rates in real terms, which would tend to reduce periphery GDP. But in a liquidity trap – at least of sufficient duration – real interest rates would fall, boosting periphery (as well as core) GDP.

The effects on the periphery GDP would also depend on how the core fiscal spending affects the composition of euro area demand. Higher core government spending could be expected to boost inflation in the core relative to the periphery. The implied depreciation of the periphery's terms of trade should increase the periphery's real net exports and hence provide some stimulus to periphery GDP. Periphery net exports would also improve to the extent that a larger fraction of core government spending was comprised of imports of periphery goods and services.

We formulate a two country New Keynesian model to help gauge the likely effects of a fiscal expansion by core euro area countries. Our benchmark model is particularly helpful in pinpointing how the various aggregate and compositional channels shape the response of periphery output. Even so, we also use a larger-scale DGSE model – which includes endogenous investment, nominal wage and price rigidities, and allows for non-Ricardian consumption behavior – to refine our quantitative assessments in a more empirically-realistic setting.

Outside of a liquidity trap, we find that the effects of higher core government spending on periphery GDP tend to be small and even negative if the import content of government spending is low. The small response of periphery GDP reflects that the central bank raises real interest rates immediately, more than offsetting the stimulus arising from a small depreciation of the periphery's terms of trade. This limited role for terms of trade adjustment seems consistent with Europe's experience since the Great Recession, in which relative prices have adjusted sluggishly despite large differences in resource gaps between core and periphery economies, as can be seen in Figure 1.

By contrast, in a liquidity trap, the interest rate response is weaker, and the other channels tend to dominate. The size of the periphery GDP response to a core spending hike increases with the expected duration of the liquidity trap, with the import content of core government spending, and with the responsiveness of inflation. In a relatively short-lived trap lasting only a few quarters, the GDP stimulus to the periphery is fairly small unless a sizeable fraction of core spending is imported (roughly 10 percent or more).[1] However, higher core spending can provide a potent source of stimulus to the periphery if monetary policy is expected to be constrained from raising interest rates for a couple of years or more, even if the higher spending falls mainly on domestically produced goods. Under such conditions, lower CU real interest rates strongly amplify the stimulus coming from terms of trade depreciation.

An important upshot is that the stimulative effects of a core fiscal expansion on euro area GDP are likely to be heavily weighted towards the core in normal times, or even in a short-lived liquidity trap; periphery output contracts unless the core spending has a substantial import content. By contrast, the stimulus associated with higher core spending has relatively more balanced effects on periphery and core GDP in a long-lived liquidity trap. For example, the larger scale model implies

[1] Several recent papers have analyzed fiscal spillovers in a liquidity trap, including Fahri and Werning (2012), Devereux and Cook (2011), and Fujiwara and Ueda (2013). The qualitative analysis of Fahri and Werning (2012) shows that the pattern of spillovers flips sign from negative in normal times when the currency union monetary authority raises interest rates to positive in a liquidity trap. The other papers focus on an environment with flexible exchange rates, and argue that a country expanding fiscal spending is likely to cause its currency to depreciate enough to generate negative spillovers to its trading partners.

that the effects of higher fiscal spending are about 1/3 as large on periphery GDP as core GDP in a liquidity trap expected to last 8 quarters, but nearly 1/2 as large in a 12 quarter liquidity trap. The more balanced effects in a protracted liquidity trap reflect that the higher core spending lowers real interest rates in both periphery and core, which boosts domestic demand in both regions.

We next consider core fiscal expansion from a more normative perspective. From the standpoint of the euro area as a whole, fiscal expansion in the current environment might seem desirable given substantial resource slack, undesirably low inflation, and the expectation that policy rates will remain low for a prolonged period.[2] However, this aggregate perspective ignores that resource slack appears to be very large in the periphery, and relatively modest in the core. Given that the core economies would bear the cost of financing the stimulus but "need it least," there is a strong incentive for these economies to provide less stimulus than desirable from a euro area perspective. In this vein, we illustrate how policies that take explicit account of periphery welfare – and thus appear desirable from the "cooperative" perspective of maximizing welfare across regions – may imply excessive stimulus for the core, and result in an overshooting of both the core output gap and inflation.[3] Somewhat more generally, our results underscore that a large aggregate multiplier is not enough in assessing whether fiscal policy is likely to improve welfare; the distributional impact on output and inflation in each economy, as well as initial business cycle positions, are also consequential.

This paper is organized as follows. Section 2 presents the benchmark log-linearized model and benchmark calibration. Section 3 shows impulse response to a core fiscal expansion with a

[2] While our discussion here focuses on the desirability of fiscal expansion in a prolonged liquidity trap, it bears emphasizing that a core fiscal expansion could potentially be counterproductive if monetary policy had latitude to cut interest rates sufficiently. Indeed, the analysis of both Gali and Monacelli (2008) and Pappa (2007) suggests that it might be desirable to respond to a contraction in periphery demand by cutting core fiscal spending – thus better aligning business cylces within the CU – and then cutting interest rates aggressively. While the implication that core consolidation may be desirable seems quite model-specific, the more general message that core fiscal expansion would not be desirable if monetary policy could do the lifting seems very reasonable.

[3] Of course, some stimulus could well desirable even from the standpoint of maximizing core welfare; but given small output gaps and the amplified fiscal multiplier in a liquidity trap, considerably less would be needed than if periphery welfare were also taken into account.

focus on factors determining spillovers to the periphery. Section 4 considers both the positive and normative effects of alternative fiscal expansion packages against a baseline for the euro area. Section 5 examines robustness in the larger scale model, while Section 6 concludes.

2. The Benchmark Open Economy Model

Our benchmark model is comprised of two countries that may differ in population size. Similar to Gali and Monacelli (2008), our model assumes that financial markets are complete both domestically and internationally, that producers set the same price in both the home and foreign market (producer currency pricing), and that monopolistically competitive firms are subject to Calvo–style nominal price frictions. We generalize the Gali and Monacelli model by allowing for habit persistence in consumption, and by assuming that some fraction of government consumption may be imported. Given the symmetric structure across countries, our discussion below focuses mainly on the home country.

Our formulation below highlights how the model can be decomposed into two parts. The first part, which determines the equilibrium for the currency union (CU) as a whole, is completely standard. The familiar three equations – the New Keynesian IS curve, the AS curve, and the policy reaction function – determine aggregate CU output, inflation, and policy rates, respectively; and per usual, a core fiscal expansion boosts CU output and inflation. The second part involves characterizing the difference between the response of periphery and core variables. These differences depend exclusively on the terms of trade and exogenous shocks, including to fiscal policy. Importantly, monetary policy only affects the core and periphery only through its effects on the CU as a whole, but does not influence the terms of trade, or the differences between the responses of periphery and core variables.

Our discussion below focuses on the log-linearized equations of the model; a full description of the underlying model structure is provided in Appendix A.

2.1. The Log-Linearized Benchmark Model

Consumption demand in each economy is determined by the consumption Euler equation condition, which for the home economy is given by:

$$\lambda_{ct} = \lambda_{ct+1|t} + i_t^{CU} - \pi_{ct+1|t}, \tag{1}$$

where i_t^{CU} is the policy rate of the central bank in the currency union (CU), π_{ct} is consumer price inflation in the home economy, and λ_{ct} is the marginal utility of consumption:

$$\lambda_{ct} = -\frac{1}{\widehat{\sigma}}(c_t - \varkappa c_{t-1} - \nu\nu_t). \tag{2}$$

The marginal utility of consumption varies inversely with current consumption c_t, but rises both with past consumption due to habit persistence. Taken together, these equations imply that consumption falls in response to higher real interest rates, with the sensitivity depending on intertemporal elasticity in substitution parameter $\widehat{\sigma} = \sigma\,(1 - \varkappa - \nu)$. The preference shock ν_t boosts consumption demand at any given interest rate.[4]

Consumption demand in the CU as a whole is determined as a population-weighted average of the demand of the home and foreign economies (with weights ζ and ζ^*, respectively). Imposing the aggregate resource constraints which equate CU consumption to CU output y_t^{CU} less government spending g_t^{CU} (i.e., $c_y c_t^{CU} = y_t^{CU} - g_y g_t^{CU}$) and average CPI inflation in each country to CU inflation ($\zeta\pi_{Ct} + \zeta^*\pi_{Ct}^* = \pi_t^{CU}$), aggregate demand in the CU may be expressed in terms of a familiar New Keynesian IS curve:

$$x_t^{CU} = \frac{1}{1+\varkappa}x_{t+1|t}^{CU} + \frac{\varkappa}{1+\varkappa}x_{t-1}^{CU} - c_y\widehat{\sigma}(i_t^{CU} - \pi_{t+1|t}^{CU} - r_t^{CU,pot}), \tag{3}$$

[4] While our model also allows for the discount factor shocks ζ_t and ζ_t^*, these shocks have been omitted from the description of the log-linearized equations. The discount factor shock boosts consumption demand, but has no effect on potential output or labor supply.

where c_y denotes the consumption-output ratio in steady state, and g_y.is the government spending share. As seen from eq. (3), the CU output gap x_t^{CU} depends both on past and future output gaps, and inversely on the difference between the real policy rate in the CU $i_t^{CU} - \pi_{t+1|t}^{CU}$ and its potential or "natural" rate of $r_t^{CU,pot}$.

On the aggregate supply side, the inflation rate of domestically-produced goods in each country is determined by a New Keynesian Phillips Curve. Thus, the home inflation rate π_{Dt} depends both on the current marginal cost of production mc_t and future expected inflation:

$$\pi_{Dt} = \beta\pi_{Dt+1|t} + \kappa_{mc} mc_t. \tag{4}$$

Given our assumption of monopolistically competitive producers and Calvo-style staggered price contracts, the parameter κ_{mc} determining the sensitivity of inflation to marginal cost mc_t depends on the mean price contract duration $\frac{1}{1-\xi_P}$ according to $\kappa_{mc} = \frac{(1-\xi_P)(1-\beta\xi_P)}{\xi_P}$. Thus, longer-lived price contracts flatten the slope of the Phillips Curve. Marginal cost in turn depends on the gap between the product real wage ζ_t and the marginal product of labor mpl_t:

$$mc_t = \zeta_t - mpl_t = [\chi n_t - \lambda_{ct} + \omega_c \tau_t] + \alpha n_t - (1-\alpha) z_t. \tag{5}$$

The effects on marginal cost associated with fluctuations in the product real wage are captured by the term in brackets. Because wages are fully flexible, the product real wages rises in response to an increase in work hours n_t (χ is the inverse Frisch elasticity), a fall in the marginal utility of consumption λ_{ct} (reflecting a wealth effect), or to a depreciation of the terms of trade τ_t. Marginal costs also rise in response to factors which reduce the marginal product of labor, including a rise in hours work (with sensitivity α), or decline in technology z_t.

Aggregate CU inflation is determined as a population-weighted average of equation (4):

$$\pi_t^{CU} = \beta\pi_{t+1|t}^{CU} + \kappa_{mc} mc_t^{CU}. \tag{6}$$

Using the production function to substitute for hours in terms of output, CU marginal cost can be expressed solely in terms of the CU output gap and its lag (with the latter reflecting the effect of habit persistence in consumption on labor supply). Thus, the New Keynesian Phillips Curve for CU inflation is given by:

$$\pi_t^{CU} = \beta \pi_{t+1|t}^{CU} + \kappa_{mc}[\phi_x x_t^{CU} + \frac{1}{c_y \widehat{\sigma}}(x_t^{CU} - \varkappa x_{t-1}^{CU})], \tag{7}$$

where the composite parameter $\phi_x = \frac{\alpha+\chi}{1-a}$ captures the influence of diminishing returns and the disutility of working, and $\frac{1}{c_y \widehat{\sigma}}$ the wealth effect on labor supply.

The currency union central bank is assumed to adhere to a Taylor-type policy rule subject to the ZLB of the form:

$$i_t^{CU} = \max\left(-i, \psi_\pi \pi_t^{CU} + \psi_x x_t^{CU}\right), \tag{8}$$

Thus, outside of a liquidity trap, the policy rate i_t^{CU} rises in response to an increase in the CU inflation rate π_t^{CU} or expansion in the CU output gap x_t^{CU}. Because the policy rate is measured as a deviation from the steady state nominal interest rate i – the sum of the steady state interest rate r and inflation rate $\pi-$ the zero bound constraint becomes binding only when the policy rate falls below $-i$. Currency union inflation π_t^{CU} is itself a population-weighted average of the inflation rate π_{Ct} in both the home and foreign country:

$$\pi_t^{CU} = \zeta \pi_{Ct} + \zeta^* \pi_{Ct}^*. \tag{9}$$

where each country inflation rate is simply the log percentage change in the respective consumption price index (i.e., $\pi_{Ct} = \ln(P_{Ct}/P_{Ct-1})$). The CU output gap x_t^{CU} is the difference between currency union output y_t^{CU} and its potential level $y_t^{CU,pot}$, with both variables again simply population-weighted averages of the respective country variables.

Both the potential output measure $y_t^{CU,pot}$ relevant for the CU output gap ($x_t^{CU} = y_t^{CU} - y_t^{CU,pot}$) and the potential real rate $r_t^{CU,pot}$ depend only on population-weighted averages of the underlying shocks and lags of $y_t^{CU,pot}$ (due to habit persistence). For example, abstracting from habit persistence for expositional simplicity, CU potential output is given by:

$$y_t^{CU,pot} = \frac{1}{\widehat{\sigma}(1-g_y)\phi_x + 1}\left(g_y g_t^{CU} + \nu(1-g_y)\nu_t^{CU} + (1-g_y)(1+\chi)z_t^{CU}\right), \tag{10}$$

A rise in average CU government spending g_t^{CU} has the same positive effect on currency union potential output and the potential real interest rate $r_t^{CU,pot}$ irrespective of how it is distributed across the member states (as does the preference shock ν_t^{CU} and technology shock z_t^{CU}). This result rests on our assumption of a symmetric structure across the home and foreign economy, aside from population size and home bias in trade.

Our formulation highlights how a core fiscal expansion can be thought of as partly operating through aggregate channels – boosting euro area inflation, the output gap, and possibly the policy rate. Given the simple equation structure implied by the IS curve (3), the Phillips Curve (7), and the CU policy rule (8), the fiscal expansion has exactly the same effects on aggregate variables (including x_t^{CU}, π_t^{CU},and i_t^{CU}) as in a similarly calibrated closed economy model. Of course, in addition to the aggregate impact, we are also interested in how the effects of core fiscal stimulus would be distributed between the periphery and core. Accordingly, we next solve for the differences in the responses between the home and foreign economy. This approach allows us to solve the model in a way that sheds light on compositional question of why the stimulus has a differential impact on each economy.

In this vein, the resource constraint implies that home output y_{Dt} may be expressed as a weighted average of consumption c_t, government spending g_t, and "net exports" nx_t, which are the the difference between exports $m_t^*$and imports m_t scaled by the trade share of GDP:

$$y_{Dt} = c_y c_t + g_y g_t + nx_t, \tag{11}$$

Net exports in turn depend on the percentage difference between exports and imports of each type of tradable good, including of private consumption goods (i.e., $m^*_{ct} - m_{ct}$) and government goods/services $(m^*_{gt} - m_{gt})$:

$$nx_t = \omega_{cy}(m^*_{ct} - m_{ct}) + \omega_{gy}(m^*_{gt} - m_{gt}). \tag{12}$$

Each component is weighted by its respective GDP share (i.e. $\omega_{cy} = \omega_C \times \frac{C}{Y}$ and $\omega_{gy} = \omega_G \times \frac{G}{Y}$). Net exports of either type of tradeable rise if home goods become relatively cheaper – that is, the terms of trade τ_t depreciates – or if foreign demand rises relative to home demand. Thus:

$$\begin{aligned} m^*_{ct} - m_{ct} &= c^*_t - c_t + \epsilon_c \tau_t, & (13) \\ m^*_{gt} - m_{gt} &= g^*_t - g_t + \epsilon_g \tau_t. & (14) \end{aligned}$$

The parameters ϵ_c and ϵ_g capture the sensitivity of each component of real net exports to the terms of trade and may differ between consumption and government goods.[5]

Using the home resource constraint and its analogue for the foreign economy, the difference between home and foreign GDP may be expressed:

$$\begin{aligned} y_{Dt} - y^*_{Dt} &= c_y(c_t - c^*_t) + g_y(g_t - g^*_t) + (nx_t - nx^*_t) & (15a) \\ &= c_y(1 - \omega_c - \omega^*_c)(c_t - c^*_t) + g_y(1 - \omega_g - \omega^*_g)(g_t - g^*_t) + \epsilon \tau_t. \end{aligned}$$

Home relative output $y_{Dt} - y^*_{Dt}$ can rise for three reasons. First, home relative output increases if home relative consumption $(c_t - c^*_t)$ rises. Some of the output stimulus is offset due to "leakage" to net exports, with this dampening effect captured by the openness coefficients ω_c and ω^*_c on relative consumption (following the second equality). Second, home output rises if home relative government spending rises, with the dampening effect through trade similarly captured by ω_g and ω^*_g. Third, home relative output rises if the terms of trade τ_t depreciates, with the degree of stimulus

[5] In terms of the model parameters, we have $\epsilon_c = \left(\frac{(1+\rho_C)}{\rho_C}(2 - \omega^*_C - \omega_C) - 1\right)$ and $\epsilon_g = \left(\frac{(1+\rho_G)}{\rho_G}(2 - \omega^*_G - \omega_G) - 1\right)$.

a weighted average of the price sensitivity of consumption and government services given by the composite parameter ϵ (where $\epsilon = c_y(\omega_C + \omega_C^*)\epsilon_c + g_y(\omega_G + \omega_C^*)\epsilon_g$). As we will emphasize below, the effects of a rise in foreign government spending are more balanced on home and foreign output to the extent that a larger share of foreign government goods are imported (i.e., ω_G^* is higher).

Home relative consumption $c_t - c_t^*$ itself depends only on the terms of trade (and exogenous preference shocks) through the complete markets risk-sharing condition:

$$c_t - c_t^* = \varkappa(c_{t-1} - c_{t-1}^*) + \widehat{\sigma}(1 - \omega_C - \omega_C^*)\tau_t + \frac{1}{\sigma}(\nu_t - \nu_t^*). \tag{16}$$

Thus, a depreciation of the home terms of trade increases home relative consumption, as do preference shocks that boost the home marginal utility of consumption ν_t relative to that abroad.

Substituting equation (16) into (15a), it is evident that home relative output varies positively with the terms of trade, the relative fiscal stance $(g_t - g_t^*)$, and exogenous shocks (also expressed as differentials). Habit persistence introduces some delay into the responses. An important upshot is that a rise in foreign government spending tends to reduce home GDP markedly relative to foreign GDP unless either the terms of trade depreciates enough, or the direct impact on the home economy is large due to a high foreign import share coefficient ω_G^*. The stimulus to the home economy from the terms of trade channel may alternatively be interpreted in terms of relative long-term real interest rate differentials or inflation rates:

$$\tau_t = \mathrm{E}_t \sum_{j=1}^{\infty}(\pi_{Dt+j} - \pi_{Dt+j}^*) = -\mathrm{E}_t \sum_{j=0}^{\infty}(r_{t+j} - r_{t+j}^*), \tag{17}$$

This equation is derived by imposing that the terms of trade revert to zero in the very long-run, reflecting complete markets and our assumption that shocks are stationary. Thus, assuming that the home terms of trade depreciates initially in response to a shock – say due to a rise in foreign government spending – the "long-run" real interest rate in the periphery must fall, even if it rises in the near-term (as would occur if the terms of trade depreciated gradually for some time). Since it is the long-run real interest rate response that matters for consumption in the benchmark model, periphery relative consumption rises (concurring with equation 16). Equivalently, home relative consumption is high when long-run expected domestic inflation is higher than expected inflation abroad.

From the home price-setting equation (4) and its foreign counterpart, it follows inflation differentials between the home and foreign economy depend on the difference between home and foreign marginal costs:

$$\pi_{Dt} - \pi^*_{Dt} = \beta(\pi_{Dt+1|t} - \pi^*_{Dt+1|t}) + \kappa_{mc}(mc_t - mc^*_t). \tag{18}$$

Relative marginal costs – using equation (5) and its foreign analogue – may be expressed:

$$mc_t - mc^*_t = \frac{\alpha + \chi}{1 - \alpha}(y_{Dt} - y^*_{Dt}) + \tau_t - (1 + \chi)(z_t - z^*_t). \tag{19}$$

Relative marginal cost turns out to depend only on the terms of trade and exogenous shocks. As discussed above, a terms of trade deterioration boosts the relative demand for home goods $y_{Dt} - y^*_{Dt}$, which causes home relative marginal costs to rise due to higher wage pressures and diminishing returns (with the size of these effects determined by the inverse Frisch elasticity of labor supply χ and the capital share parameter α in equation 19). In addition, there is a 'direct' and reinforcing channel through the terms of trade. A terms of trade depreciation boosts home relative consumption, which raises home relative marginal costs through a wealth effect on wages.

Since inflation differences between the home and foreign economy vary inversely with terms of trade growth according to $\pi_t - \pi^*_t = -(\tau_t - \tau_{t-1})$ (see eq. A.19) , the solution for the inflation differential in eq. (18) implies that the terms of trade evolves according to:

$$(\tau_t - \tau_{t-1}) = \beta(\tau_{t+1|t} - \tau_t) - \kappa_{mc}(mc_t - mc^*_t). \tag{20}$$

From an intuitive perspective, a rise in core fiscal spending g_t^* initially increases aggregate demand by relatively more in the core (as seen from equation 15a). This boosts relative marginal production costs in the core, which causes the home terms of trade to depreciate (from equation 20, $mc_t^* > mc_t$, so that τ_t rises). The terms of trade depreciation gradually shifts more of the aggregate demand increase to the home economy. This rebalancing continues until there is no further pressure for relative price adjustment. This upward pressure on the terms of trade diminishes as the gap between the terms of trade and the "potential" terms of trade τ_t^{pot} closes, as can be seen by a reformulation of equation (20):

$$(\tau_t - \tau_{t-1}) = \beta(\tau_{t+1|t} - \tau_t) - \kappa_{mc}\phi_{mc}(\tau_t - \tau_t^{pot}), \tag{21}$$

which abstracts from habit persistence for expositional convenience.[6] Thus, if the terms of trade is low relative to its potential level (so that the home currency is overvalued), the terms of trade tends to depreciate.

Equation 15a underscores that the terms of trade simply evolves as an autonomous difference equation. Thus, the evolution of the terms of trade does not depend on CU monetary policy, or whether the currency union is in a liquidity trap. Because relative output levels, relative inflation rates, and relative consumption levels also only depend on the terms of trade, monetary policy has no effect on these variables: it can only operate through effects that are felt uniformly across the currency union members.[7]

[6] The parameter ϕ_{mc}, which is derived from eqs. (19) and (15a) using that $mc_t - mc_t^* = 0$ in the flexible price equilibrium, reflects the sensitivity of relative marginal costs to the terms of trade gap $(\tau_t - \tau_t^{pot})$. With habit persistence, the terms of trade can also be represented as a function only of the terms of trade gap (as a third order difference equation).

[7] Moreover, given that we have solved for both aggregate CU variables and corresponding cross-country differences, country-specific variables may be solved for by the relevant identifies. For example, given that aggregate CU output is defined as $y_t^{CU} = \zeta y_{Dt} + \zeta^* y_{Dt}^*$, output of the home country may be solved for as $y_{Dt} = y_t^{CU} + (1-\zeta)y_t^d$, where $y_t^d = y_{Dt} - y_{Dt}^*$;. and foreign output is given by $y_{Dt}^* = y_t^{CU} - \zeta y_t^d$.

2.2. Calibration

We calibrate our model at quarterly frequency, and assume a symmetric structure for each country block aside from differences in trade intensities (due to different population size). While many aspects of our calibration are standard, two classes of parameters – including those which govern the responsiveness of inflation, and those which influence trade flows – deserve particular emphasis.

The degree to which inflation responds to output slack is the key determinant of both the terms of trade response and of the aggregate response of CU output and inflation. We have calibrated the parameters of the Phillips curve equation and monetary policy rule to imply a low degree of inflation responsiveness on two main grounds. First, if inflation was quite responsive, the much larger negative output gap in the periphery than the core since 2009 would have been expected to push periphery inflation well below core inflation. However, the evidence indicates that inflation has run only a bit lower in the periphery than in the core since 2009, and hence the periphery's terms of trade – as shown in Figure 2 – has depreciated only a couple of percent. Second, an extensive literature that has estimated the sensitivity of inflation to marginal cost – the parameter κ_{mc} in equation 7 – suggests a low value in the range of $\kappa_{mc} = 0.009 - 0.014$.[8] Our own analysis using the terms of trade in Figure 2 and relative labor shares to proxy for the marginal costs $mc_t - mc_t^*$ seems to corroborate these empirical estimates. In particular, the lower panel plots $(\tau_t - \tau_{t-1}) - \beta(\tau_{t+1|t} - \tau_t)$ (vertical axis) against $mc_t - mc_t^*$ (horizontal axis) as implied by equation (20), and is suggestive of a very low sensitivity over the 1996:1-2013:4 sample period. Our specific calibration of $\kappa_{mc} = 0.007$ is a bit lower than these empirical estimates and also than the value implied by fitting a simple OLS regression as in the lower panel of Figure 2, but seems appropriate given that our model omits wage rigidities.[9] The implied contract duration parameter is $\xi_p = 0.92$.

[8] The median estimates of the Phillips Curve slope in recent empirical studies by e.g. Adolfson et al (2005), Altig et al. (2011), Galí and Gertler (1999), Galí, Gertler, and López-Salido (2001), Lindé (2005), and Smets and Wouters (2003, 2007) are in the range of $0.009 - .014$.

[9] While damping κ_{mc} seems a reasonable expedient to derive a plausible sensitivity of inflation to the output gap in the benchmark model, our larger-scale model in Section 5 explicitly includes wage rigidities.

The second key group of parameters are those determining the responsiveness of trade flows as a share of domestic output, including import share of private (consumption) spending ω_C, of public spending ω_G, and the trade price elasticity of each of these components (ϵ_c and ϵ_g, respectively). Ceteris paribus, a higher trade share or higher trade price elasticity amplifies the "leakage" associated with a core fiscal expansion to the periphery, and thus should push in the direction of more balanced effects across regions. Trade data from Eurostat for Spain and Italy indicate an average import/GDP ratio of those economies of about 22 percent in 2007 after netting out intra-periphery imports. In calibrating the trade share in our two country framework, a notable complication involves how to treat periphery trade with non-EU members: periphery imports are closer to 14-15 percent of GDP if all non-EU trade is excluded from our computation. We assume an import share of 15 percent of GDP for the periphery in our baseline and hence effectively exclude non-EU trade, but recognize that the trade effects in reality would depend on how the periphery's real exchange rate varied relative to non-EU trading partners.[10] Given that periphery GDP is about half of that of the core euro area countries, we set the country size parameters $\zeta = 1/3$ and $\zeta^* = 2/3$; accordingly, balanced trade implies a trade share of 7.5 percent of GDP for the core.

Our model requires parsing this import share of GDP into private and public spending components. While information about the import share of public spending is somewhat sparse, a study by xx estimates the import share for Germany and the Netherlands to be around 10 percent, which would imply $\omega_G^*= 0.10$. But for illustrative purposes and to bracket a range of values, we set $\omega_G^* = \omega_G = 0$ under our benchmark – consistent with most of the literature – and then consider $\omega_G^* = 0.2$ (implying $\omega_G = 0.4$) as high side alternatives. Under the benchmark with $\omega_G = \omega_G^* = 0$, the import share of consumption is about 20 percent in the periphery and 10 percent in the core

[10] If the ECB was unconstrained by the ZLB, a tightening of policy would be expected to cause the euro to appreciate, and probably imply some appreciation of the periphery's exchange rate relative to its non-EU trading partners; in contrast, the periphery real exchange rate might well depreciate in a deep enough liquidity trap.

(i.e., $\omega_C = 0.2$ and $\omega_C^* = 0.1$).[11] The trade price elasticity for both private consumption and government spending is assumed to be slightly above unity (1.1), consistent with estimates from the macro literature on trade price elasticities.

The calibration of remaining parameters is fairly standard. The discount factor of $\beta = 0.995$ implies a steady state real interest rate of 2 percent (at an annualized rate). With a steady state inflation rate of 2 percent (i.e., $\pi = .005$), the steady state nominal interest rate is 4 percent (i.e., $i = .01$ at a quarterly rate). We set the intertemporal substitution elasticity $\sigma = 1$, which is consistent with log utility over consumption.[12] The habit parameter $\varkappa$ is set to 0.9. This value is towards the upper end of the range of estimates in the empirical literature, but helps our model generate a fairly plausible path for the aggregate spending multiplier without additional features such as hand-to-mouth agents (i.e., reasonably consistent with the evidence on multipliers from Blanchard and Perotti (2002), even if a bit on the low side). The Frisch elasticity of labor supply of $\frac{1}{\chi} = 0.4$ and capital share of $\alpha = 0.3$ are in the typical range specified in the literature. The government share of steady state output is set to 23 percent ($g_y = 0.23$), which is in line with the average government spending share of GDP in the euro area in recent years..

Our benchmark model assumes that the currency union central bank follows a Taylor-rule in equation (A.27) that is somewhat more aggressive on inflation than a standard Taylor rule, and thus sets $\psi_\pi = 2.5$, and $\psi_x = 0.125$. Finally, all exogenous variables (including domestic and foreign government spending) are assumed to follow an AR(1) process with persistence of 0.9 unless otherwise specified.

[11] The sizeable disparity between the import share of consumption and that of GDP reflects that nearly a quarter of output is devoted to government spending.

[12] The scale parameter on the consumption taste shock ν is set to 0.01 (this parameter is set to have a negligible impact on model dynamics).

3. Impulse Response to Higher Core Government Spending

Figure 3 examines the effects of a positive shock to core government spending that has a persistence of 0.9 at a quarterly frequency. The size of the shock is scaled to be one percent of core baseline GDP (i.e., 2/3 percent of CU GDP).

We begin by considering impulse responses in normal times in which monetary policy is unconstrained by the zero lower bound. From an aggregate perspective, the higher core spending boosts CU output (the red dotted line), CU inflation (not shown), and induces the central bank to raise the policy rate. Output rises above potential (the blue dashed line) because the Taylor rule implies that real interest rates increase by somewhat less than the potential real rate $r_t^{CU,pot}$ (recalling equation 3), which in turn accounts for the upward pressure on inflation. The noticeable persistence in the output response reflects habit persistence in consumption. As discussed above, these effects on the CU are identical to those that would obtain in a closed economy model.

Turning to the compositional effects across core and periphery, it is evident that the stimulative effects are confined exclusively confined to the core. While core output remains about 0.6 percent above baseline after four quarters (consistent with a multiplier of about 0.8), periphery output actually contracts modestly. Two related perspectives are useful for understanding the effects on periphery output. First, the higher real interest rate in the periphery (due to the higher CU policy rate) causes periphery domestic demand to contract, which more than offsets the stimulus to periphery net exports arising from a depreciation of the periphery's terms of trade. This depreciation itself reflects that core output expands by more than periphery output, which boosts inflation by relatively more in the core. However, with price adjustment much slower than would occur under flexible prices (as seen in the figure), this expenditure switching effect in favor of periphery net exports is quite modest quantitatively.

A second perspective is based on our model decomposition of the effects of a core spending into an aggregate CU impact and a compositional effect on CU relative aggregate demand $y_{Dt} - y^*_{Dt}$. Recall that the latter depends on the strength of the terms of trade channel relative to direct impact of higher core government purchases:

$$y_{Dt} - y^*_{Dt} = c_y(1 - \omega_c - \omega^*_c)(c_t - c^*_t) + g_y(1 - \omega_g - \omega^*_g)(g_t - g^*_t) + \epsilon\tau_t. \tag{22}$$

Given that g^*_t rises while g_t is unchanged, relative demand must shifts sharply to the core (i.e., $y_{Dt} < y^*_{Dt}$) unless the terms of trade τ_t depreciates enough to boost periphery real net exports (captured by the final term $\epsilon\tau_t$) and raise periphery relative consumption. With sluggish price adjustment muting the terms of trade response, relative demand indeed shifts toward the core.

The latter interpretation is particularly useful for understanding the effects of core fiscal stimulus in a liquidity trap. As emphasized in the model discussion, only the responses of CU aggregates differ from normal times: the terms of trade, and hence relative demand, are unchanged. To illustrate this, the solid lines in Figure 3 show the effects of the same rise in core spending in a liquidity trap lasting 12 quarters; a liquidity trap of this duration is generated from an adverse consumption taste shock that persistently depresses $r_t^{CU,pot}$. Comparing the liquidity trap with normal times, the path of both core and periphery output is shifted up by the same amount in percentage terms – about 1/4 percentage point after a year – while the response of the terms of trade is unchanged. Thus, a liquidity trap "lifts all boats" in the same proportion. CU inflation also rises by substantially more. The reasons for the amplified effects of core fiscal spending on CU output in a liquidity trap are familiar from an extensive literature which has showed that fiscal stimulus is more potent in a liquidity trap, cf. Christiano, Eichenbaum, and Rebelo (2011) and Woodford (2011). In particular, CU output shows a larger and more persistent response because policy rates remain tethered at zero even in the face of higher expected inflation; in a persistent liquidity trap, lower real rates may crowd in private demand, in contrast to the crowding out which occurs in normal times.

All told, the output rise in the periphery after four quarters in the 12 quarter trap shown in the figure is about one quarter as large as in the core. The pattern of spillovers to periphery GDP in our model – negative in normal times, and positive in a liquidity trap – is consistent with the qualitative analysis of Fahri and Werning (2012). As in their model, the boost to periphery GDP due to terms of trade depreciation is reinforced in a liquidity trap by a crowding in of private consumption, in contrast to the crowding out which occurs in normal times. While both Devereux and Cook (2011) and Fujiwari and Ueda (2013) show that fiscal expansion can have negative spillovers abroad, their results are based on an environment with flexible exchange rates. In particular, the country expanding fiscal spending in their model experiences an immediate real exchange rate depreciation that hurts its trading partners, in contrast to the appreciation of the expanding country in our CU setting.

3.1. The Longer the Liquidity Trap, the Stronger the Spillover Effects

A key question is how the effects of a core spending expansion would vary with the expected duration of the liquidity trap. The upper panels of Figure 4 show the effect of the same core government spending expansion on both periphery output (left panel) and core output (right panel) for liquidity traps ranging in duration from zero quarters (normal times) to 12 quarters. The effects are derived as the average response over the first four quarters following the stimulus, and hence can essentially be read off the IRFs in Figure 3 for both the normal times case and for the 12 quarter trap. The figure indicates that the spillovers to the periphery are negative in a liquidity trap lasting four quarters or less, and are virtually zero in a six quarter liquidity trap. Accordingly, the stimulus associated with fiscal expansion accrues almost wholly to the core in a relatively short-lived liquidity trap.

Our result that the spillovers to be periphery are negative in a shorter-lived liquidity trap –

and that the aggregate multipliers are fairly modest – may seem surprising in light of the literature suggesting a sharp disparity between the effects of fiscal expansion between a liquidity trap and normal times. There are three important reasons for why a short-lived liquidity trap doesn't look too different from normal times in our baseline model. One reason is that we allow for substantial habit persistence in consumption. This allays the strong "crowding out" effects on consumption that would occur in normal times when interest rates rise in response to higher government spending, while limiting the crowding in effects due to lower real interest rates in a liquidity trap.

The second reason is that government spending shocks are assumed to persist well beyond the duration of the liquidity trap. As emphasized by Woodford (2011) and Christiano, Eichenbaum, and Rebelo (2012), this fiscal overhang attenuates the aggregate CU multiplier relative to a "ideally-structured" fiscal intervention that dissipates before the economy exits the liquidity trap In our model, this dampening effect is reflected by the rise in the policy rate – apparent in Figure 3 – immediately after the liquidity trap ends. Because this means that long-term interest rates rise even while the economy is in a liquidity trap, private CU consumption may be crowded out, and spillovers to the periphery can be modestly negative (as in Figure 4 for short-lived traps). While the aggregate CU multiplier – and hence spillovers – would be higher if the government spending stimulus could be concentrated during the period in which monetary policy was constrained, practical impediments make it unlikely to achieve a rapid phase-in and phase-out within a few quarters. Cogan et al (2011) have underscored these practical limitations by pointing out that only around a third of the increased U.S. federal spending on goods and services authorized by the American Reconstruction and Recovery Act Stimulus was earmarked to be spent within the first two years of the ARRA's passage in February 2009.

The third reason – explored more fully below – is that inflation is much less responsive than often assumed in the literature.

Taking stock of our results, our benchmark model suggests that a core fiscal expansion would probably be of little help to the periphery in a short-lived liquidity trap, assuming – as we have thus far – that the core spending fell exclusively on core goods. Virtually all of the stimulus to GDP would accrue to the core. By contrast, in a longer lived liquidity trap, higher core spending could provide considerable stimulus to the periphery, even though the core would still gets the lion's share of the stimulus to CU GDP.

We should emphasize that considerable caution is required in using our benchmark model to infer how long a liquidity trap is required for periphery GDP to get a measurable boost from higher core spending. While the benchmark model suggests that the spillover effects to the periphery only appear sizeable if the liquidity trap lasts at least 11-12 quarters, the benchmark model does omit a number of features – including non-Ricardian consumption behavior – that can account for a higher multiplier even if price adjustment is very sluggish. The more policy oriented model we examine in Section 5 implies spillovers to the periphery that are comparable to those in our benchmark model even under a noticeably shorter liquidity trap duration; notably, the spillovers for an 8-9 quarter trap in the larger-scale model are comparable to those shown in Figure 3 and 4 for a 11-12 quarter liquidity trap. Moreover, as we will show, core spending provides much more of a boost to the periphery even in the benchmark model if a sizeable fraction is spent on imports.

3.2. The Steeper the Phillips Curve, the Stronger the Spillover Effects

While slow price adjustment seems consistent with Europe's experience since the Great Recession, it is possible that the Phillips Curve slope is higher than we have assumed in our baseline. A higher Phillips Curve slope might be consistent with observed inflation behavior if potential output has fallen even more sharply than typically estimated, especially in the periphery, so that output and employment gaps are much smaller. Alternatively, downward wage rigidities and weak productivity growth may help explain the apparent resilience of euro area inflation, similar to the forces that Christiano, Eichenbaum, and Trabandt (2013) have argued help account for U.S. inflation behavior.

Accordingly, Figure 5 shows IRFs to the core spending shock under a calibration with a steeper Phillips Curve slope: specifically, we set $\xi_p = 0.85$, implying a Phillips Curve slope parameter of $\kappa_{mc} = .027$. As seen in the figure, the spillovers in normal times are not much different under this calibration. The faster terms of trade adjustment than in the benchmark does imply somewhat more balanced stimulus across the periphery and core (recalling equation eq. (22)). However, this effect in the direction of more balance – which is quite modest quantitatively – is essentially offset as the larger rise in CU inflation prompts a larger rise in CU policy rates, which reduces the aggregate CU multiplier relative to benchmark. The fiscal expansion under the higher Phillips Curve slope does have dramatically different implications than in the benchmark in a persistent liquidity trap. With the higher Phillips Curve slope, the higher inflation implies much lower real interest rates, and consequently a much larger expansion of CU GDP. Given that this aggregate stimulus is evenly distributed, periphery GDP rises nearly as much as core GDP in a 12 quarter trap. The upper panels of Figure 4 show how the effects on core and periphery vary with the duration of the liquidity trap under this calibration.

This calibration is useful for highlighting conditions that might give rise to very large positive fiscal spillovers, and is of particular interest given that calibrations of the Phillips Curve slope in this range are often used in the literature. While a responsiveness of inflation in the range implied by Figure 5 seems too much of a stretch to take seriously in light of the Great Recession experience, the scenario does suggest the possibility of some upside risk to fiscal spillovers if inflation proves somewhat more responsive than assumed in our benchmark calibration.

3.3. The Larger the Import Content of Spending, the Stronger the Spillover Effects

Policymakers often draw attention to terms of trade adjustment as a key channel through which the periphery might benefit from a core fiscal expansion. Nevertheless, even if price adjustment turned out to be much faster than appears plausible – as in our last scenario – it is striking how little of the GDP stimulus to the core is redirected to periphery through terms of trade adjustment. To help understand this, it is useful to observe that the composite parameter ϵ in eq. (22)) – which determines how periphery trade flows as a share of GDP respond to the terms of trade – is only about 0.3 under our benchmark calibration. Thus, assuming that relative consumption doesn't rise very much in the periphery – true in our model given habit – a large terms of terms of trade depreciation would be required to achieve much of a rebalancing of relative aggregate demand $y_{Dt} - y^*_{Dt}$ towards the periphery in response to core fiscal expansion. Even if the terms of trade depreciated by as much as 1 percent in response to a 1 percentage point rise in core spending – several times the impact under the benchmark calibration in Figure 3, and double that in Figure 5 – the aggregate demand stimulus would accrue heavily to the core under the assumption that all core spending fell on domestic goods.

Accordingly, we next consider how allowing for a sizeable component of core spending to fall on periphery imports could facilitate rebalancing the aggregate demand stimulus more evenly across the core and periphery. In the extreme case in which the core government spending was disbursed equally across currency union members according to population size – a "no home bias" case in which $\omega^*_G = 1/3$ and $\omega_G = 2/3$ – the periphery and core would share equally in the stimulus. In a somewhat less extreme case, Figure 6 shows that effects in which the import share of core government spending ω^*_G is set to 0.20 (20 percent of government spending in the steady state). As this reallocation of spending has no consequences for CU aggregates, the effects of the core spending hike on CU output are identical to Figure 3 (in which $\omega^*_G = 0$). However, the changes in the pattern of GDP response across core and periphery are striking: the rise in periphery GDP is more than half as large as the rise in core GDP even in normal times. Thus, core spending may provide considerable stimulus to the core even in a short-lived liquidity trap if it falls substantially on periphery imports. The boost to both periphery (and core) GDP is even larger in a long-lived liquidity trap. These results underscore how direct purchases may allow core fiscal spending to have much more balanced effects on core and periphery even if terms of trade adjustment is quite sluggish (as seems likely in practice).

4. Welfare Effects of Higher Core Government Spending

The literature analyzing the effects of fiscal expansion in a liquidity trap has largely focused on environments which abstract from differences in economic conditions across countries or states. The implicit assumption is that each member of a common currency area – whether a country or state – faces an equally severe downturn, and would get a similar boost in government spending if a stimulus package were enacted. The situation facing policymakers in Europe is different in two important respects. First, resource slack in the periphery economies appears much larger than in the core – as might be expected given those economies were the focal point of the euro area debt crisis – and inflation is correspondingly more subdued. Second, assuming that fiscal stimulus would have to come mainly from the core economies, the expansionary effects on CU GDP would be likely to fall disproportionately on the core economies.

These asymmetries across member states – both in initial business cycle positions, and in the impact of fiscal policy – have important implications for gauging the appropriate scale and duration of fiscal expansion. Some policies that may help the periphery – and that may be regarded as beneficial from the perspective of reducing CU output and inflation gaps – may impose high costs on the core. In this section, we illustrate some of the considerations that would seem relevant in designing a fiscal stimulus program in this environment, which include taking account of how welfare can be impacted differently across regions.

As a starting point, we construct a plausible baseline for periphery and core output gaps and inflation rates against which we analyze the impact of a core fiscal expansion. The evolution of the baseline over the remainder of the decade is depicted by the solid lines in Figure 7.[13] The output gap in the periphery is assumed to be around -4 percent in early 2014, and to narrow slowly over the next few years as output growth rises only modestly above potential. The output gap in the core is estimated to be only around -1 percent in early 2014, and to nearly close within three years. Inflation remains well below 2 percent in both core and periphery, but runs particularly low in the periphery. In general, the baseline matters both for considering the welfare effects of fiscal expansion, and because the evolution of the CU output gap and inflation influence how rapidly the central bank adjusts policy rates in response to fiscal actions.

We next consider the effects of a persistent expansion in core spending against this baseline. Specifically, core government spending is assumed to follow an MA(10), and to rise by 2 percentage points of core baseline GDP for 10 quarters (1-1/3 percent of CU GDP) before returning to its initial level. The stimulus is "well-timed" insofar as it is expected to be implemented against the backdrop of a liquidity trap that would last 10 quarters absent any fiscal stimulus.[14]**.**Two alternatives for the composition of core government spending are considered: in one case, core spending falls exclusively on domestically-produced goods (the red dotted lines), while in the alternative 20 percent of core government spending falls on imports from the periphery (the blue dashed lines). The scenarios

[13] The baseline projections for inflation and the output gap are taken from the spring IMF World Economic Outlook, which contains annual projections for these variables for 2014-2019. We construct quarterly series for the projections using SEP for the years 2014-2015, and by splining the annual series for 2016-2019. For the ECB policy rate, we use OIS rates to compute an expected policy rate path. Appendix **??** provides further details. In our model, we use a combination of supply (technology) and demand (consumption taste) shocks to replicate the IMF outlook for output gaps and inflation rates in the periphery and the core as well as the currency union policy rate for 2014Q1-2019Q4.

[14] We assume in our simulations below that the CU central bank does not counteract the core fiscal stimulus by raising rates any earlier than in the absence of stimulus. Even so, we assume that the central bank raises policy rates more quickly upon lift-off from the effective lower bound if the state of the economy warrants (as prescribed by the Taylor rule). This limited form of commitment modestly amplifies the stimulus from the fiscal expansion.

are assumed to begin in 2014:Q1.

From an aggregate CU perspective, the expansion in core spending achieves a much more rapid narrowing of the CU output gap over the period in which the stimulus remains in effect than in the baseline. The CU output gap is about 1-1/3 percent smaller in early 2016 than in the absence of stimulus (solid black lines).[15] CU inflation is also boosted substantially, and in fact persistently overshoots its steady state value of 2 percent. To the extent that social welfare depended on the aggregate CU output and inflation gaps, an expansion in core spending clearly has scope to improve those components of welfare.

However, the narrowing of the aggregate output and inflation gaps masks considerable divergence in the effects across regions. Focusing on the case in which core spending falls exclusively on domestic goods, the stimulus achieves a modest narrowing of the periphery's output gap of a little over 1/2 percentage point over the duration of the stimulus, and also markedly narrows the periphery inflation gap. By contrast, this fiscal stimulus program pushes core output well above potential and core inflation moves temporarily above 3 percent. The overshooting of the core output and inflation gap reflects both that the baseline (pre-stimulus) core output and inflation gaps are relatively small, and that the core fiscal spending has a disproportionately large effect on core output and inflation. The effects of stimulus are more balanced across regions in the case in which 20 percent of core government purchases fall on periphery imports: the boost to periphery GDP and inflation is clearly much larger, while core output and inflation exhibit much less overshooting.

This divergence in the effects across regions is suggestive of how the desirability of any particular fiscal stimulus package is likely to hinge on whose welfare is maximized: the CU as a whole, the core, or the periphery. From the standpoint of policymakers in the core contemplating fiscal stimulus, it is reasonable to posit that their objectives would extend well beyond minimizing core output gaps

[15] CU output rises by more than 1-1/2 percent, reflecting that potential output also expands; thus, the implied spending multiplier is well above unity.

and inflation gaps: they would presumably care about how the additional public spending was valued at the margin, and the extent to which it fell on home versus foreign goods. But supposing that the loss function of core policymakers depended mainly on minimizing core output and core inflation gaps,[16] the core would likely opt for a significantly smaller fiscal expansion than would policymakers maximizing an objective function which weighted output and inflation gaps in both member states. Put in slightly different terms, the Nash solution in which the core maximizes it own welfare is likely to imply a smaller fiscal expansion that the cooperative solution that also takes account of periphery welfare directly.

This point can be illustrated by assuming that welfare can be measured using a simple quadratic objective function that for a policymaker maximizing both core and periphery welfare is of the form:

$$L_t^{CP} = \sum_{s=0} \beta^s \left\{ \zeta \left[\left(\pi_{t+s}^{Per} - \pi^* \right)^2 + \lambda_y \left(x_{t+s}^{Per} \right)^2 \right] + (1-\zeta) \left[\left(\pi_{t+s}^{Core} - \pi^* \right)^2 + \lambda_y \left(x_{t+s}^{Core} \right)^2 \right] \right\}, \quad (23)$$

Thus, the welfare loss L_t^{CP} is population-weighted average of the loss function for each region (core or periphery). Each region's loss function is simply a sum of the squared inflation gap and squared output gap, with λ_y determining the relative weight on the output gap. The welfare loss for the core alone, L_t^C is analogous, except that it puts exclusive weight on minimizing output and inflation gaps in the core. The relative weight on the output gap of λ_y is assumed to be 1/3 for both core and periphery.

The upper panel of Table 1 reports the total losses to the CU under the baseline in which there is no fiscal stimulus. This loss of 34.5 – shown in the first column – is a population weighted average of core's loss (10.8) and the periphery's loss (82.1). The losses are computed based on output and inflation gaps from 2014:Q1 to 2019:Q4. Panel B shows how the welfare losses are affected under the 2 percent of core GDP fiscal expansion examined in Figure 7, with the first

[16] This assumption would seem most reasonable to the extent that the additional stimulus was on public goods for which the marginal utility of consumption was expected to decrease very gradually with the flow of purchases (e.g., construction equipment, or other durable goods).

row showing the effects under the assumption that all core spending is on domestic goods, and the second row under the assumption that 20 percent is imported . Both the periphery and core gain through core fiscal stimulus of this magnitude. The periphery achieves a particularly large welfare gain, reflecting that there is a high marginal value to reducing the periphery's large output and inflation gaps under the quadratic objective. The core experiences a slight improvement even if all spending is on domestic goods, which mainly reflects that the stimulus helps keep core inflation on average closer to 2 percent. The improvement for both core and periphery is noticeably larger in the case in which more core spending falls on imported goods; the core's improvement reflects that there is much less overshooting of both output and inflation.

Table 1: Welfare Effects of Higher Core Spending in Figure 7

Panel A: Welfare Loss in Baseline

Total Loss L_t^{CP}	Core Loss in Baseline	Periphery Loss in Baseline
34.5	10.8	82.1

Panel B: Welfare Losses under Fiscal Expansion in Figure 7

Import content	Total Loss L_t^{CP}	Core Loss under Expansion	Periphery Loss under Expansion
$\omega_G^* = 0$	22.8	8.0	52.2
$\omega_G^* = 0.2$	19.7	5.9	47.1

While the core might benefit from the fiscal expansion considered above, it is clear from the Figure 7 that the core would likely be better off with a smaller-sized spending package (assuming it minimized its own quadratic loss function). In this vein, Table 3 reports welfare effects under a fiscal expansion with the same contour as in Figure 7 – namely, a 10 quarter fiscal expansion – but in which the scale of the expansion is chosen to maximize core welfare L_t^C. The optimal scale of the fiscal expansion turns out to be about 60 percent as large as in Figure 7 under either assumption about the composition of core purchases. Thus, even though the core is slightly better off with the larger spending package in Figure 7 than none at all (assuming that factors other than those we have assumed don't dominate the welfare calculus), the core loses at the margin relative to the smaller spending package.

Table 2: Welfare Effects under "Optimal" Spending Hike for Core

Panel A: Welfare Loss in Baseline

Total Loss L_t^{CP}	Core Loss in Baseline	Periphery Loss in Baseline
34.5	10.8	82.1

Panel B: Welfare Losses under Fiscal Expansion in Figure 7

Import content	Total Loss L_t^{CP}	Core Loss under Expansion	Periphery Loss under Expansion
$\omega_G^* = 0$	23.4	4.2	62.0
$\omega_G^* = 0.2$	22.0	3.9	58.1

Taken together, the foregoing results suggest a strong rationale for some amount of fiscal stimulus in a long-lived liquidity trap. Assuming that core output would remain below potential and inflation below 2 percent without fiscal stimulus, even the core would have reason to expand fiscal spending to the extent that its objectives were reasonably well captured by the loss function posited above. However, our results underscore how the degree of stimulus that the core would find it optimal to supply is likely to be considerably lower than the level implied by maximizing a "cooperative" welfare measure that gave explicit weight to the periphery economies. Given the modest output gap in the baseline, a faster recovery in the core would make fiscal expansion less appealing to core policymakers than in the analysis above.

While the core might benefit from the fiscal expansion considered above, it is clear from the Figure 7 that the core would likely be better off with a smaller-sized spending package (assuming it minimized its own quadratic loss function). In this vein, Table 2 reports welfare effects under a fiscal expansion with the same contour as in Figure 7 – namely, a 10 quarter fiscal expansion – but in which the scale of the expansion is chosen to maximize core welfare L_t^C. The optimal scale of the fiscal expansion turns out to be about 60 percent as large as in Figure 7 under either assumption about the composition of core purchases. Thus, even though the core is slightly better off with the larger spending package in Figure 7 than none at all (assuming that factors other than we have assumed don't dominate the welfare calculus), the core loses at the margin relative to the smaller spending package.

Taken together, the foregoing results suggest a strong rationale for some amount of fiscal stimulus in a long-lived liquidity trap. Assuming that core output would remain below potential and inflation below 2 percent without fiscal stimulus, even the core would have reason to expand fiscal spending to the extent that its objectives were reasonably well captured by the loss function posited above. However, our results underscore how the degree of stimulus that the core would find it optimal to supply is likely to be considerably lower than the level implied by maximizing a "cooperative" welfare measure that gave explicit weight to the periphery economies. Given the modest output gap in the baseline, a faster recovery in the core would make fiscal expansion less appealing to core policymakers than in the analysis above.

5. The Effects of a Core Spending Expansion in a Larger Scale Model

The benchmark model is useful for highlighting many of the key factors likely to shape how a core fiscal expansion would affect the periphery. However, the benchmark model well understate both the aggregate effects of core fiscal expansion and spillovers to the periphery due to the exclusion of Keynesian accelerator effects on household and business spending. A consequence is that the aggregate multiplier is relatively modest even in a liquidity trap unless inflation rises significantly.

Accordingly, we next reconsider the effects of a core spending expansion in a larger-scale two country model with endogenous investment that closely follows Erceg and Linde (2013). Abstracting from trade linkages, the specification of each country block builds heavily on the estimated models of Christiano, Eichenbaum and Evans (2005) and Smets and Wouters (2003, 2007). Thus, the model includes both sticky nominal wages and prices, allowing for some intrinsic persistence in both component; habit persistence in consumption; and embeds a $Q-$theory investment specification modified so that changing the level of investment (rather than the capital stock) is costly. However, our model departs from this earlier literature in two substantive ways. First, we assume that a fraction of the households are “Keynesian”, and simply consume their current after-tax income; this evidently contrasts with our benchmark model which assumes that all households make consumption decisions based on their permanent income. Galí, López-Salido and Vallés (2007) show that the inclusion of non-Ricardian households helps account for structural VAR evidence indicating that private consumption rises in response to higher government spending. Second, we incorporate a financial accelerator following the basic approach of Bernanke, Gertler and Gilchrist (1999). Although these features boost the natural real interest rate and hence tend to amplify the spending multiplier even in normal times, their effect on the aggregate multiplier is considerably larger in a liquidity trap; as we will show, these features can help account for sizeable spillovers to the periphery even if inflation doesn’t respond very much.

On the open economy dimension, the model assumes producer currency pricing as in the benchmark, but we consider the alternative of local currency pricing in the context of sensitivity analysis.[17] Moreover, in contrast to the benchmark model studied previously, financial markets are now assumed to be incomplete. But given that the trade price elasticity is calibrated to be close to unity, the impact of market incompleteness is modest (see Cole and Obstfeld, 1991, for a more detailed discussion).

A detailed description of the model and its calibration is provided in Appendix B. However, several features of the calibration are worth pointing out. First, our calibration assumes an central bank reaction function rule which responds quite aggressively to inflation (when unconstrained),

[17] Although not reported, we have verified that the difference between PCP and LCP is small in our framework given that the nominal exchange rate is fixed.

and that both wages and prices respond very sluggishly to shocks. Specifically, the monetary rule has a long-run coefficient of 2.5 on inflation, of 0.5 on the output gap, and 0.7 on the lagged interest rate. Our choice of a Calvo price contract duration parameter of $\xi_P = .92$ implies a very low Phillips Curve slope of about .005, which is below most estimates reported in the empirical literature, though within reported confidence intervals; and wages exhibit a commensurate degree of stickiness. As in the benchmark model these parameter choices are aimed at capturing the resilience of core inflation in the euro area, including in periphery countries which have experienced massive and persistent resource gaps. Second, we set the share of Keynesian households to optimizing households to a little below half, implying that the former comprise about 1/4 of aggregate consumption in the steady state, and calibrate the parameters affecting the financial accelerator as in BGG (1999). Finally, government spending in each country is assumed to be comprised of domestic and imported goods in exactly the same proportion as private spending – 10 percent for the core, and hence 20 percent for the periphery. This is in between the low and high values for ω_G we used in the benchmark model.

5.1. Higher Core Spending

Figure 8 shows the effects of a front-loaded increase in government expenditures equal to 1 percent of *core* steady state output. The government spending shock follows an AR(1) with a persistence of 0.9. The spending hike occurs against the backdrop of initial conditions consistent with a deep recession and liquidity trap expected to last eight quarters. The initial conditions are generated by a sequence of adverse supply (productivity) and demand (consumption taste) shocks.

We begin by examining the responses to the core spending expansion in a normal situation in which policy is unconstrained. CU output rises considerably on impact – the multiplier is about unity – and then dies out more quickly than the path of spending as CU policy rates increase. The stimulus to GDP is heavily concentrated in the core. Periphery real net exports benefit from a real exchange rate depreciation – reflecting that higher core government spending puts upward pressure on the relative price of core goods – and due to some direct purchases of goods/services from the core government. However, periphery GDP still contracts noticeably as this stimulus to net exports is swamped by a fall in domestic demand that is driven by the higher policy rates. After a year, output in the periphery falls about -0.1 percent below baseline.

By contrast, the stimulus to the periphery is substantially positive even in a liquidity trap lasting about 8 quarters. As in the simpler model, short-term real interest rates fall enough to crowd in private domestic demand, which in this model includes investment. This crowding in, albeit modest in an 8 quarter trap, helps to amplify the stimulus to the periphery arising from the net export channel. All told, periphery rises about 0.3 percent after a year, about a third as much as the expansion in core output. In interepreting these effects, it is important to recall that the government spending shock dies out; thus, the implied multiplier for the CU – seen in the bottom right panel – is well above unity, even though CU output rises only a little over 0.6 percent after a year.

In Figure 9, we contrast a longer-lived trap (12 quarters) vs. the 8-quarter trap shown in Figure 8. As can be seen by comparing the results, we find that.periphery output would expand around 0.4 percent after four quarters, half as much as the expansion in core output. Thus, core fiscal stimulus can have very substantial spillovers to the periphery in a prolonged liquidity trap.

6. Conclusions

[**Remains to be written.**]

References

Adolfson, Malin, Stefan Laséen, Jesper Lindé and Mattias Villani (2005). "The Role of Sticky Prices in an Open Economy DSGE Model: A Bayesian Investigation." *Journal of the European Economic Association Papers and Proceedings,* 3(2-3), 444-457.

Altig, David, Lawrence J. Christiano, Martin Eichenbaum, and Jesper Lindé (2011). "Firm-Specific Capital, Nominal Rigidities and the Business Cycle." *Review of Economic Dynamics,* 14(2), 225-247.

Bernanke, Ben, Gertler, Mark and Simon Gilchrist (1999). "The Financial Accelerator in a Quantitative Business Cycle Framework." In *Handbook of Macroeconomics*, edited by John B. Taylor and Michael Woodford, North-Holland Elsevier Science.

Blanchard, Olivier and Roberto Perotti (2002). "An Empirical Characterization of The Dynamic Effects of Changes in Government Spending and Taxes on Output." *The Quarterly Journal of Economics*, 117(4), 1329-1368.

Christiano, Lawrence J., Martin Eichenbaum, and Charles Evans (2005). "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy." *Journal of Political Economy*, 113(1), 1-45.

Christiano, Lawrence J., Martin Eichenbaum, and Sergio Rebelo (2011). "When is the Government Spending Multiplier Large?" *Journal of Political Economy*, 119(1), 78-121.

Christiano, Lawrence J., Martin Eichenbaum, and Mathias Trabandt (2013). "Understanding the Great Recession." Manuscript, Federal Reserve Board.

Clarida, Richard, Jordi Galí and Mark Gertler (2001), "Optimal Monetary Policy in Open Versus Closed Economics: An Integrated Approach", *American Economic Review Papers and*

Proceedings 91, 248-252.

Coenen, Günter, Christopher J. Erceg, Charles Freedman, Davide Furceri, Michael Kumhof, René Lalonde, Douglas Laxton, Jesper Lindé, Annabelle Mourougane, Dirk Muir, Susanna Mursula, Carlos de Resende, John Roberts, Werner Roeger, Stephen Snudden, Mathias Trabandt, and Jan in't Veld (2012). "Effects of Fiscal Stimulus in Structural Models." *American Economic Journal: Macroeconomics*, 4(1), 22–68.

Cogan, John F., Tobias Cwik, John B. Taylor, and Volker Wieland (2010). "New Keynesian versus Old Keynesian Government Spending Multipliers." *Journal of Economic Dynamics and Control*, 34, 281-295.

Cook, David and Michael B. Devereux (2011). "Optimal Fiscal Policy in a World Liquidity Trap." *European Economic Review*, 55(2), 443-462.

Eggertsson, Gauti and Michael Woodford (2003). "The Zero Interest-Rate Bound and Optimal Monetary Policy." *Brookings Papers on Economic Activity*, 1, 139-211.

Eggertsson, Gauti (2008). "Great Expectations and the End of the Depression." *American Economic Review*, 98(4), 1476-1516.

Erceg, Christopher, Luca Guerrieri, and Christopher Gust (2006). "SIGMA: A New Open Economy Model for Policy Analysis." *Journal of International Central Banking*, 2(1), 1-50.

Erceg, Christopher and Jesper Lindé (2013). "Fiscal Consolidation in a Currency Union: Spending Cuts vs. Tax Hikes", *Journal of Economic Dynamics and Control* 37, 422-445.

Fujiwari, Ippei and Kozo Ueda (2013) "The Fiscal Multiplier and Spillover in a Global Liquidity Trap." *Journal of Economic Dynamics and Control*, 37, 1264-1283.

Fahri, Emmanuel and Ivan Werning (2012) "Fiscal Multipliers: Liquidity Traps and Currency Unions." Manuscript, Harvard University.

Galí, Jordi, David López-Salido, and Javier Vallés (2007). "Understanding the Effects of Government Spending on Consumption." *Journal of the European Economic Association*, 5(1), 227-270.

Galí, Jordi and Tommaso Monacelli (2008), "Optimal Monetary and Fiscal Policy in a Currency Union," *Journal of International Economics* 76, 116–132.

Jung, Taehun, Yuki Teranishi, and Tsotumu Watanabe (2005). "Optimal Monetary Policy at the Zero-Interest-Rate Bound." *Journal of Money, Credit, and Banking*, 37(5), 813-835.

Lindé, Jesper (2005). "Estimating New Keynesian Phillips Curves: A Full Information Maximum Likelihood Approach." *Journal of Monetary Economics*, 52(6), 1135-1149.

Perotti, Roberto (2007). "In Search of the Transmission Mechanism of Fiscal Policy." *NBER Macroeconomics Annual*, 22, 169-226.

Ramey, Valerie A. (2011). "Identifying Government Spending Shocks: It's All in the Timing." *Quarterly Journal Of Economics*, 126(1), 1-50.

Smets, Frank and Raf Wouters (2003). "An Estimated Stochastic Dynamic General Equilibrium Model of the Euro Area." *Journal of the European Economic Association*, 1(5), 1123-1175.

Smets, Frank and Raf Wouters (2007). "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach." *American Economic Review*, 97(3), 586-606.

Uhlig, Harald (2010). "Some Fiscal Calculus." *American Economic Review Papers and Proceedings*, 100(2), 30-34.

Woodford, Michael (2003). *Interest and Prices.* Princeton University Press.

Woodford, Michael (2011). "Simple Analytics of the Government Expenditure Multiplier." *American Economic Journal: Macroeconomics.* 3(1), 1-35.

Appendix A. The Benchmark Model

This Appendix provides a detailed description of the benchmark model from which the log-linearized equations in Section 2 are derived.

A.1. Households

The utility functional of household h in the home economy is given by:

$$\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \varsigma_{t+j} \left\{ \begin{array}{c} \frac{1}{1-\frac{1}{\sigma}} \left(C_{t+j}(h) - \varkappa C_{t+j-1} - C\nu_{t+j} \right)^{1-\frac{1}{\sigma}} - \chi_0 \frac{(N_{t+j}(h))^{1+\chi}}{1+\chi} + \frac{\vartheta_g}{1-\frac{1}{\sigma}} G_{t+j}^{1-\frac{1}{\sigma}} \\ +\mu_0 F\left(\frac{MB_{t+j+1}(h)}{P_{Ct+j}} \right) \end{array} \right\} \tag{A.1}$$

The preference specification in equation (A.1) implies that household h derives utility from private consumption $C_t(h)$, government spending $G_t(h)$,and real balances $\frac{MB_t(h)}{P_{Ct}}$, whereas utility declines in hours worked $N_t(h)$. The utility function is assumed to be separable in each of these arguments. The subutility function over consumption incorporates external habit persistence – captured by the presence of lagged aggregate consumption C_{t-1} – with the degree of habit determined by the parameter $\varkappa \in (0,1)$. There are two types of preference shocks, including a consumption taste (demand) shock ν_t, and a discount factor shock ς_t. The latter type of shock has been widely used in the ZLB literature (see e.g, Eggertsson, 2010, and Christiano, Eichenbaum and Rebelo, 2011) as a driving force of the "Great Recession." Following Eggertsson and Woodford (2003), the subutility function over real balances, $F\left(\frac{MB_{t+j+1}(h)}{P_{t+j}}\right)$, is assumed to have a satiation point for $\overline{MB}/P$. Hence, inclusion of money - which is a zero nominal interest asset - provides a rationale for the zero lower bound on nominal interest rates. However, we maintain the assumptions that money is additive and that μ_0 is arbitrarily small so that changes in real money balances have negligible implications for government debt and output. Finally, we assume that $0 < \beta < 1$, $\sigma > 0$, $\chi > 0$, $\chi_0 > 0$ and $\vartheta_g > 0$.

Household h faces a flow budget constraint in period t which states that combined expenditure on goods and on the net accumulation of financial assets must equal its disposable income:

$$P_{Ct}\left(1+\tau_{Ct}\right)C_t\left(h\right)+\int_s \xi_{t,t+1}B_{t+1}(h)-B_t(h)+B_{G,t}(h) = \left(1-\tau_{N,t}\right)W_t(h)N_t\left(h\right)-T_t + R_{Kt}K+\left(1+i_{t-1}^{CU}\right)B_{G,t-1}(h)+\Gamma_t(h). \tag{A.2}$$

In (A.2), all variables have been expressed in per capita terms. A household may either spend its income either on consumption goods, which are subject to a sales tax of τ_{Ct}, or can save by investing in either government bonds $B_{G,t}(h)$ or contingent claims. The term $\xi_{t,t+1}$ denotes the price of an asset that will pay one unit of domestic currency in a particular state of nature at date $t+1$, and $B_{t+1}(h)$ the quantity of claims purchased. Each household earns per capita labor income net of taxes $\left(1-\tau_{N,t}\right)W_t(h)N_t\left(h\right)$, earns rental income of $R_{Kt}K$ on its fixed stock of capital K, receives an aliquot share $\Gamma_t\left(h\right)$ of the firm profits, and pays lump sum taxes of T_t to the government.

Each household h maximizes the utility functional (A.1) with respect to its consumption, hours worked, government bonds, and holdings of contingent claims subject to its budget constraint (A.2), taking bond prices, the wage, the rental price of capital (R_{Kt}), and the price of the consumption bundle (P_{Ct}) as given. The first order condition(s) for contingent claims both at home and abroad implies the complete markets condition that the marginal utility of a "euro" is equalized across home and foreign households:

$$\lambda_t = \lambda_t^*,$$

Because the marginal utility of consumption equals $\Lambda_{Ct} = \lambda_t P_{Ct}$ (and analogously for foreign households), the complete markets condition may be written in the familiar form:

$$\Lambda_{Ct}^* = \Lambda_{Ct}\frac{P_{Ct}^*}{P_{Ct}} = \Lambda_{Ct}Q_{Ct}. \tag{A.3}$$

Thus, a depreciation of the home economy's consumption-based real exchange rate (Q_{Ct} rises) boosts the marginal utility of foreign consumption relative to the marginal utility of home consumption.

The first order conditions with respect to C_t, N_t , and $B_{G,t}$ are given by:

$$
\begin{aligned}
\Lambda_{Ct} &= \frac{\left(C_t - \varkappa C_{t-1} - C\nu_t\right)^{-\frac{1}{\sigma}}}{\left(1+\tau_{C,t}\right)}, \\
mrs_t &= \frac{\chi_0 N_t^{\chi}}{\Lambda_{Ct}} = \left(1-\tau_{N,t}\right)\frac{W_t}{P_{Ct}}, \\
\Lambda_{Ct} &= \beta \mathrm{E}_t \delta_t \frac{\left(1+i_t^{CU}\right) P_{Ct}}{P_{Ct+1}} \Lambda_{Ct+1}.
\end{aligned} \tag{A.4}
$$

The first of these conditions indicates that the marginal utility of consumption decreases in current consumption, but decreases in past consumption due to habit. The second equation is the labor supply curve, which relates the household's marginal cost of working – expressed in terms of the consumption good, i.e., $mrs_t = \frac{\chi_0 N_t^{\chi}}{\Lambda_{Ct}}$ – to the after-tax consumption real wage. The final expression is the consumption Euler equation, where $\delta_t = \frac{\varsigma_{t+1}}{\varsigma_t}$ is simply a rescaling of the time preference shock.

The problem for the foreign households h^* is isomorphic to the problem outlined above for the domestic households.

A.2. Firms and Price-Setting

Below, we describe the problem for the home producers of both final and intermediate goods.

A.2.1. Production of Final Goods

We assume that a single final domestic output good Y_{Dt} is produced using a continuum of differentiated intermediate goods $Y_{Dt}(f)$. The technology for transforming these intermediate goods into the final output good is constant returns to scale, and is of the Dixit-Stiglitz form:

$$Y_{Dt} = \left[\int_0^1 Y_{Dt}(f)^{\frac{1}{1+\theta_p}} df \right]^{1+\theta_p}, \tag{A.5}$$

where $\theta_p > 0$.

Firms that produce the final output good are perfectly competitive in both product and factor markets. Thus, final goods producers minimize the cost of producing a given quantity of the output index, Y_{Dt}, taking as given the price $P_{Dt}(f)$ of each intermediate good $Y_{Dt}(f)$. Moreover, final goods producers sell units of the final output good at a price P_{Dt} that can be interpreted as the aggregate domestic price index:

$$P_{Dt} = \left[\int_0^1 P_{Dt}(f)^{\frac{-1}{\theta_p}} df \right]^{-\theta_p}. \tag{A.6}$$

A.2.2. Production of Domestic Intermediate Goods

Intermediate good i is produced by a monopolistically competitive firm, whose output $Y_{Dt}(i)$ is produced according to a Cobb-Douglas production function:

$$Y_{Dt}(i) = K(i)^{\alpha}(Z_t L_t(i))^{1-\alpha}, \tag{A.7}$$

where Z_t denotes a stationary, country-specific shock to the level of technology. Intermediate goods producers face perfectly competitive factor markets for hiring capital and labor. Thus, each firm chooses $K(i)$ and $L_t(i)$, taking as given both the rental price of capital R_{Kt} and the aggregate wage rate W_t. Within a country, labor and the capital stock (albeit fixed in the aggregate) are completely mobile; thus, the standard static first-order conditions for cost minimization imply that all intermediate firms have identical marginal cost per unit of output:

$$MC_t = \left(\frac{W_t}{1-\alpha} \right)^{1-\alpha} \left(\frac{R_{Kt}}{\alpha} \right)^{\alpha} \frac{1}{Z_t^{1-\alpha}}, \tag{A.8}$$

where the standard static cost minimization problem of the firm implies that

$$R_{Kt} = \frac{\alpha}{1-\alpha} W_t \frac{L_t}{K}. \tag{A.9}$$

Intermediate goods-producing firms set prices according to Calvo-style staggered contracts, and set the same price in both the home and foreign market (i.e., the home market price $P_{Dt}(i)$ equals the price in the foreign market of $P^*_{Mt}(i)$). In particular, firm i faces a constant probability, $1-\xi_p$, of being able to re-optimize its price, $P_{Dt}(i)$. Firms which are not allowed to reoptimize their prices in period t (which is the case with probability ξ_p), update their prices according to the following formula

$$\tilde{P}_{Dt}(i) = (1+\pi_D) P_{Dt-1}(i), \tag{A.10}$$

where π_D is the steady-state (net) inflation rate and $\tilde{P}_{Dt}$ is the updated price.

Given Calvo-style pricing frictions, firm i that is allowed to reoptimize its price ($P^{opt}_{Dt}(i)$) solves the following problem

$$\max_{P^{opt}_{Dt}(i)} \mathrm{E}_t \sum_{j=0}^{\infty} \xi_p^j \psi_{t,t+j} \left[(1+\pi_D)^j P^{opt}_{Dt}(i) - MC_{t+j} \right] Y_{Dt+j}(i),$$

where $\psi_{t,t+j}$ is the stochastic discount factor (the conditional value of future profits in utility units, i.e. $\beta^j \mathrm{E}_t \varsigma_{t+j} \frac{\lambda_{t+j}}{\lambda_t}$, recalling that the household is the owner of the firms), θ_p the net markup and the demand function for firm i has the following general form $Y_{Dt+j}(i) = \left[\frac{P^{opt}_{Dt}(i)}{P_{Dt}}\right]^{\frac{-(1+\theta_p)}{\theta_p}} Y_{Dt}$. The first-order condition is given by:

$$\mathrm{E}_t \sum_{j=0}^{\infty} \xi_p^j \psi_{t,t+j} \left[\frac{(1+\pi_D)^j P^{opt}_{Dt}(i)}{1+\theta_p} - MC_{t+j} \right] Y_{Dt+j}(i) = 0. \tag{A.11}$$

Given that all firms which can re-optimize set the same price, the price index for domestically-produced goods evolves according to:

$$P_{Dt} = \left[(1-\xi_p) \left(P^{opt}_{Dt} \right)^{\frac{-1}{\theta_p}} + \xi_p \left((1+\pi) P_{Dt-1} \right)^{\frac{-1}{\theta_p}} \right]^{-\theta_p}. \tag{A.12}$$

The productive structure of the foreign economy is isomorphic. Thus, the final good is comprised of a bundle of intermediate goods according to the production function $Y^*_{Dt} = \left[\int_0^1 Y^*_{Dt}(f)^{\frac{1}{1+\theta_p}} df\right]^{1+\theta_p}$, and the price of this final good is output of the of final goods is denoted by $P^*_{Dt} = \left[\int_0^1 P^*_{Dt}(f)^{\frac{-1}{\theta_p}} df\right]^{-\theta_p}$.

A.3. Traded Goods

Household consumption C_t in the home economy depends both on its consumption of the domestically-produced final output good C_{Dt} and on its consumption of the foreign final output good M_{Ct} (i.e., consumer goods imports) according to the CES utility function:

$$C_t = \left((1-\omega_C)^{\frac{\rho_C}{1+\rho_C}} C_{Dt}^{\frac{1}{1+\rho_C}} + \omega_C^{\frac{\rho_C}{1+\rho_C}} M_{Ct}^{\frac{1}{1+\rho_C}}\right)^{1+\rho_C}. \tag{A.13}$$

The quasi-share parameter ω_C in equation (A.13) may be interpreted as determining household preferences for home relative to foreign goods, or equivalently, the degree of home bias in household consumption expenditure. The domestically-produced final good is purchased at a price of P_{Dt}, while the foreign imported good is purchased at a price of P_{Mt}; given the fixed exchange rate and our assumption of producer currency pricing, the law of one price holds, so that $P_{Mt} = P^*_{Dt}$. Households choose C_{Dt} and M_{Ct} to minimize the cost of producing the consumption good C_t taking the prices P_{Dt} and P_{Mt} as given. This familiar cost-minimization problem implies the following demand schedules for the imported and domestically-produced good:

$$M_{Ct} = \omega_C \left(\frac{P_{Mt}}{P_{Ct}}\right)^{\frac{-(1+\rho_C)}{\rho_C}} C_t \quad \text{and} \quad C_{Dt} = (1-\omega_C)\left(\frac{P_{Dt}}{P_{Ct}}\right)^{\frac{-(1+\rho_C)}{\rho_C}} C_t, \tag{A.14}$$

while the consumer price index P_{Ct}, is given by:

$$P_{Ct} = \left((1-\omega_C) P_{Dt}^{\frac{1}{1+\rho_C}} + \omega_C P_{Mt}^{\frac{1}{1+\rho_C}}\right)^{1+\rho_C}. \tag{A.15}$$

Similarly to households, the home government also produces final government goods (and services) G_t using both the domestically-produced final good G_{Dt} and imports of the foreign final good M_{Gt} according to the CES production function:

$$G_t = \left((1-\omega_G)^{\frac{\rho_G}{1+\rho_G}} G_{Dt}^{\frac{1}{1+\rho_G}} + \omega_G^{\frac{\rho_G}{1+\rho_G}} M_{Gt}^{\frac{1}{1+\rho_G}} \right)^{1+\rho_G}. \tag{A.16}$$

The parameter ω_G measures the import share of government consumption; thus, total home imports depend both on the demand of households, and of the government. The government's demand schedules for both the domestically-produced final good and for imported goods are isomorphic to that of households:

$$M_{Gt} = \omega_G \left(\frac{P_{Mt}}{P_{Gt}} \right)^{\frac{-(1+\rho_G)}{\rho_G}} G_t \quad \text{and} \quad G_{Dt} = (1-\omega_G) \left(\frac{P_{Dt}}{P_{Gt}} \right)^{\frac{-(1+\rho_G)}{\rho_G}} G_t, \tag{A.17}$$

although it is important to note that the degree of home bias in government spending ω_G may differ from that in private spending ω_C, and that the government's willingness to substitute between home and traded goods ($\frac{-(1+\rho_G)}{\rho_G}$) may also differ from that of households ($\frac{-(1+\rho_C)}{\rho_C}$). The price index for government purchases is given by:

$$P_{Gt} = \left((1-\omega_G) P_{Dt}^{\frac{1}{1+\rho_G}} + \omega_G P_{Mt}^{\frac{1}{1+\rho_G}} \right)^{1+\rho_G}. \tag{A.18}$$

We define the terms-of-trade as

$$\tau_t = \frac{P_{Mt}}{P_{Dt}} = \frac{P_{Dt}^*}{P_{Dt}}, \tag{A.19}$$

so that an increase in τ_t implies that the home economy can buy less imports for any given level of exports.

A.4. Fiscal Policy

The government finances its nominal spending on goods and services $P_{Gt}G_t$ through a consumption sales tax, labor tax, and lump-sum tax (we assume that seignorage revenue is de minimis). Thus, evolution of nominal government debt, $B_{G,t}$, is determined by:

$$B_{G,t} = (1 + i_{t-1}) B_{G,t-1} + P_{Gt}G_t - \tau_{C,t}P_{Ct}C_t - \tau_{N,t}W_tL_t - T_t. \tag{A.20}$$

We assume that the consumption sales tax $\tau_{C,t}$ and labor tax $\tau_{N,t}$ are determined exogenously, so that lump-sum taxes adjust to satisfy the government's intertemporal budget constraint. Thus, the fiscal rule has no effect on macro variables (other than the stock of debt and the lump-sum tax level itself).

A.5. Aggregate Resource Constraints

The aggregate resource constraint for the domestic economy is given by

$$Y_{Dt} = C_{Dt} + G_{Dt} + \frac{\zeta^*}{\zeta} \left[M^*_{Ct} + M^*_{Gt} \right], \tag{A.21}$$

where exports are weighted by the relative population size of the foreign to home country $\frac{\zeta^*}{\zeta}$ as the variables are expressed in per capita terms. Similarly, the resource constraint for the foriegn economy is given by

$$Y^*_{Dt} = C^*_{Dt} + G^*_{Dt} + \frac{\zeta}{\zeta^*} \left[M_{Ct} + M_{Gt} \right]. \tag{A.22}$$

where exports are weighted by the relative population size of the home to foreign country $\frac{\zeta}{\zeta^*}$. The total population is normalized to unity, i.e.,

$$\zeta + \zeta^* = 1. \tag{A.23}$$

We also make the assumption that trade is balanced for both private consumption and government services, which implies that:

$$\zeta \omega_C = \zeta^* \omega^*_C, \tag{A.24}$$

and

$$\zeta \omega_G = \zeta^* \omega^*_G. \tag{A.25}$$

Given complete financial markets, the current account and net foreign assets are always equal to zero. The nominal trade balance (in absolute levels) is given by

$$TB_t \equiv \frac{\zeta^*}{\zeta} P_{Dt} \left[M^*_{Ct} + M^*_{Gt} \right] - P_{Mt} \left[M_{Ct} + M_{Gt} \right]. \tag{A.26}$$

A.6. Monetary Policy

The currency union central bank is assumed to adhere to a Taylor-type policy rule subject to the ZLB. Given that we start out with a log-linearized version of the model, it is convenient to simply specify the reaction function as a linear relation (aside from the zero lower bound), expressing variables in deviation from baseline form:

$$i_t^{CU} = \max\left(-i, \psi_\pi \pi_t^{CU} + \psi_x x_t^{CU}\right), \tag{A.27}$$

Here i denotes the steady-state (net) nominal interest rate (equal to $r + \pi$ where $r \equiv 1/\beta - 1$), π_t^{CU} is currency union inflation, and x_t^{CU} is the currency union output gap. Currency union inflation π_t^{CU} is itself a population-weighted average of the inflation rate π_{Ct} in both the home and foreign country:

$$\pi_t^{CU} = \zeta \pi_{Ct} + \zeta^* \pi^*_{Ct}. \tag{A.28}$$

where each country inflation rate is simply the log percentage change in the respective consumption price index (i.e., $\pi_{Ct} = \ln(P_{Ct}/P_{Ct-1})$). The CU output gap x_t^{CU} is the difference between currency union output y_t^{CU} and its potential level $y_t^{CU,pot}$, with both variables again simply population-weighted averages of the respective country variables:

$$y_t^{CU} = \zeta y_{Dt} + \zeta^* y^*_{Dt}, \tag{A.29}$$

and:

$$y_t^{CU,pot} = \zeta y_{Dt}^{pot} + \zeta^* y_{Dt}^{*,pot}. \tag{A.30}$$

Appendix B. The Large-Scale Open Economy Model

This model is adapted from Erceg and Lindé (2013) aside from some features of the fiscal policy specification. Our model consists of two countries (or country blocks) that differ in size, but are otherwise isomorphic. The first country is the home economy, or "South", while the second country is referred to as the "North." The countries share a common currency, and monetary policy is conducted by a single central bank. During "normal" times when the zero bound constraint on policy rates is not binding, the central bank adjusts policy rates in response to the aggregate inflation rate and output gap of the currency union. By contrast, fiscal policy may differ across the two blocks. Given the isomorphic structure, our exposition below largely focuses on the structure of the South.

As the recent recession has provided strong evidence in favor of the importance of financial frictions, our model also features a financial accelerator channel which closely parallels earlier work by Bernanke, Gertler, and Gilchrist (1999) and Christiano, Motto, and Rostagno (2008). Given that the mechanics underlying this particular financial accelerator mechanism are well-understood, we simplify our exposition by focusing on a special case of our model which abstracts from a financial accelerator. We conclude our model description with a brief description of how the model is modified to include the financial accelerator (Section B.6).

B.1. Firms and Price Setting

B.1.1. Production of Domestic Intermediate Goods

There is a continuum of differentiated intermediate goods (indexed by $i \in [0,1]$) in the South, each of which is produced by a single monopolistically competitive firm. In the domestic market, firm i faces a demand function that varies inversely with its output price $P_{Dt}(i)$ and directly with aggregate demand at home Y_{Dt}:

$$Y_{Dt}(i) = \left[\frac{P_{Dt}(i)}{P_{Dt}}\right]^{\frac{-(1+\theta_p)}{\theta_p}} Y_{Dt}, \tag{B.31}$$

where $\theta_p > 0$, and P_{Dt} is an aggregate price index defined below. Similarly, firm i faces the following export demand function:

$$X_t(i) = \left[\frac{P^*_{Mt}(i)}{P^*_{Mt}}\right]^{\frac{-(1+\theta_p)}{\theta_p}} M^*_t, \tag{B.32}$$

where $X_t(i)$ denotes the quantity demanded of domestic good i in the North block, $P^*_{Mt}(i)$ denotes the price that firm i sets in the North market, P^*_{Mt} is the import price index in the North, and M^*_t is an aggregate of the North's imports (we use an asterisk to denote the North's variables).

Each producer utilizes capital services $K_t\,(i)$ and a labor index $L_t\,(i)$ (defined below) to produce its respective output good. The production function is assumed to have a constant-elasticity of substitution (CES) form:

$$Y_t\,(i) = \left(\omega_K^{\frac{\rho}{1+\rho}} K_t(i)^{\frac{1}{1+\rho}} + \omega_L{}^{\frac{\rho}{1+\rho}} (Z_t L_t(i))^{\frac{1}{1+\rho}}\right)^{1+\rho}. \tag{B.33}$$

The production function exhibits constant-returns-to-scale in both inputs, and Z_t is a country-specific shock to the level of technology. Firms face perfectly competitive factor markets for hiring capital and labor. Thus, each firm chooses $K_t\,(i)$ and $L_t\,(i)$, taking as given both the rental price of capital R_{Kt} and the aggregate wage index W_t (defined below). Firms can costlessly adjust either factor of production, which implies that each firm has an identical marginal cost per unit of output, MC_t. The (log-linearized) technology shock is assumed to follow an AR(1) process:

$$z_t = \rho_z z_{t-1} + \varepsilon_{z,t}. \tag{B.34}$$

We assume that purchasing power parity holds, so that each intermediate goods producer sets the same price $P_{Dt}(i)$ in both blocks of the currency union, implying that $P^*_{Mt}(i) = P_{Dt}(i)$ and that $P^*_{Mt} = P_{Dt}$. The prices of the intermediate goods are determined by Calvo-style staggered contracts (see Calvo, 1983). In each period, a firm faces a constant probability, $1-\xi_p$, of being able to reoptimize its price ($P_{Dt}(i)$). This probability of receiving a signal to reoptimize is independent across firms and time. If a firm is not allowed to optimize its prices, we follow Christiano, Eichenbaum and Evans (2005) and Smets and Wouters (2003), and assume that the firm must reset its home price as a weighted combination of the lagged and steady state rate of inflation $P_{Dt}(i)=\pi_{t-1}^{\iota_p}\pi^{1-\iota_p}P_{Dt-1}(i)$ for the non-optimizing firms. This formulation allows for structural persistence in price-seeting if ι_p exceeds zero.

When a firm i is allowed to reoptimize its price in period t, the firm maximizes:

$$\max_{P_{Dt}(i)} \mathbb{E}_t \sum_{j=0}^{\infty} \psi_{t,t+j} \xi_p^j \left[\prod_{h=1}^{j} \pi_{t+h-1} (P_{Dt}(i) - MC_{t+j})(Y_{Dt+j}(i) + X_t(i)) \right]. \tag{B.35}$$

The operator $\mathbb{E}_t$ represents the conditional expectation based on the information available to agents at period t. The firm discounts profits received at date $t+j$ by the state-contingent discount factor $\psi_{t,t+j}$; for notational simplicity, we have suppressed all of the state indices.[B.1] The first-order condition for setting the contract price of good i is:

$$\mathbb{E}_t \sum_{j=0}^{\infty} \psi_{t,t+j} \xi_p^j \left(\frac{\prod_{h=1}^{j} \pi_{t+h-1}(i) P_{Dt}(i)}{(1+\theta_p)} - MC_{t+j} \right) (Y_{Dt+j}(i) + X_t(i)) = 0. \tag{B.36}$$

B.1.2. Production of the Domestic Output Index

Because households have identical Dixit-Stiglitz preferences, it is convenient to assume that a representative aggregator combines the differentiated intermediate products into a composite home-produced good Y_{Dt}:

$$Y_{Dt} = \left[\int_0^1 Y_{Dt}(i)^{\frac{1}{1+\theta_p}} di \right]^{1+\theta_p}. \tag{B.37}$$

[B.1] We define $\xi_{t,t+j}$ to be the price in period t of a claim that pays one dollar if the specified state occurs in period $t+j$ (see the household problem below); then the corresponding element of $\psi_{t,t+j}$ equals $\xi_{t,t+j}$ divided by the probability that the specified state will occur.

The aggregator chooses the bundle of goods that minimizes the cost of producing Y_{Dt}, taking the price $P_{Dt}(i)$ of each intermediate good $Y_{Dt}(i)$ as given. The aggregator sells units of each sectoral output index at its unit cost P_{Dt}:

$$P_{Dt} = \left[\int_0^1 P_{Dt}(i)^{\frac{-1}{\theta_p}} di \right]^{-\theta_p} . \tag{B.38}$$

We also assume a representative aggregator in the North who combines the differentiated South products $X_t(i)$ into a single index for foreign imports:

$$M_t^* = \left[\int_0^1 X_t(i)^{\frac{1}{1+\theta_p}} di \right]^{1+\theta_p} , \tag{B.39}$$

and sells M_t^* at price P_{Dt}.

B.1.3. Production of Consumption and Investment Goods

Final consumption goods are produced by a representative consumption goods distributor. This firm combines purchases of domestically-produced goods with imported goods to produce a final consumption good (C_{At}) according to a constant-returns-to-scale CES production function:

$$C_{At} = \left(\omega_C^{\frac{\rho_C}{1+\rho_C}} C_{Dt}^{\frac{1}{1+\rho_C}} + (1-\omega_C)^{\frac{\rho_C}{1+\rho_C}} (\varphi_{Ct} M_{Ct})^{\frac{1}{1+\rho_C}} \right)^{1+\rho_C} , \tag{B.40}$$

where C_{Dt} denotes the consumption good distributor's demand for the index of domestically-produced goods, M_{Ct} denotes the distributor's demand for the index of foreign-produced goods, and φ_{Ct} reflects costs of adjusting consumption imports. The final consumption good is used by both households and by the government. The form of the production function mirrors the preferences of households and the government sector over consumption of domestically-produced goods and imports. Accordingly, the quasi-share parameter ω_C may be interpreted as determining the preferences of both the private and public sector for domestic relative to foreign consumption goods, or equivalently, the degree of home bias in consumption expenditure. Finally, the adjustment cost term φ_{Ct} is assumed to take the quadratic form:

$$\varphi_{Ct} = \left[1 - \frac{\varphi_{M_C}}{2}\left(\frac{\frac{M_{Ct}}{C_{Dt}}}{\frac{M_{Ct-1}}{C_{Dt-1}}} - 1\right)^2\right]. \tag{B.41}$$

This specification implies that it is costly to change the proportion of domestic and foreign goods in the aggregate consumption bundle, even though the level of imports may jump costlessly in response to changes in overall consumption demand.

Given the presence of adjustment costs, the representative consumption goods distributor chooses (a contingency plan for) C_{Dt} and M_{Ct} to minimize its discounted expected costs of producing the aggregate consumption good:

$$\min_{C_{Dt+k}, M_{Ct+k}} \mathbb{E}_t \sum_{k=0}^{\infty} \psi_{t,t+k} \Bigg\{ (P_{Dt+k} C_{Dt+k} + P_{Mt+k} M_{Ct+k}) \tag{B.42}$$

$$+ P_{Ct+k}\left[C_{A,t+k} - \left(\omega_C^{\frac{\rho_C}{1+\rho_C}} C_{Dt+k}^{\frac{1}{1+\rho_C}} + (1-\omega_C)^{\frac{\rho_C}{1+\rho_C}} (\varphi_{Ct+k} M_{Ct+k})^{\frac{1}{1+\rho_C}}\right)^{1+\rho_C}\right]\Bigg\}.$$

The distributor sells the final consumption good to households and the government at a price P_{Ct}, which may be interpreted as the consumption price index (or equivalently, as the shadow cost of producing an additional unit of the consumption good).

We model the production of final investment goods in an analogous manner, although we allow the weight ω_I in the investment index to differ from that of the weight ω_C in the consumption goods index.[B.2]

B.2. Households and Wage Setting

We assume a continuum of monopolistically competitive households (indexed on the unit interval), each of which supplies a differentiated labor service to the intermediate goods-producing sector (the only producers demanding labor services in our framework) following Erceg, Henderson and

[B.2] Notice that the final investment good is not used by the government.

Levin (2000). A representative labor aggregator (or "employment agency") combines households' labor hours in the same proportions as firms would choose. Thus, the aggregator's demand for each household's labor is equal to the sum of firms' demands. The aggregate labor index L_t has the Dixit-Stiglitz form:

$$L_t = \left[\int_0^1 \left(\zeta N_t \left(h \right) \right)^{\frac{1}{1+\theta_w}} dh \right]^{1+\theta_w}, \tag{B.43}$$

where $\theta_w > 0$ and $N_t(h)$ is hours worked by a typical member of household h. The parameter ζ is the size of a household of type h, and effectively determines the size of the population in the South. The aggregator minimizes the cost of producing a given amount of the aggregate labor index, taking each household's wage rate $W_t\left(h\right)$ as given, and then sells units of the labor index to the production sector at their unit cost W_t:

$$W_t = \left[\int_0^1 W_t \left(h \right)^{\frac{-1}{\theta_w}} dh \right]^{-\theta_w}. \tag{B.44}$$

The aggregator's demand for the labor services of a typical member of household h is given by

$$N_t \left(h \right) = \left[\frac{W_t \left(h \right)}{W_t} \right]^{-\frac{1+\theta_w}{\theta_w}} L_t / \zeta. \tag{B.45}$$

We assume that there are two types of households: households that make intertemporal consumption, labor supply, and capital accumulation decisions in a forward-looking manner by maximizing utility subject to an intertemporal budget constraint (FL households, for "forward-looking"); and the remainder that simply consume their after-tax disposable income (HM households, for "hand-to-mouth" households). The latter type receive no capital rental income or profits, and choose to set their wage to be the average wage of optimizing households. We denote the share of FL households by $1\text{-}\varsigma$ and the share of HM households by ς.

We consider first the problem faced by FL households. The utility functional for an optimizing representative member of household h is

$$\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \left\{ \frac{1}{1-\sigma} \left(C_{t+j}^O(h) - \varkappa C_{t+j-1}^O - \nu_{ct} \right)^{1-\sigma} + \frac{\chi_0 Z_{t+j}^{1-\sigma}}{1-\chi} (1 - N_{t+j}(h))^{1-\chi} + \mu_0 F\left(\frac{MB_{t+j+1}(h)}{P_{Ct+j}} \right) \right\}, \tag{B.46}$$

where the discount factor β satisfies $0 < \beta < 1$. As in Smets and Wouters (2003, 2007), we allow for the possibility of external habit formation in preferences, so that each household member cares about its consumption relative to lagged aggregate consumption per capita of forward-looking agents C_{t-1}^O. The period utility function depends on an each member's current leisure $1 - N_t(h)$, his end-of-period real money balances, $\frac{MB_{t+1}(h)}{P_{Ct}}$, and a preference shock, ν_{ct}. The subutility function $F(.)$ over real balances is assumed to have a satiation point to account for the possibility of a zero nominal interest rate; see Eggertsson and Woodford (2003) for further discussion.[B.3] The (log-linearized) consumption demand shock ν_{ct} is assumed to follow an AR(1) process:

$$\nu_{ct} = \rho_\nu \nu_{ct-1} + \varepsilon_{\nu_c,t.} \tag{B.47}$$

Forward-looking household h faces a flow budget constraint in period t which states that its combined expenditure on goods and on the net accumulation of financial assets must equal its disposable income:

$$\begin{gathered} P_{Ct}(1+\tau_{Ct}) C_t^O(h) + P_{It} I_t(h) + MB_{t+1}(h) - MB_t(h) + \int_s \xi_{t,t+1} B_{Dt+1}(h) \\ -B_{Dt}(h) + P_{Bt} B_{Gt+1} - B_{Gt} + \frac{P_{Bt}^* B_{Ft+1}(h)}{\phi_{bt}} - B_{Ft}(h) \\ = (1-\tau_{Nt}) W_t(h) N_t(h) + \Gamma_t(h) + TR_t(h) + (1-\tau_{Kt}) R_{Kt} K_t(h) + \\ P_{It} \tau_{Kt} \delta K_t(h) - P_{Dt} \phi_{It}(h). \end{gathered} \tag{B.48}$$

Consumption purchases are subject to a sales tax of τ_{Ct}. Investment in physical capital augments the per capita capital stock $K_{t+1}(h)$ according to a linear transition law of the form:

$$K_{t+1}(h) = (1-\delta) K_t(h) + I_t(h), \tag{B.49}$$

[B.3] For simplicity, we assume that μ_0 is sufficiently small that changes in the monetary base have a negligible impact on equilibrium allocations, at least to the first-order approximation we consider.

where δ is the depreciation rate of capital.

Financial asset accumulation of a typical member of FL household h consists of increases in nominal money holdings $(MB_{t+1}(h) - MB_t(h))$ and the net acquisition of bonds. While the domestic financial market is complete through the existence of state-contingent bonds B_{Dt+1}, cross-border asset trade is restricted to a single non-state contingent bond issued by the government of the North economy.[B.4]

The terms B_{Gt+1} and B_{Ft+1} represents each household member's net purchases of the government bonds issued by the South and North governments, respectively. Each type of bond pays one currency unit (e.g., euro) in the subsequent period, and is sold at price (discount) of P_{Bt} and P^*_{Bt}, respectively. To ensure the stationarity of foreign asset positions, we follow Turnovsky (1985) by assuming that domestic households must pay a transaction cost when trading in the foreign bond. The intermediation cost depends on the ratio of economy-wide holdings of net foreign assets to nominal GDP, P_tY_t, and are given by:

$$\phi_{bt} = \exp\left(-\phi_b\left(\frac{B_{Ft+1}}{P_tY_t}\right)\right). \tag{B.50}$$

If the South is an overall net lender position internationally, then a household will earn a lower return on any holdings of foreign (i.e., North) bonds. By contrast, if the South has a net debtor position, a household will pay a higher return on its foreign liabilities. Given that the domestic government bond and foreign bond have the same payoff, the price faced by domestic residents net of the transaction cost is identical, so that $P_{Bt} = \frac{P^*_{Bt}}{\phi_{bt}}$. The effective nominal interest rate on domestic bonds (and similarly for foreign bonds) hence equals $i_t = 1/P_{Bt} - 1$.

Each member of FL household h earns after-tax labor income, $(1-\tau_{Nt})W_t(h)N_t(h)$, where τ_{Nt} is a stochastic tax on labor income. The household leases capital at the after-tax rental rate $(1-\tau_{Kt})R_{Kt}$, where τ_{Kt} is a stochastic tax on capital income. The household receives a depreciation

[B.4] Notice that the contingent claims B_{Dt+1} are in zero net supply from the standpoint of the South as a whole.

write-off of $P_{It}\tau_{Kt}\delta$ per unit of capital. Each member also receives an aliquot share $\Gamma_t(h)$ of the profits of all firms and a lump-sum government transfer, $TR_t(h)$ (which is negative in the case of a tax). Following Christiano, Eichenbaum and Evans (2005), we assume that it is costly to change the level of gross investment from the previous period, so that the acceleration in the capital stock is penalized:

$$\phi_{It}(h) = \frac{1}{2}\phi_I \frac{(I_t(h) - I_{t-1})^2}{I_{t-1}}. \tag{B.51}$$

In every period t, each member of FL household h maximizes the utility functional (B.46) with respect to its consumption, investment, (end-of-period) capital stock, money balances, holdings of contingent claims, and holdings of domestic and foreign bonds, subject to its labor demand function (B.45), budget constraint (B.48), and transition equation for capital (B.49). In doing so, a household takes as given prices, taxes and transfers, and aggregate quantities such as lagged aggregate consumption and the aggregate net foreign asset position.

Forward-looking (FL) households set nominal wages in staggered contracts that are analogous to the price contracts described above. In particular, with probability $1 - \xi_w$, each member of a household is allowed to reoptimize its wage contract. If a household is not allowed to optimize its wage rate, we assume each household member resets its wage according to:

$$W_t(h) = \omega_{t-1}^{\iota_w}\omega^{1-\iota_w}W_{t-1}(h), \tag{B.52}$$

where ω_{t-1} is the gross nominal wage inflation in period $t-1$, i.e. W_t/W_{t-1}, and $\omega = \pi$ is the steady state rate of change in the nominal wage (equal to gross price inflation since steady state gross productivity growth is assumed to be unity). Dynamic indexation of this form introduces some element of structural persistence into the wage-setting process. Each member of household h chooses the value of $W_t(h)$ to maximize its utility functional (B.46) subject to these constraints.

Finally, we consider the determination of consumption and labor supply of the hand-to-mouth (HM) households. A typical member of a HM household simply equates his nominal consumption spending, $P_{Ct}\left(1+\tau_{Ct}\right)C_t^{HM}\left(h\right)$, to his current after-tax disposable income, which consists of labor income plus lump-sum transfers from the government:

$$P_{Ct}\left(1+\tau_{Ct}\right)C_t^{HM}\left(h\right)=(1-\tau_{Nt})W_t\left(h\right)N_t\left(h\right)+TR_t(h). \tag{B.53}$$

The HM households are assumed to set their wage equal to the average wage of the forward-looking households. Since HM households face the same labor demand schedule as the forward-looking households, this assumption implies that each HM household works the same number of hours as the average for forward-looking households.

B.3. Monetary Policy

We assume that the central bank follows a Taylor rule for setting the policy rate of the currency union, subject to the zero bound constraint on nominal interest rates. Thus:

$$i_t=\max\left\{-i,\left(1-\gamma_i\right)\left(\tilde{\pi}_t+\gamma_\pi(\tilde{\pi}_t-\pi)+\gamma_x\tilde{x}_t\right)+\gamma_i i_{t-1}\right\} \tag{B.54}$$

In this equation, i_t is the quarterly nominal interest rate expressed in deviation from its steady state value of i. Hence, imposing the zero lower bound implies that i_t cannot fall below $-i$. $\tilde{\pi}_t$ is price inflation rate of the currency union, π the inflation target, and $\tilde{x}_t$ is the output gap of the currency union. The aggregate inflation and output gap measures are defined as a GDP-weighted average of the inflation rates and output gaps of the South and North. Finally, the output gap in each member is defined as the deviation of actual output from its potential level, where potential is the level of output that would prevail if wages and prices were completely flexible.

B.4. Fiscal Policy

The government does not need to balance its budget each period, and issues nominal debt B_{Gt+1} at the end of period t to finance its deficits according to:

$$\begin{aligned} P_{Bt}B_{Gt+1} - B_{Gt} = P_{Ct}G_t + TR_t - \tau_{Nt}W_tL_t - \tau_{Ct}P_{Ct}C_t - (\tau_{Kt}R_{Kt} - \delta P_{It})K_t \\ -(MB_{t+1} - MB_t), \end{aligned} \tag{B.55}$$

where C_t is total private consumption. Equation (B.55) aggregates the capital stock, money and bond holdings, and transfers and taxes over all households so that, for example, $TR_t = \int_0^1 TR_t(h)dh$. The taxes on capital τ_{Kt} and consumption τ_{Ct} are assumed to be fixed, and the ratio of real transfers to (trend) GDP, $tr_t = \frac{TR_t}{P_tY}$, is also fixed.[B.5] Government purchases have no direct effect on the utility of households, nor do they affect the production function of the private sector.

The process for the (log of) government spending is given by an AR(1) process:

$$(g_t - g) = \rho_g (g_{t-1} - g) + \varepsilon_{g,t}. \tag{B.56}$$

We assume that policymakers in the core and periphery adjust labor income taxes to stabilize the debt/GDP ratio and the deficit. Specifically, the labor tax rate evolves according to:

$$\tau_{Nt} - \tau_N = \nu_1 (\tau_{Nt-1} - \tau_N) + (1 - \nu_1) [\nu_2 (b_{Gt} - b_G) + \nu_3 (\Delta b_{Gt+1} - \Delta b_G)]. \tag{B.57}$$

B.5. Resource Constraint and Net Foreign Assets

The domestic economy's aggregate resource constraint can be written as:

$$Y_{Dt} = C_{Dt} + I_{Dt} + \phi_{It}, \tag{B.58}$$

where ϕ_{It} is the adjustment cost on investment aggregated across all households. The final consumption good is allocated between households and the government:

$$C_{At} = C_t + G_t, \tag{B.59}$$

[B.5] Given that the central bank uses the nominal interest rate as its policy instrument, the level of seigniorage is determined by nominal money demand.

where C_t is total private consumption of FL (optimizing) and HM households:

$$C_t = C_t^O + C_t^{HM}. \tag{B.60}$$

Total exports may be allocated to either the consumption or the investment sector abroad:

$$M_t^* = M_{Ct}^* + M_{It}^*. \tag{B.61}$$

Finally, at the level of the individual firm:

$$Y_t(i) = Y_{Dt}(i) + X_t(i) \quad \forall i. \tag{B.62}$$

The evolution of net foreign assets can be expressed as:

$$\frac{P_{B,t}^* B_{F,t+1}}{\phi_{bt}} = B_{F,t} + P_{Mt}^* M_t^* - P_{Mt} M_t. \tag{B.63}$$

This expression can be derived from the budget constraint of the FL households after imposing the government budget constraint, the consumption rule of the HM households, the definition of firm profits, and the condition that domestic state-contingent non-government bonds (B_{Dt+1}) are in zero net supply.

Finally, we assume that the structure of the foreign country (the North) is isomorphic to that of the home country (the South).

B.6. Production of capital services

We incorporate a financial accelerator mechanism into both country blocks of our benchmark model following the basic approach of Bernanke, Gertler and Gilchrist (1999). Thus, the intermediate goods producers rent capital services from entrepreneurs (at the price R_{Kt}) rather than directly from households. Entrepreneurs purchase physical capital from competitive capital goods producers (and resell it back at the end of each period), with the latter employing the same technology to transform investment goods into finished capital goods as described by equations B.49) and B.51).

To finance the acquisition of physical capital, each entrepreneur combines his net worth with a loan from a bank, for which the entrepreneur must pay an external finance premium (over the risk-free interest rate set by the central bank) due to an agency problem. Banks obtain funds to lend to the entrepreneurs by issuing deposits to households at the interest rate set by the central bank, with households bearing no credit risk (reflecting assumptions about free competition in banking and the ability of banks to diversify their portfolios). In equilibrium, shocks that affect entrepeneurial net worth – i.e., the leverage of the corporate sector – induce fluctuations in the corporate finance premium.[B.6]

B.7. Solution Method and Calibration

To analyze the behavior of the model, we log-linearize the model's equations around the non-stochastic steady state. Nominal variables are rendered stationary by suitable transformations. To solve the unconstrained version of the model, we compute the reduced-form solution of the model for a given set of parameters using the numerical algorithm of Anderson and Moore (1985), which provides an efficient implementation of the solution method proposed by Blanchard and Kahn (1980). When we solve the model subject to the non-linear monetary policy rule (B.54), we use the techniques described in Hebden, Lindé and Svensson (2009). An important feature of the Hebden, Lindé and Svensson algorithm is that the duration of the liquidity trap is endogenously determined.[B.7]

The model is calibrated at a quarterly frequency. Structural parameters are set at identical

[B.6] We follow Christiano, Motto and Rostagno (2008) by assuming that the debt contract between entrepreneurs and banks is written in nominal terms (rather than real terms as in Bernanke, Gertler and Gilchrist, 1999). For further details about the setup, see Bernanke, Gertler and Gilchrist (1999), and Christiano, Motto and Rostagno (2008). An excellent exposition is also provided in Christiano, Trabandt and Walentin (2007).

[B.7] In future work, it would be of interest to solve the model in a fully non-linear form.

values for each of the two country blocks, except for the parameter ζ determining population size (as discussed below), the fiscal rule parameters, and the parameters determining trade shares. We assume that the discount factor $\beta = 0.995$, consistent with a steady-state annualized real interest rate $\overline{r}$ of 2 percent. By assuming that gross inflation $\pi = 1.005$ (i.e. a net inflation of 2 percent in annualized terms), the implied steady state nominal interest rate i equals 0.01 at a quarterly rate, and 4 percent at an annualized rate.

The utility functional parameter σ is set equal to 1 to ensure that the model exhibit balanced growth, while the parameter determining the degree of habit persistence in consumption $\varkappa = 0.8$. We set $\chi = 4$, implying a Frisch elasticity of labor supply of 1/2, which is roughly consistent with the evidence reported by Domeij and Flodén (2006). The utility parameter χ_0 is set so that employment comprises one-third of the household's time endowment, while the parameter μ_0 on the subutility function for real balances is set at an arbitrarily low value (so that variation in real balances do not affect equilibrium allocations). We set the share of HM agents $\varsigma = 0.47$, implying that these agents account for about 20 percent of aggregate private consumption spending (the latter is much smaller than the population share of HM agents because the latter own no capital).

The depreciation rate of capital δ is set at 0.03 (consistent with an annual depreciation rate of 12 percent). The parameter ρ in the CES production function of the intermediate goods producers is set to -2, implying an elasticity of substitution between capital and labor $(1+\rho)/\rho$, of 1/2. The quasi-capital share parameter ω_K – together with the price markup parameter of $\theta_P = 0.20$ – is chosen to imply a steady state investment to output ratio of 15 percent. We set the cost of adjusting investment parameter $\phi_I = 3$, slightly below the value estimated by Christiano, Eichenbaum and Evans (2005). The calibration of the parameters determining the financial accelerator follows Bernanke, Gertler and Gilchrist (1999). In particular, the monitoring cost, μ, expressed as a proportion of entrepreneurs' total gross revenue, is set to 0.12. The default rate of entrepreneurs is 3 percent per year, and the variance of the idiosyncratic productivity shocks to entrepreneurs is 0.28.

Our calibration of the parameters of the monetary policy rule and the Calvo price and wage contract duration parameters – while within the range of empirical estimates – tilt in the direction of reducing the sensitivity of inflation to shocks. These choices seem reasonable given the resilience of inflation in most euro area countries in the aftermath of the global financial crisis. In particular, we set the parameters of the monetary rule such that $\gamma_\pi = 1.5$, $\gamma_x = 0.125$, and $\gamma_i = 0.7$, implying a considerably larger response to inflation than a standard Taylor rule (which would set $\gamma_\pi = 0.5$). The price contract duration parameter $\xi_p = 0.92$, and the price indexation parameter $\iota_p = 0.65$. Our choice of ξ_p implies a Phillips curve slope of about 0.005, which is a bit lower than the median estimates in the literature that cluster in the range of $0.009 - 0.014$, but well within the standard confidence intervals provided by empirical studies (see e.g. Adolfson et al (2005), Altig et al. (2010), Galí and Gertler (1999), Galí, Gertler, and López-Salido (2001), Lindé (2005), and Smets and Wouters (2003, 2007)). Our choices of a wage markup of $\theta_W = 1/3$, a wage contract duration parameter of $\xi_w = 0.90$, and a wage indexation parameter of $\iota_w = 0.65$, together imply that wage inflation is about as responsive to the wage markup as price inflation is to the price markup.[B.8]

The parameters pertaining to fiscal policy are intended to roughly capture the revenue and spending sides of euro area government budgets. The share of government spending on goods and services is set equal to 23 percent of steady state output. The government debt to GDP ratio, b_G, is set to 0.75, roughly equal to the average level of debt in euro area countries at end-2008. The ratio of transfers to GDP is set to 20 percent. The steady state sales (i.e., VAT) tax rate τ_C is set to 0.2, while the capital tax τ_K is set to 0.30. Given the annualized steady state real interest rate

[B.8] Given strategic complementarities in wage-setting, the wage markup influences the slope of the wage Phillips Curve.

(2 percent), the government's intertemporal budget constraint then implies that the labor income tax rate τ_N equals 0.42 in steady state. We assume an unaggressive tax adjustment rule in (B.57) by setting $\nu_1 = 0.985$ and $\nu_2 = \nu_3 = .1$.

The size of the South is calibrated to be 1/3 of euro area GDP, so that $\zeta = 0.5$. This corresponds to the collective share of Greece, Ireland, Portugal, Italy, and Spain in euro area GDP, or alternatively, to the combined GDP of France and Spain (clearly, our model framework can be applied to many other country pairings, with similar implications). Identifying the former group of countries as the South to calibrate trade shares, the average share of imports of the South from the remaining countries of the euro area was about 14 percent of GDP in 2008 (based on Eurostat). This pins down the trade share parameters ω_C and ω_I for the South under the additional assumption that the import intensity of consumption is equal to 3/4 that of investment. Given that trade is balanced in steady state, this calibration implies an export and import share of the North countries of 7 percent of GDP.

We assume that $\rho_C = \rho_I = 2$, consistent with a long-run price elasticity of demand for imported consumption and investment goods of 1.5. The adjustment cost parameters are set so that $\varphi_{M_C} = \varphi_{M_I} = 1$, which slightly damps the near-term relative price sensitivity. The financial intermediation parameter ϕ_b is set to a very small value (0.00001), which is sufficient to ensure the model has a unique steady state.

Finally, the persistence coefficient ρ_{ν_c} for the consumption demand shock ν_{ct} (see eq. B.47) is set to 0.9, while the persistence coefficient ρ_z for the technology shock (see eq. B.34) assumes the value 0.975. Finally, the persistence of the government spending shock, g_t in eq. (B.56), ρ_g is set to 0.9.

Figure 1: Inflation, Unemployment, and Terms-of-Trade in Selected Euro Area Economies

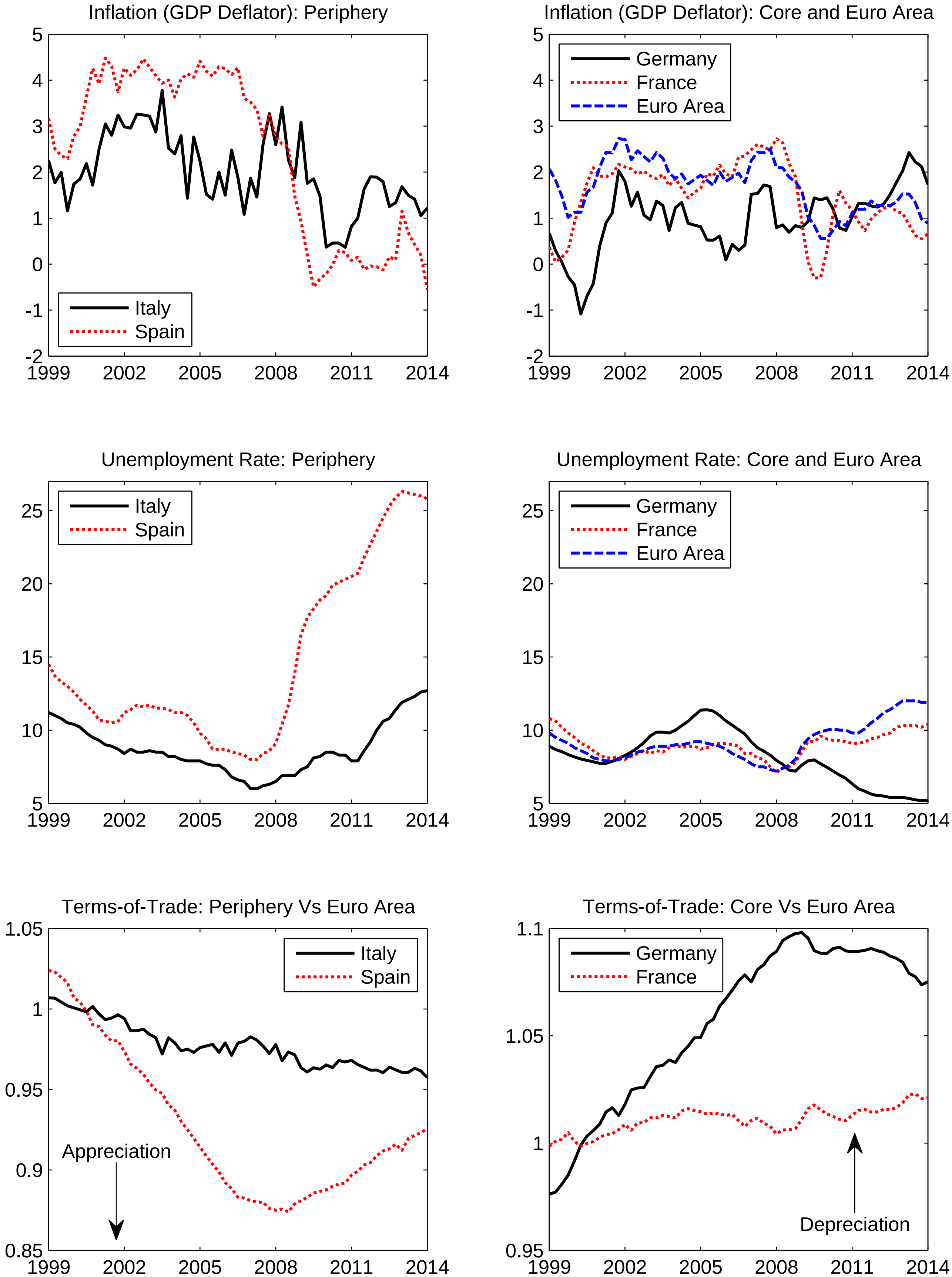
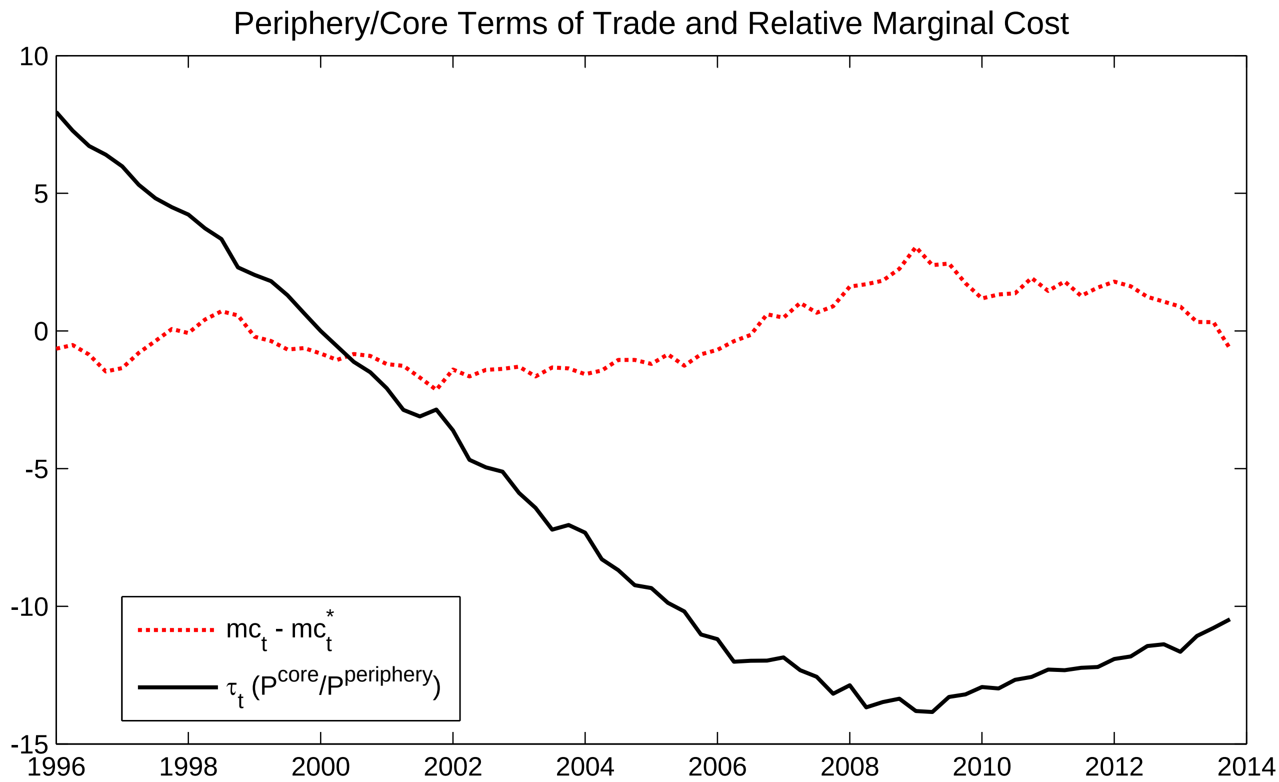


Figure 2: Calibrating the Speed of Price Adjustment



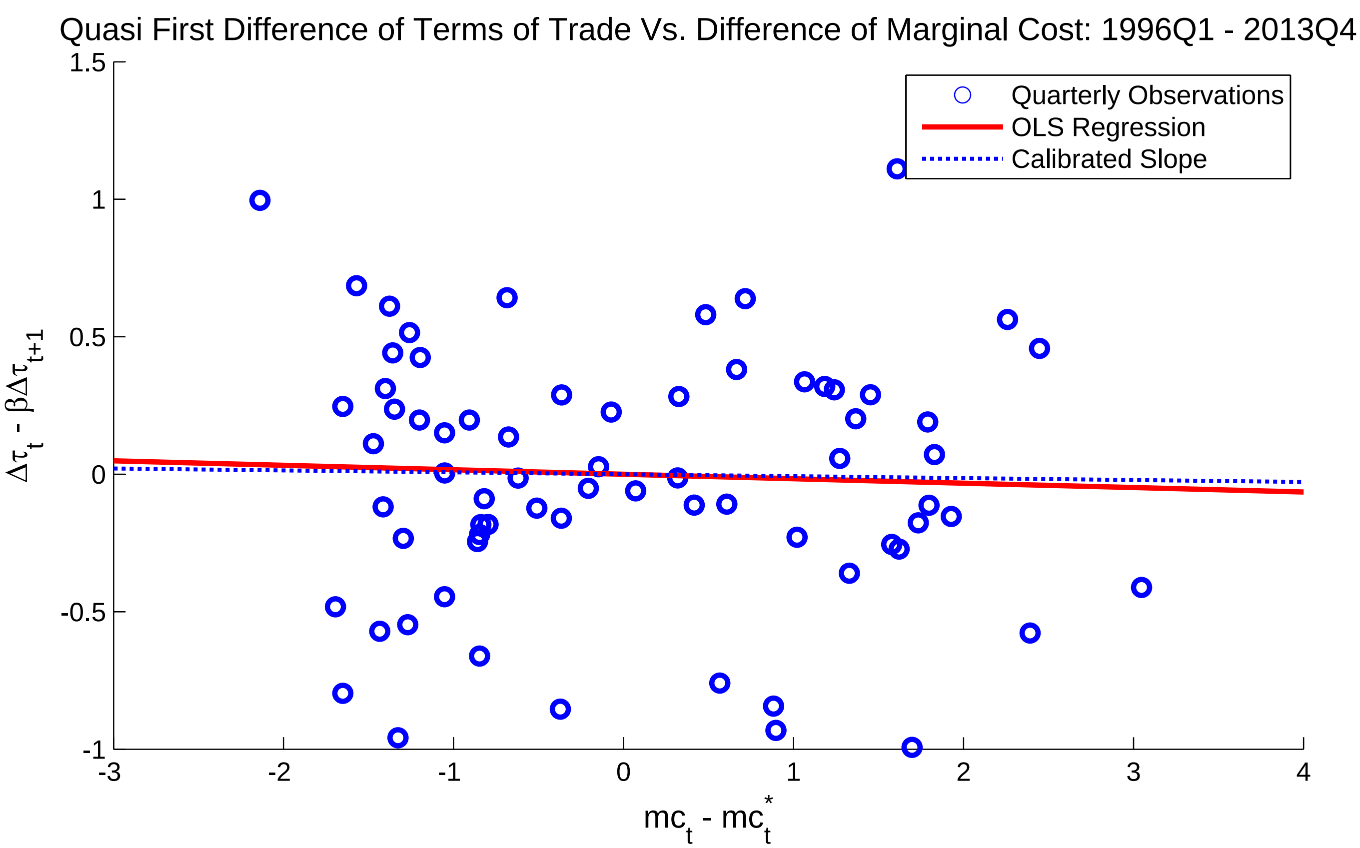


Figure 3: Spending Hike in Core With 1 Percent of GDP: Slow Price Adjustment

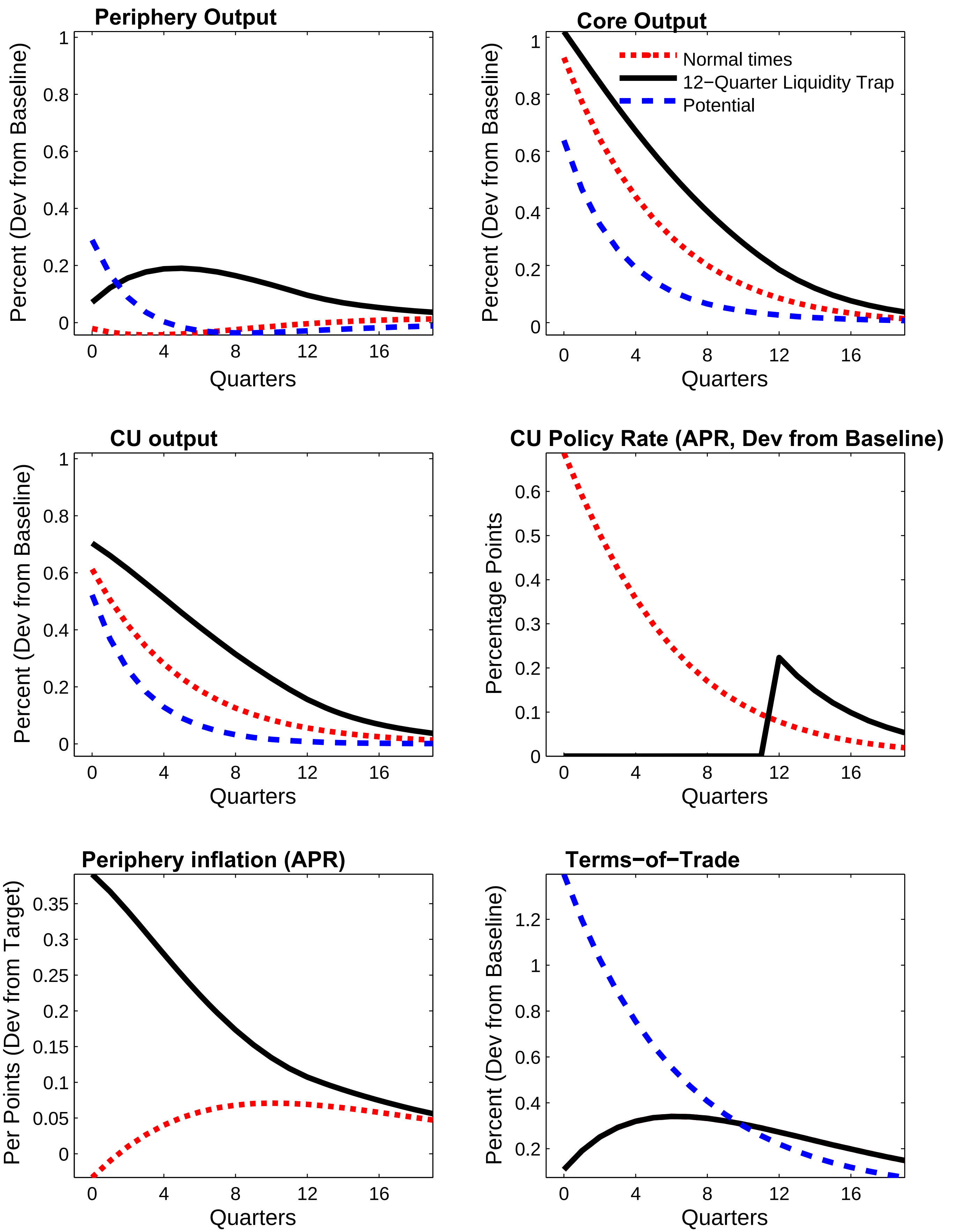
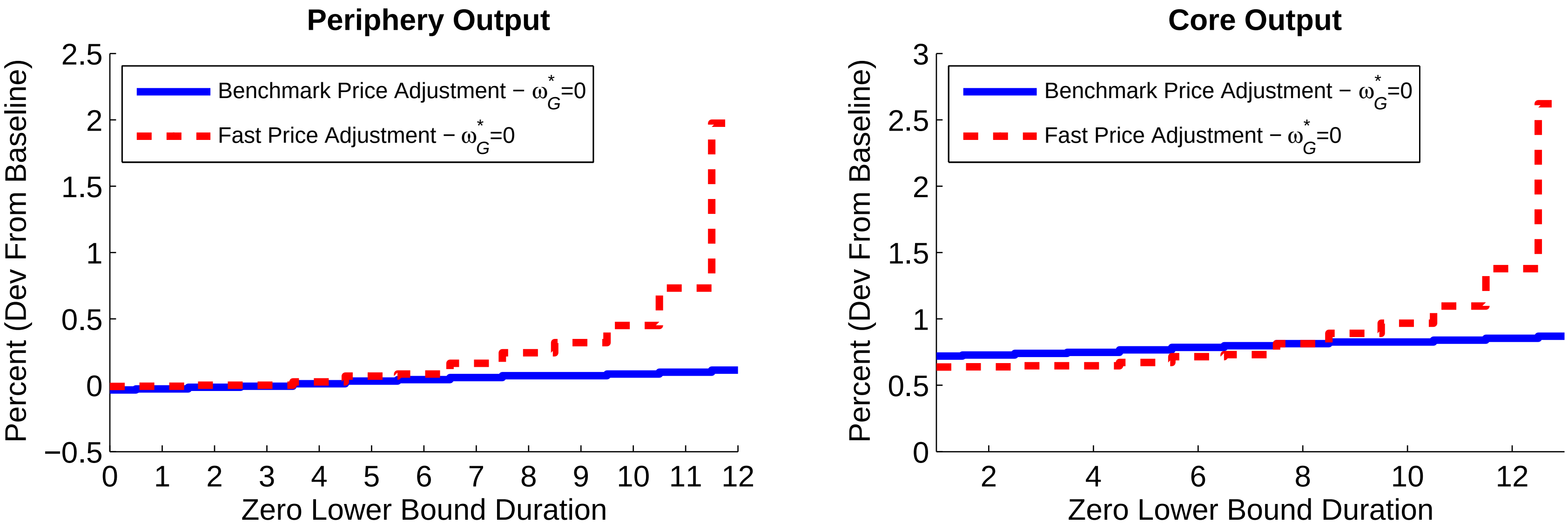


Figure 4: Output (Average in First Year) Responses in Core and Periphery as Function of Liquidity Trap Duration Following a Spending Hike in the Core.

Panel A: Benchmark (Slow) vs. Faster Price Adjustment, No Import Content in Core Spending



Panel B: Benchmark (Slow) Price Adjustment, Varying the Degree of Import Content in Core Govt Spending

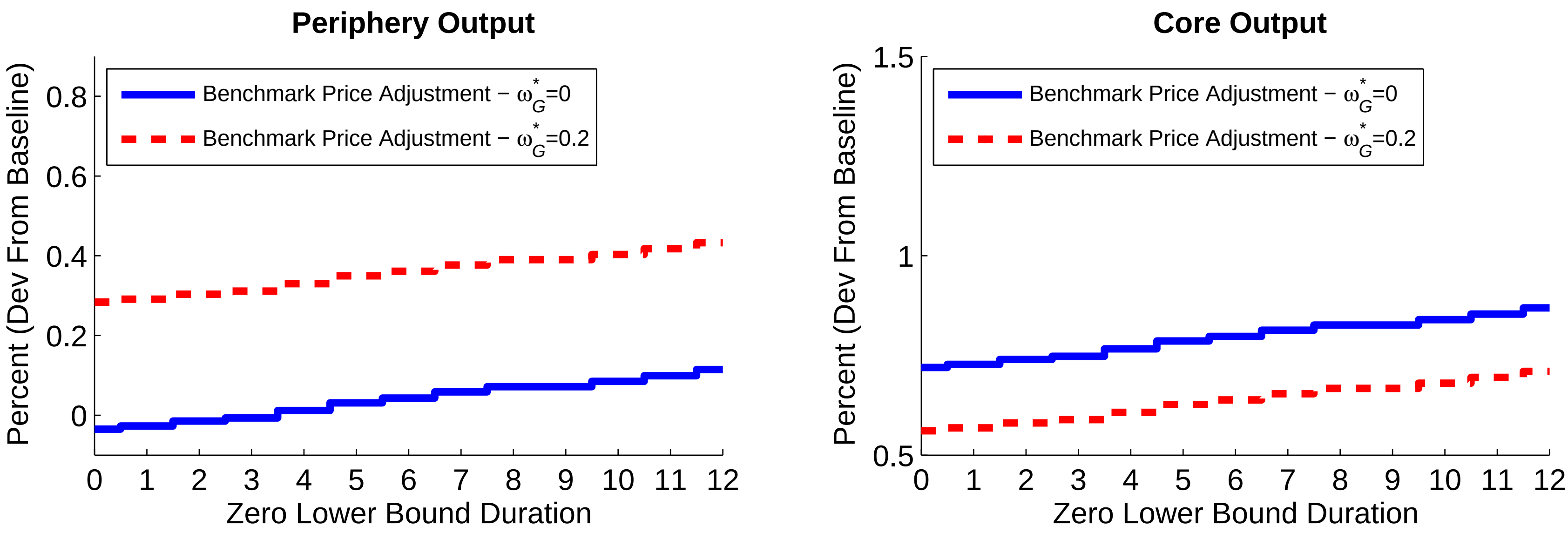


Figure 5: Spending Hike in Core With 1 Percent of GDP: Fast Price Adjustment

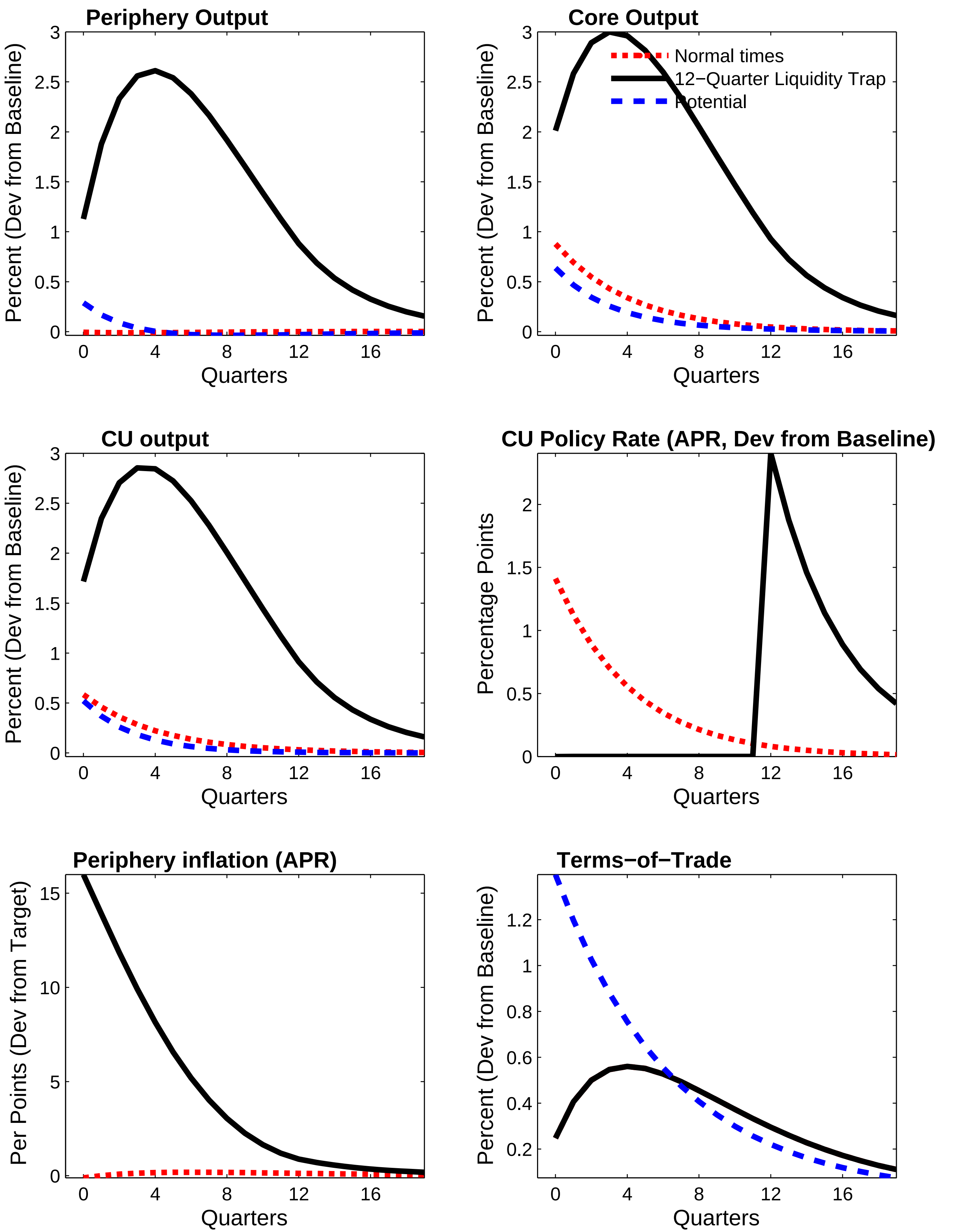


Figure 6: Spending Hike in Core With 1 Percent of GDP: Slow Price Adjustment: Allowing for Import−Content in Core Government Spending.

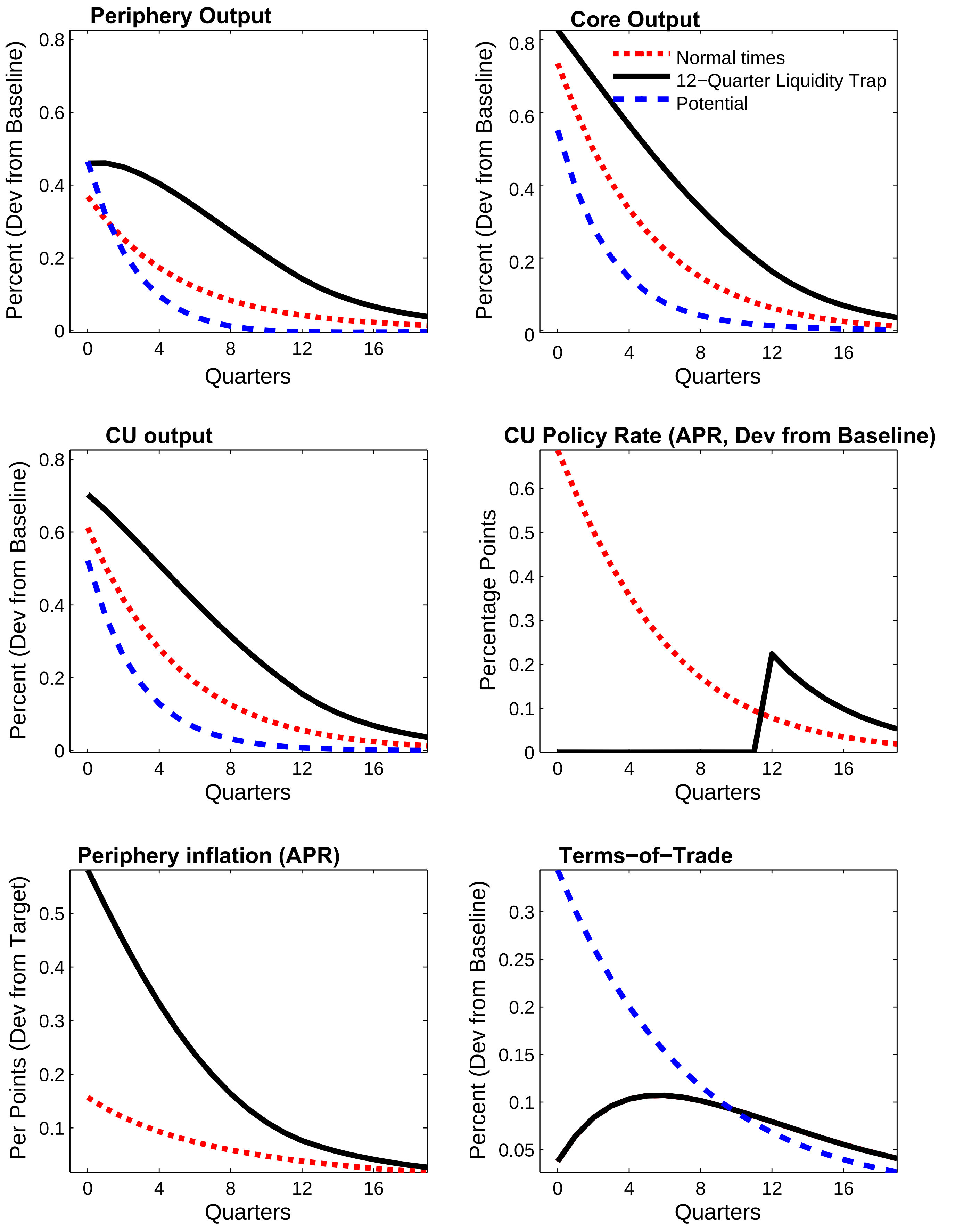


Figure 7: Impact of Fiscal Stimulus in Core When ECB Keeps Exitdate Unchanged.

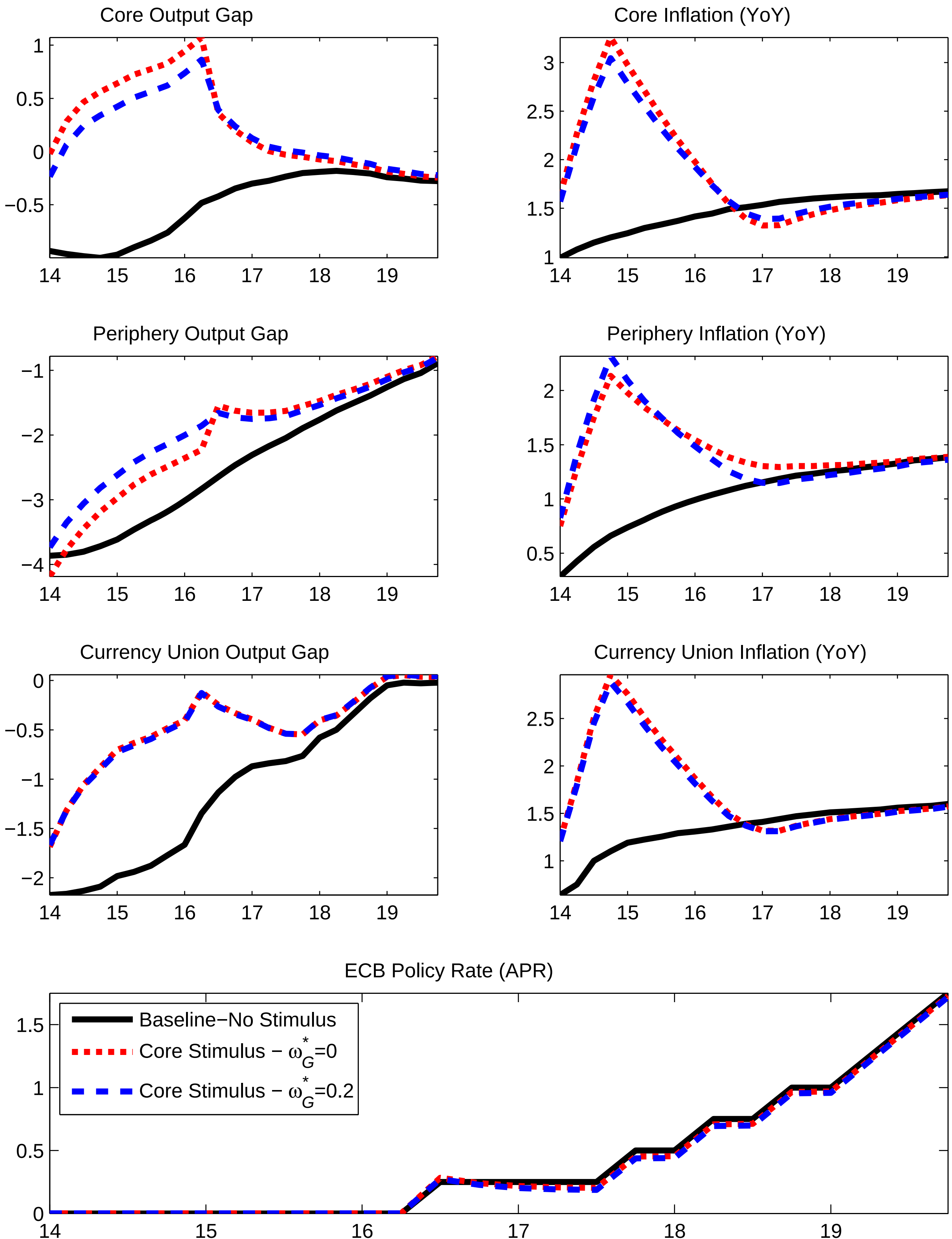


Figure 8: Core Spending Hike in Large−Scale Model in Normal Times and when the Currency Union is in a 2−Year Liquidity Trap.

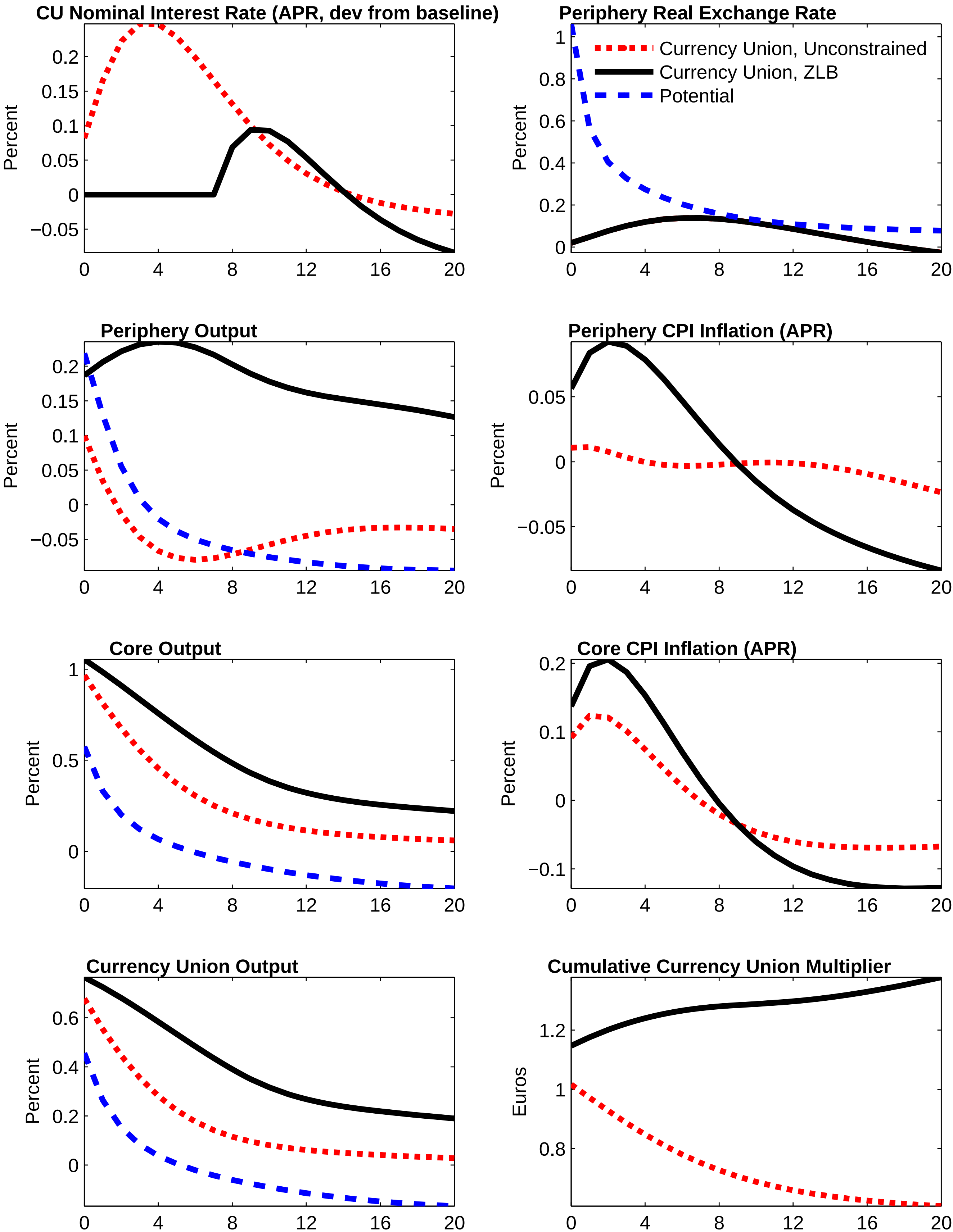


Figure 9: Spending Hike in Core in Large−Scale Model in a Currency Union: Implications of Extending the Liquity Trap Duration to 3−years.