The Transmission of Domestic Shocks in Open Economies

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June 2007

Abstract: This paper uses an open economy DSGE model to explore how trade openness affects the transmission of *domestic* shocks. For some calibrations, closed and open economies appear dramatically different, reminscient of the implications of Mundell-Fleming style models. However, we argue such stark differences hinge on calibrations that impose an implausibly high trade price elasticity and Frisch elasticity of labor supply. Overall, our results suggest that the main effects of openness are on the composition of expenditure, and on the wedge between consumer and domestic prices, rather than on the response of aggregate output and domestic prices.

JEL Classification: F41, F47, E52
Keywords: open economy Phillips Curve, variable markups, imported intermediate inputs.

Acknowledgements: We thank Andrew Levin and Steve Kamin for helpful comments and suggestions, and seminar participants at the Federal Reserve Board. The views expressed in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System or of any other person associated with the Federal Reserve System.

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1 Introduction

With the rapid expansion in world trade during the past two decades, policymakers have become increasingly interested in the consequences of greater trade openness for macroeconomic behavior. Considerable attention has focused on how external shocks may play a more prominent role in driving domestic fluctuations as trade linkages grow, and as developing countries such as China exert a progressively larger influence on global energy and commodity prices. Our paper examines a different aspect of globalization that has received less scrutiny in the recent literature. In particular, we investigate whether changes in trade openness are likely to have a substantial impact on the transmission of domestic shocks.

Economists have long recognized that openness could potentially affect the responses of real activity to domestic shocks, including to monetary and fiscal policy. The Mundell (1962) and Fleming (1962) framework showed that fiscal shocks could have dramatically different effects depending on whether an economy was open or closed: in contrast to the stimulative effect of a government spending rise on output in a closed economy, the same shock had no effect on output in an open economy, as real exchange rate appreciation crowded out real net exports.

A longstanding literature has also assessed the consequences of openness for prices. Perhaps most obviously, economists drew attention to the potential divergence between domestic prices and consumer prices in an open economy, reflecting the sensitivity of the latter to import prices. But important contributions in the 1970s and early 1980s also analyzed how the behavior of domestic price-setting could be affected by openness. Influential work by Dornbusch (1983) linked the desired markup in a monopolistic competition framework to the real exchange rate, and showed how the markup could be expected to decline in response to real exchange rate appreciation (reflecting increased competitive pressure from abroad). In an NBER conference volume nearly a quarter century ago, Dornbusch and Fischer (1984) used this framework to argue that changes in the slope of the Phillips Curve due to increased trade openness were likely to have substantial implications for the transmission of monetary

and fiscal policy. Specifically, these authors argued that monetary shocks were likely to cause domestic prices to respond more quickly due to an effective steepening of the Phillips Curve.

In this paper, we use a two country DSGE model "SIGMA" – and several simplified offshoots – to revisit the question of how openness affects the economy's responses to monetary and fiscal shocks, as well as to a representative supply shock. Our analysis is heavily influenced by a sequence of recent important papers that compare the characteristics of optimal policy rules in closed and open economies by Galí and Monacelli (2005), Clarida, Galí, and Gertler (2001), and Clarida, Galí, and Gertler (2002). However, these papers used highly stylized versions of the New Keynesian model with the main goal of showing the formal similarity between the policy problem in closed and open economies: thus, policy prescriptions from the closed economy carried over to the open economy with suitable changes in parameters to account for openness. Our paper differs substantially insofar our objective is to provide a quantitative account of the differences in the transmission channel as the trade openness of the economy varies.

In conformity with our quantitative emphasis, SIGMA embeds many of the dynamic complications that have been identified in the literature as important in explaining open economy behavior. On the aggregate demand side, it allows for the possibility that trade openness may markedly influence the effective interest sensitivity of the economy, and that trade may react more quickly to policy changes than other demand components (e.g., Svensson (2001)). Through the medium of an internationally traded bond, agents can borrow or lend to smooth consumption, with potentially important consequences for consumption and real interest rates. On the supply side, SIGMA allows for variable desired markups that depend on the real exchange rate, in the spirit of Dornbusch (1983) (and of more recent work by Bergin and Feenstra (2001) and Gust, Leduc, and Vigfusson (2006)). Prices are set in a staggered fashion in both the home and foreign market, with exporters setting their price in local currency terms, as in Betts and Devereux (1996) and a large related literature. Openness can affect marginal cost through changing the wealth effect on the the desired labor supply of households (as in Galí and Monacelli (2005)), and through its influence on

capital accumulation.[1]

Our core simulation exercises using the SIGMA model are presented in Section 2, following a brief model description. In particular, we examine the effects of three different shocks, including a one percentage point decline in the home country's inflation target, a one percent of baseline GDP rise in government spending, and a highly persistent rise in the level of total factor productivity. For each shock, we analyze the implications of openness under three different calibrations of our model. Our benchmark calibration sets the home bias parameters in consumption and investment to imply an average trade share of 12 percent, roughly equal to the trade share of the United States. We contrast this with an alternative "nearly closed" calibration that sets the trade share close to zero, and a second alternative that sets the trade share at a very high value of 35 percent. In each case, the home country is assumed to comprise 25 percent of world output (though our results are not very sensitive to this parameter). Monetary policy is assumed to follow a simple Taylor rule that reacts to the inflation gap (the difference between domestic inflation and its target value) and the true output gap.

We find that the inflation target change has quite similar effects on output and domestic price inflation across the three calibrations of openness. The main differences across calibrations are compositional, with exports bearing more of the burden of adjustment on the real side as openness increases, and CPI inflation dropping more quickly than domestic price inflation. Interestingly, some limited case study evidence comparing historical disinflation episodes that occurred in the United States, Canada, and the United Kingdom during the 1980s and early 1990s seems to corroborate our simulation results: sacrifice ratios were quite similar across the three countries.

Our SIGMA simulations also indicate that the responses of output, domestic price inflation, and real interest rates to a technology shock vary only modestly with the degree of

[1] Razin and Yuen (2002) show that greater openness in capital markets can affect marginal cost and lead to a steeper Phillips curve. In this paper, we mainly focus on the consequences of trade openness, though we briefly discuss the effects of greater financial openness in our model in Section 5.1.

openness. The degree of trade openness does have somewhat more pronounced consequences for the macroeconomic responses to a government spending shock. With greater openness to trade, output and domestic price inflation rise by less as more of the demand stimulus is satisfied by higher imports; this effect in concert with a slightly higher interest-sensitivity of the economy induces a smaller increase in real interest rates. But taken together, our simulation results suggest that the main effects of openness are on the composition of expenditure, and on the wedge between consumer and domestic prices, rather than on the response of aggregate output and domestic prices.

We next proceed with an extensive sensitivity analysis that attempts to evaluate the robustness of our key findings. Given the complexity of SIGMA, we find it useful to take a heuristic approach that is aimed at accounting for the broad features of the SIGMA simulation within the context of a much simpler "workhorse" model. Accordingly, we show in Section 3 that most of the key results from the SIGMA simulations – at least pertaining to the implications of openness – can be rationalized by a simple extension of the small open economy model of Galí and Monacelli (2005) to include nominal wage rigidities (as well as price rigidities) and additional shocks. While our model allows for spillover effects between the two countries, it can be approximated by a system of dynamic equations that parallels the closed economy model of Erceg, Henderson, and Levin (2000) in the special case in which the home country's share of world output becomes arbitrarily small. As in Galí and Monacelli (2005), the differences between the closed and open economies can be summarized by a single composite parameter that affects the behavioral equations in exactly the same way as the intertemporal elasticity of substitution parameter (say σ) in a closed economy model: i.e., by affecting the interest elasticity of aggregate demand, and the wealth effect. Given that this generalized intertemporal elasticity of substitution parameter – which we call σ^{open} below – captures all effects arising through changes in trade openness or through different trade price elasticities, it is simple to investigate how changes in openness affect equilibrium responses under a wide range of calibrations.

Our analysis shows that, in principle, there could be very pronounced divergence in the

effects of the domestic shocks on output and domestic inflation as trade openness increases. In particular, with very high trade price elasticities and a high Frisch elasticity of labor supply, the enhanced ability to smooth consumption in the open economy markedly affects the wealth effect of shocks on labor supply, and the slope of the household's MRS schedule (tending to flatten it). These changes can have substantial effects on aggregate supply, and through their effect on real wages and marginal costs, on output and inflation. Moreover, on the aggregate demand side, higher openness increases the effective interest-elasticity of the economy (assuming that the trade price elasticity is higher than the intertemporal elasticity of substitution). In the extreme case in which the trade price elasticity becomes infinitely high, our workhorse model in fact implies that government spending shocks have no effect on output, reminiscent of the implications of Mundell-Fleming style models.

However, with more reasonable calibrations of the trade price elasticity – the 1-1/2 under our benchmark is in fact at the high end of macroeconomic estimates – openness does not seem to change markedly the interest-sensitivity of the economy, or the determinants of aggregate supply. Accordingly, while it does exert *some* impact on domestic price inflation and output, the effects seem fairly modest given the wide range of calibrations of openness considered. From an intuitive perspective, even a highly open economy resembles a closed economy to the extent that its goods are only moderately substitutable for foreign goods.

We then proceed to consider a number of variations of our workhorse model by grafting onto it various complications embedded in SIGMA (each in isolation). Section 4.1 contrasts incomplete markets (a bond only economy) with the complete markets setting, and finds fairly small differences. Section 4.2 considers the incorporation of endogenous capital accumulation. With capital accumulation, the differences between closed and open economies are even smaller than in our workhorse model. Section 4.3 considers a specification in which imports are used as intermediate goods, as in McCallum and Nelson (1999); for reasonable calibrations of the import share, it seems to have fairly small effects on our results. Finally, we examine the implications of a framework that allows for variable desired markups. We find that this mechanism can amplify differences in the response of inflation as the degree of

openness varies.

Taken together, our analysis suggests that while openness does have some consequences for the behavior of domestic shocks – especially to fiscal policy – it does not seem plausible that differences are nearly as pronounced as suggested by the earlier Mundell-Fleming literature.

2 Theoretical and Empirical Motivation

In this section, we use a two country version of the SIGMA model to illustrate how trade openness affects the propagation of three different domestic shocks, including a reduction in the central bank's target inflation rate, a rise in government spending, and a highly persistent rise in technology. In the case of the shock to the inflation target, we compare the model's implications to historical episodes of disinflation that occurred in the United States, Canada, and the United Kingdom during the early 1980s and early 1990s.

2.1 SIGMA Simulations

SIGMA is a dynamic general equilibrium model that incorporates an array of nominal and real rigidities designed to yield plausible implications across a broad spectrum of shocks (For a more complete description of SIGMA, see Erceg, Guerrieri, and Gust (2006)). SIGMA allows for nominal price stickiness by incorporating monopolistically competitive firms which set prices according to Calvo-style staggered contracts that are indexed to lagged inflation. Similarly, SIGMA incorporates wage stickiness by positing that households are monopolistic suppliers of labor services and set wages in Calvo-style staggered contracts indexed to lagged wage inflation. SIGMA also includes habit persistence in consumption and adjustment costs on investment, features that have been identified as empirically important in the closed economy models of Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2003).

Households require both imported goods as well as domestic goods for consumption and

investment. Although domestic financial markets are assumed to be complete, international financial markets are incomplete, as there is only a single bond that is traded internationally. To rationalize a lower sensitivity of trade flows to the exchange rate in the short run than long run, SIGMA incorporates costs to adjusting trade flows. Following Kimball (1995) and Bergin and Feenstra (2001), SIGMA includes demand curves with non-constant elasticities (NCES) that induce 'strategic complementarity' in price setting, and create an incentive for firms to charge different prices at home and abroad (i.e., price to market). This feature also gives rise to variations in desired markups that reduce the pass-through of exchange rate changes to import prices.

Monetary policy in SIGMA is assumed to follow a Taylor rule in which the nominal interest rate responds to the deviation of *domestic* inflation from the central bank's inflation target and to the output gap. Government purchases are assumed to be exogenous and have no direct effect on the utility of households. We also assume that these purchases are financed solely through lump-sum taxes.[2]

Figure 1 shows the effects of a one percentage point permanent reduction in SIGMA of the home country's inflation target for three different degrees of trade openness. The solid blue line shows the effects under our benchmark calibration of SIGMA in which the home country is calibrated based on U.S. data, so that the ratio of imports to GDP is 12 percent. The dashed green line shows an alternative in which we lower the import share to 1 percent, while the dotted red line shows an alternative in which the import share is 35 percent.[3]

The effects of the reduction in the inflation target are qualitatively similar regardless of the degree of openness. The reduction in the inflation target requires policymakers to increase interest rates which induces a hump-shaped contraction in output as well as an appreciation of the real exchange rate (not shown). Private absorption falls in response

[2] In general, SIGMA allows for the possibility that some households are liquidity-constrained, and must consume all of their disposable income each period. This feature can generate a larger multiplier on the government spending shock than in the simulations reported below. However, for expositional simplicity, we set the share of such households to zero in the simulations reported below.

[3] In these experiments, we vary openness by changing the share parameter in the NCES aggregators used to produce consumption and investment from the home and foreign goods.

to the higher interest rates, and exports falls due to the induced appreciation of the real exchange rate. Both domestic and consumer price inflation fall, taking nearly two years to reach their new target level.

Perhaps somewhat remarkably, the responses of key macro aggregates – including output, domestic price inflation, and the real interest rate – show little quantitative variation with different degrees of openness. The sacrifice ratio – which we measure as the sum of output gaps in the twenty quarters following the start of the disinflation, divided by the change in the inflation rate (of one percentage point) – is about 1.1 under each calibration. Aside from the slightly larger initial output decline under the high openness calibration, the main differences in the responses are compositional. For the highly open economy, more of the output contraction is attributable to a fall in real net exports; in addition, given the larger share of imported goods in the consumption basket, there is a greater disparity between the response of consumer price inflation and domestic price inflation.

As we will discuss subsequently, the similarity in the responses of output, domestic price inflation, and the real interest rate is mainly attributable to two factors. First, the interest-sensitivity of aggregate demand does not change substantially as the openness of the economy increases. Although our benchmark calibration imposes a rather high long-run trade price elasticity of 1-1/2, implying (through the uncovered interest parity condition) that exports are quite sensitive to the real interest rate, private absorption has a comparable interest-sensitivity due to the high responsiveness of investment. Accordingly, the interest-sensitivity of aggregate demand only rises slightly as exports receive a larger expenditure weight.[4] As we discuss below, the interest-sensitivity of the economy rises is more apparent somewhat shows somewhat more pronounced variation with openness. In particular, with shocks This can be

[4] It is important to note that the interest- sensitivity does depend on the persistence of the shock's effects on the real interest rate. For shocks that exert more persistent effects on real interest rates, exports show a relatively higher interest-sensitivity than private domestic demand, and the aggregate interest-sensitivity of the economy rises more substantially with openness. For example, the interest-sensitivity rises more quickly with openness under an alternative model calibration that increases the duration of wage and price contracts (since the real interest rate response in that case is more persistent). Similarly, the government spending shock below has a more persistent impact on the real interest rate, with the implication that the economy becomes more interest-sensitive with greater openness.

garnered from the bottom panels of the figure: exports only contract a bit more sharply than private absorption in response to higher real interest rates. Even the slightly larger initial output decline in the high openness case - which reflects the relatively bigger contraction in exports than private demand - would in fact disappear under a lower degree of exchange rate passthrough from U.S. exporters to foreign markets (since this would effectively damp the responsiveness of real exports to the exchange rate or interest rate). The second factor accounting for the similarity across responses is that the the determinants of marginal cost don't change significantly; roughly speaking, openness has only small effects on the slope of the Phillips Curve.

Interestingly, historical episodes of disinflation in the United States, Canada, and the United Kingdom seem reasonably supportive of the model's implications. Figure 2 shows the evolution of inflation (measured through the annual changes in the GDP deflator) and the output gap (as measured by the OECD) for the U.S., Canada, and the U.K. for two different periods of disinflation (the early 1980s and early 1990s). As seen in the left column of Figure 2, inflation in both the United States and Canada fell from roughly 10 percent to 4 percent during the disinflations that occurred during the early 1980s, while the output gap expanded (in absolute value) by roughly 6-7 percent in each country. The sacrifice ratio in the United Kingdom was somewhat lower during that episode, as inflation fell by considerably more, while the output gap expanded by a similar amount. In the 1990s, the three experiences seem reasonably similar, with Canada perhaps having a somewhat higher sacrifice ratio than the United States, and the United Kingdom a slightly lower sacrifice ratio. Thus, while the evidence is somewhat noisy, the sacrifice ratio does not appear to vary with openness in a systematic way.[5]

Figure 3 shows the effects of an increase in government spending.[6] From a qualitative perspective, the government spending hike has similar effects on key macroeconomic variables irrespective of trade openness. Thus, output increases initially due to the direct effects

[5] See also Ball (1994) for similar evidence for a broader set of countries.

[6] Government spending is modelled as an AR(1) process with an autocorrelation coefficient equal to 0.97.

of higher government spending. Because aggregate demand expands more than potential output, real interest rates rise. The combination of higher real interest rates and an induced appreciation of the real exchange rate causes output to revert gradually towards baseline (due to a crowding out of private domestic demand and real net exports). However, the Taylor rule does not raise real interest rates enough to keep output from rising above potential, which puts upward pressure on domestic price inflation.

Comparing the alternative calibrations, it is evident that higher openness mitigates the rise in output, real interest rates, and inflation. This is attributable to several factors. First, because SIGMA specifies an equal import intensity of government and private consumption, imports play a larger role in accommodating a rise in government demand as openness increases, so the the pressure on domestic resources is correspondingly smaller. Second, openness modestly increases the interest sensitivity of the economy, so that smaller real interest rate increases are required to stabilize nominal demand. Given that our benchmark Taylor rule doesn't raise interest rates enough to completely stabilize nominal demand, the higher interest sensitivity translates into smaller output and inflation variation in a more open economy. A third reason is that the government spending shock exerts a smaller stimulative effect on potential output as the economy becomes more open. This is because openness helps smooth consumption (through borrowing), which in turn reduces the wealth effect on labor supply. Given that wages are sticky, the smaller expansion in potential output serves to put less upward pressure on domestic price inflation and real interest rates. Finally, with a larger share of trade in output, the appreciation of the dollar reduces U.S. import prices, which puts greater pressure on domestic producers to reduce their markups in order to remain competitive.[7]

As might be expected, openness also has pronounced implications for the wedge between consumer and domestic price inflation, and for the responses of the GDP expenditure components. In the nearly closed economy, domestic and consumer price inflation move together,

[7] This is a consequence of our variable markups framework, which is discussed more extensively in Section 4.4.

but the wedge between them increases as import prices (and indirectly the exchange rate) play a more important role in influencing consumer prices. Moreover, even though the effects of the government spending rise on GDP are fairly modest, the behavior of the export/GDP share indicates how exports play a much larger role in the adjustment process as the economy becomes more open.

Figure 4 shows a persistent increase in the level of technology.[8] The effects are qualitatively similar across the three calibrations. In each case, output has a hump-shaped response peaking around five or six quarters after the shock, both domestic and consumer price inflation fall on impact, and the real exchange rate depreciates.

The fall in domestic price inflation occurs because wages adjust slowly to their higher post-shock level. Openness tends to mute the decline in domestic price inflation through two channels. First, it reduces the magnitude of the rise in the real wage (by reducing the positive wealth effect on labor supply). Second, real exchange rate depreciation, and the consequent rise in import prices, induces domestic producers to raise their markup as they feel less competition from foreign producers (reflecting that our model imposes strategic complementarities in price-setting). In a more open economy, the pricing decisions of foreign exporters becomes relatively more important to the price decisions of domestic firms; thus, the rise in import prices plays a more noticeable role in moderating the fall in domestic prices.

Finally, there are pronounced differences in the composition of the output response as openness increases, with real exports playing a more prominent role, as well as in the degree of divergence between consumer and domestic price inflation. Notably, given that exchange rate depreciation pushes up import prices, consumer prices show much less of a decline in the highly open economy.

[8] The technology shock is an AR(1) process with an autocorrelation coefficient equal to 0.97.

3 The Workhorse Model

Our workhorse model builds heavily on the small open economy model of Galí and Monacelli (2005), though we extend their model to a two country setting. Thus, our model is comprised of two countries that may differ in population size, but are otherwise isomorphic (hence, our exposition focuses on the "home" country). Each country in effect produces a single domestic output good, though we adopt a standard monopolistically competitive framework to rationalize stickiness in the aggregate price level. Households consume both the domestically-produced good and an imported good: preferences are assumed to be of the constant elasticity form, which allows us to analyze the implications of home bias, and a price elasticity of import demand different from unity. Finally, we generalize the Galí and Monacelli (2005) model by incorporating nominal wage rigidities.

3.1 Households and Wage Setting

There is a continuum of monopolistically competitive households indexed by $h \in [0, 1]$, each of which supplies a differentiated labor service to an intermediate goods-producing sector (the only producers demanding labor services in our framework). It is convenient to assume that 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:

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

where $\theta_w > 0$ and $N_t(h)$ is hours worked by each member of household h. Also, ζ is the size of a household of type h and effectively determines the size of the home country's population. 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:

$$W_t = \left[\int_0^1 W_t(h)^{\frac{-1}{\theta_w}} dh\right]^{-\theta_w}. \tag{2}$$

It is natural to interpret W_t as the aggregate wage index. The aggregator's demand for the labor services of a typical member of household h is given by

$$N_t(h) = \left[\frac{W_t(h)}{W_t}\right]^{-\frac{1+\theta_w}{\theta_w}} L_t/\zeta. \tag{3}$$

The utility functional of household h is

$$\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \frac{\sigma}{\sigma-1} C_{t+j}(h)^{\frac{\sigma-1}{\sigma}} - \frac{\chi_0}{1+\chi} N_{t+j}(h)^{1+\chi}, \tag{4}$$

where $C_t(h)$ and $N_t(h)$ denote each member's current consumption and hours of labor, respectively. The intertemporal elasticity of consumption, σ, satisfies $\sigma > 0$, and we assume that $0 < \beta < 1$, $\chi > 0$, and $\chi_0 > 0$.

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:

$$P_{Ct} C_t(h) + \int_s \xi_{t,t+1} B_{t+1}(h) = B_t(h) + (1+\tau_w) W_t(h) N_t(h) + R_{Kt} K + \Gamma_t(h) - T_t(h). \tag{5}$$

(where variables have been expressed in per capita terms). We assume that household h can trade internationally in a complete set of contingent claims, with $\xi_{t,t+1}$ denoting 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 (for notational simplicity, we have suppressed all of the state indices.) Each household purchases the consumption good at a price P_{Ct}, and earns (per capita) labor income, $(1+\tau_W) W_t(h) N_t(h)$, where τ_W is an employment subsidy (designed to allow the flexible wage steady state to be efficient). Each member also has a fixed stock of capital (K) which it leases to firms at the rental rate R_{Kt}, and receives an aliquot share $\Gamma_t(h)$ of the profits of all firms as well as lump sum taxes, $T_t(h)$ from the government. In every period t, household h maximizes the utility

functional (4) with respect to its consumption and holdings of contingent claims subject to its budget constraint (5), taking bond prices, the rental price of capital, and the price of the consumption bundle as given.

We assume that household wages are determined by Calvo-style staggered contracts subject to wage indexation. 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 $W_t(h) = \omega_{t-1} W_{t-1}(h)$, where $\omega_t = W_t/W_{t-1}$. Household h chooses the value of $W_t(h)$ to maximize its utility functional (4), yielding the following first-order condition:

$$\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \xi_w^j \{ \frac{(1+\tau_w)}{(1+\theta_w)} \frac{\Lambda_{t+j}}{P_{Ct+j}} V_{wt+j} W_t(h) - \chi_{0t+j} N_{t+j}(h)^{\chi} \} N_{t+j}(h) = 0, \tag{6}$$

where Λ_t is the marginal value of a unit of consumption, and $V_{wt+j} = \prod_{h=1}^{j} \omega_{t+h-1}$. Roughly speaking, equation (6) says that the household chooses its contract wage to equate the present discounted value of working an additional unit of time to the discounted marginal cost. The employment subsidy τ_W is chosen to exactly offset the monopolistic distortion θ_W, so that the household's marginal rate of substitution would equal the consumption real wage in the absence of nominal wage rigidities.

3.2 Firms and Price Setting

Production of Consumption Goods. Final consumption goods are produced by a perfectly competitive "consumption good distributor." The representative distributor combines purchases of a domestically-produced good, C_{Dt}, with an imported good, M_{Ct}, to produce aggregate consumption, C_t, according to a CES production function:

$$C_t = \left((1-\omega_C)^{\frac{\rho_C}{1+\rho_C}} C_{Dt}^{\frac{1}{1+\rho_C}} + \omega_C^{\frac{\rho_C}{1+\rho_C}} M_{Ct}^{\frac{1}{1+\rho_C}} \right)^{1+\rho_C}, \tag{7}$$

In the above, C_{Dt} and M_{Ct} are themselves CES aggregates of domestically-produced and imported goods, respectively:

$$C_{Dt} = \left[\int_0^1 C_{Dt}\left(i\right)^{\frac{1}{1+\theta_p}} di\right]^{1+\theta_p} \quad \text{and} \quad M_{Ct} = \left[\int_0^1 M_{Ct}\left(i\right)^{\frac{1}{1+\theta_p}} di\right]^{1+\theta_p} \tag{8}$$

We assume that the form of these CES aggregators mirrors the preferences of households over consumption of domestically-produced goods and imports. Accordingly, the quasi-share parameter ω_C in equation (7) may be interpreted as determining household preferences for home relative to foreign goods, or equivalently, the degree of home bias in household consumption expenditure. As indicated by equation (7), the degree of home bias plays an important role in determining the degree of trade openness, since consumption depends only on domestic goods when $\omega_C = 0$.

A distributor sells its final consumption good to households at price P_{Ct} and also purchases $C_{Dt}(i)$ and $M_{Ct}(i)$ at their respective prices, $P_{Dt}(i)$ and $P_{Mt}(i)$, $\forall i \in [0,1]$. Profit maximization implies that the demand schedules for the imported and domestically-produced aggregate goods are given by:

$$M_{Ct} = \omega_C \left(\frac{P_{Mt}}{P_{Ct}}\right)^{\frac{-(1+\rho_C)}{\rho_C}} C_t \quad \text{and} \quad C_{Dt} = (1-\omega_C)\left(\frac{P_{Dt}}{P_{Ct}}\right)^{\frac{-(1+\rho_C)}{\rho_C}} C_t, \tag{9}$$

where $P_{Dt} = \left[\int_0^1 P_{Dt}\left(i\right)^{-\frac{1}{\theta_p}} di\right]^{-\theta_p}$ and $P_{Mt} = \left[\int_0^1 P_{Mt}\left(i\right)^{-\frac{1}{\theta_p}} di\right]^{-\theta_p}$. The zero profit condition in the distribution sector implies:

$$P_{Ct} = \left((1-\omega_C)P_{Dt}^{\frac{1}{1+\rho_C}} + \omega_C P_{Mt}^{\frac{1}{1+\rho_C}}\right)^{1+\rho_C}. \tag{10}$$

According to equation (10), in an open economy, the consumer price level depends on both domestic and foreign prices, while if an economy is closed to trade (i.e., $\omega_C = 0$), consumer prices depend only on domestic prices.

Production of Domestic Intermediate Goods. Intermediate good i is produced by a monopolistically competitive firm, whose output $Y_t(i)$ is produced according to a Cobb-Douglas production function:

$$Y_t\left(i\right) = K_t(i)^{\alpha}(Z_t L_t(i))^{1-\alpha}, \tag{11}$$

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 $K_t(i)$ and $L_t(i)$, taking as given both the rental price of capital R_{Kt} and the aggregate wage index W_t. Within a country, both capital and labor are completely mobile; thus, the standard static first-order conditions for cost minimization imply that all firms have identical marginal cost per unit of output:

$$MC_t = \left(\frac{W_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{R_{Kt}}{\alpha}\right)^{\alpha} \tag{12}$$

A producer sells its good to both domestic and foreign final consumption producers as well as to the government so that:

$$Y_t(i) = C_{Dt}(i) + G_t(i) + \frac{\zeta^*}{\zeta}M^*_{Ct}(i). \tag{13}$$

In the above, $G_t(i)$ represents government purchases of good i, and $M^*_{Ct}(i)$ denotes the purchases by the foreign final consumption producers (we use an asterisk to denote foreign variables). Since in our workhorse model, we assume that the law of one price holds for each good, we can use equation (13) to write the demand schedule for good i as:

$$Y_t(i) = \left(\frac{P_{Dt}(i)}{P_{Dt}}\right)^{-\frac{(1+\theta_p)}{\theta_p}}(C_{Dt} + G_t + \frac{\zeta^*}{\zeta}M^*_{Ct}), \tag{14}$$

where $G_t = \left[\int_0^1 G_t(i)^{\frac{1}{1+\theta_p}}di\right]^{1+\theta_p}$.

Similar to household wages, the domestic-currency prices of firms are determined according to Calvo-style staggered contracts subject to indexation. In particular, firm i faces a constant probability, $1-\xi_p$, of being able to re-optimize its price, $P_{Dt}(i)$. If firm i can not re-optimize its price in period t, the firm resets its price according to $P_{Dt}(i) = \pi_{t-1}P_{Dt-1}(i)$ where $\pi_t = P_{Dt}/P_{Dt-1}$. Since intermediate goods firms practice producer currency pricing, the foreign currency price of good i is determined as $P^*_{Mt}(i) = \frac{P_{Dt}(i)}{e_t}$, where e_t is the exchange rate expressed as units of the domestic currency required to purchase one unit of foreign currency.

When firm i can re-optimize in period t, the firm maximizes

$$\mathbb{E}_t \sum_{j=0}^{\infty} \xi_p^j \psi_{t,t+j} \left[(1+\tau_p) V_{Dt+j} P_{Dt}(i) Y_{t+j}(i) - MC_{t+j} Y_{t+j}(i) \right], \tag{15}$$

taking $\psi_{t,t+j}$, MC_t, τ_p, V_{Dt}, and its demand schedule as given. Here, $\psi_{t,t+j}$ is the stochastic discount factor and V_{Dt+j} is defined as $V_{Dt+j} = \prod_{h=1}^{j} \pi_{t+h-1}$.[9] The first-order condition for setting $P_{Dt}(i)$ is:

$$\mathbb{E}_t \sum_{j=0}^{\infty} \psi_{t,t+j} \xi_p^j \left(\frac{(1+\tau_p) V_{Dt+j} P_{Dt}(i)}{(1+\theta_p)} - MC_{t+j} \right) Y_{t+j}(i) = 0. \tag{16}$$

3.3 Monetary and Fiscal Policy

We assume that the central bank follows an interest rate reaction function:

$$i_t = \gamma_\pi (\pi_t - \pi_t^T) + \gamma_y (y_t - y_t^P), \tag{17}$$

where the variables have been specified as the logarithmic deviation from its steady state value. The nominal interest rate responds to the deviation of domestic price inflation from the central bank's exogenous inflation target, π_t^T, and the deviation of output from potential output, where potential output is defined as the economy's level of output in the absence of sticky wages and prices.

As noted above, openness can give rise to important differences between the domestic price level and the consumer price level. We specify a rule that responds to domestic price inflation rather than consumer price inflation in order to minimize differences between an open and closed economy that would simply be attributable to the monetary rule, rather than to differences in the underlying structure of the economy.

We assume that government purchases of the domestic good are exogenous. The government's budget is balanced every period so that lump sum taxes must equal government spending plus the subsidy to firms and households.

[9] As discussed earlier in the household problem, we defined $\xi_{t,t+j}$ to be the price in period t of a claim that pays one dollar if the specified state occurs in period $t+j$. Thus, the corresponding element of $\psi_{t,t+j}$ equals $\xi_{t,t+j}$ divided by the probability that the specified state will occur.

3.4 Benchmark Calibration

While we develop a number of analytical results below using our workhorse model, we find it useful to consider a benchmark calibration. Three key parameters that play a crucial role in influencing our results are the price elasticity for trade, $\eta_C = \frac{1+\rho_C}{\rho_C}$, the intertemporal elasticity of substitution, σ, and the labor supply elasticity, χ. While we choose benchmark values of these parameters to be consistent with our interpretation of the evidence, it is important to note that there is wide range of values for these parameters used in the literature and thus we also consider alternative calibrations.

For the trade price elasticity, we assume that $\rho_C = 2$ which implies $\eta_C = \frac{1+\rho_C}{\rho_C} = 1.5$. This estimate is towards the higher end of estimates derived using macroeconomic data, which are typically in the range of unity. Nevertheless, this voluminous literature has produced a wide range of estimates, with the upper bound in the vicinity of 3.[10]

We choose the intertemporal elasticity of substitution to be an intermediate value between estimates derived from two separate literatures. In the micro literature, estimates of the coefficient of relative risk aversion, which correspond to the inverse of the intertemporal elasticity of substitution suggest values in the range of 0.2-0.7.[11] In contrast, the business cycle literature frequently uses log utility over consumption (i.e., $\sigma = 1$) to be consistent with balanced growth. We set $\sigma = 0.5$ as a compromise between these two different perspectives.

The parameter χ corresponds to the inverse of the (Frisch) wage elasticity of labor supply. A vast amount of evidence from micro-data suggests labor supply elasticities in the range of 0.05-0.3, though the real business cycle literature tends to use much higher values.[12] We set

[10] While it is unsurprising that the vast empirical literature estimating trade price elasticities has reported a range of estimates, the level of aggregation used in estimation seems of crucial importance. Estimates of the long-run elasticity derived from aggregate data are typically in the range of unity, (e.g., Hooper, Johnson, and Marquez (2000). By contrast, estimates using disaggregated data are frequently in the range of 3 or even higher; see Obstfeld and Rogoff (2001) for a concise review or McDaniel and Balistreri (2003) for a more detailed survey.

[11] See, for example, Attanasio and Weber (1995), Attanasio and Weber (1997), or Barsky, Juster, Kimball, and Shapiro (1997).

[12] MacCurdy (1986) obtains a point estimate of 0.15 for the Frisch elasticity of labor supply for men, a finding largely confirmed in the literature (e.g., Altonji (1986), Card (1994), and more recently Pencavel (2002)). For an alternative view, see Mulligan (1998). Finally, there is more uncertainty regarding the labor

$\chi = 5$ for the benchmark calibration, which is at the upper end of estimates from the micro data.

We choose the remaining parameters of the model as follows. We calibrated the model at a quarterly frequency so that $\beta = 0.9925$. We set the elasticity of capital in production function, $\alpha = 0.35$ and choose χ_0 so that hours worked are normalized to unity in steady state. For the price and wage markup parameters, we choose $\theta_p = \theta_w = 0.2$, and set the corresponding subsidies to equivalent values, $\tau_p = \tau_w = 0.2$. We choose ξ_p and ξ_w to be consistent with four quarter contracts (subject to full indexation). Finally, we set the relative population size of the home economy ($\frac{\zeta}{\zeta^*}$) to 1/3. This value implies that the home economy corresponds to 25 percent of world output, which is roughly consistent with the U.S. share of world output.

3.5 The Flexible Price and Wage Equilibrium

It is useful to begin our analysis by investigating the behavior of a log-linearized version of the workhorse model under the assumption that wages and prices are fully flexible. Our analysis closely parallels that of Galí and Monacelli (2005), aside from modest differences arising from our two country framework, the inclusion of a government spending shock, and allowing for diminishing returns to labor. However, while their paper focused on the formal similarity between open and closed economy models, our goal is to explore the quantitative differences that arise as an economy becomes more open, and how these differences depend on underlying structural parameters such as trade price elasticities. Toward that end, we find it is helpful to provide a more detailed examination of how the underlying labor demand and supply schedules – which determine output, employment, and the real wage in the flexible price equilibrium – are affected as the degree of openness of the economy changes.

The labor demand schedule is derived directly from the firm's optimality condition for choosing its price, recalling that the latter implies that the marginal product of labor equals the product real wage (i.e., the product real wage is expressed in units of the domestically

supply elasticity for females. For this group, Pencavel (1998) obtains a point estimate of 0.21.

produced good). Thus, the (inverse) labor demand schedule may be expressed:

$$\zeta_t^d = mpl_t = (1-\alpha)z_t - \alpha L_t, \tag{18}$$

so that the "demand real wage" ζ_t^d varies inversely with hours worked; or equivalently, substituting for hours using the production function:

$$\zeta_t^d = z_t - \lambda_{mpl} y_{dt}, \tag{19}$$

so that ζ_t^d depends on output with a slope coefficient $\lambda_{mpl} = \frac{\alpha}{1-\alpha}$. Clearly, both the slope of this schedule and the manner in which it is affected by shocks is identical to the case of a closed economy.

The labor supply schedule is derived from the household's optimality condition equating its marginal rate of substitution between leisure and consumption to the consumption real wage. It is convenient to express labor supply in terms of the product real wage, so that:

$$\zeta_t^s = mrs_t = \chi_{0t} + \chi L_t + \frac{1}{\sigma} c_t + \omega_c \tau_t \tag{20}$$

where mrs_t should be interpreted as the marginal cost of working in terms of the domestically produced good, and τ_t is the ratio of the price of imports to the price of exports or the terms of trade.

Figure 5 illustrates the determination of labor market equilibrium in response to a rise in government spending. The pre-shock equilibrium occurs at point A. In a closed economy, the rise in government spending shifts the labor supply schedule outward to point D, reflecting that the higher spending depresses private consumption (from c^* initially, to c^{***} after the shock). In an open economy, the labor supply schedule is affected by both an adverse wealth effect (movement from A to B), and by an induced appreciation of the terms of trade (from B to C). The partial effect of the terms of trade appreciation is to shift labor supply outward (with the size determined by the openness parameter ω_c), since any given product real wage translates into a higher consumption real wage. The figure indicates a smaller outward shift in labor supply in the open economy (i.e., from A to C) compared with the closed

economy. While this is not a necessary implication of our model – as discussed below – it seems intuitively plausible under a reasonable calibration on two grounds. First, financial market risk-sharing should reduce the relative magnitude of the consumption decline in the open economy, at least if goods are fairly good substitutes across countries. Second, the shift in labor supply due to the terms of trade effect is necessarily small if goods are sufficiently substitutable (since terms of trade movements are minimal when goods are very close substitutes).

This argument can be supported directly by simply solving for the flexible price equilibrium. But for heuristic purposes, it is useful to follow Galí and Monacelli (2005) to represent derive a labor supply schedule expressed exclusively in terms of labor (or output) and endogenous shocks, as is familiar from the closed economy analogue, i.e.,

$$\zeta_t^{s,closed} = \chi_{0t} + \chi L_t + \frac{1}{\sigma}\frac{1}{1-g_{cy}}((1-\alpha)(L_t+z_t) - g_{cy}g_{ct}) \tag{21}$$

To do so, we begin by using the risk-sharing condition to express private consumption as a function of the terms of trade and foreign private consumption:

$$c_t = c_t^* + \frac{1}{\sigma}(1-\omega_c-\omega_c^*)\tau_t \tag{22}$$

Using this condition, the import demand equation, and the production function for the final consumption good, home demand for the domestically-produced good can be expressed as a simple function of the terms of trade:

$$c_{Dt} = c_{Dt}^* + \left[\sigma(1-\omega_c-\omega_c^*) + (\omega_c+\omega_c^*)\eta_c\right]\tau_t \tag{23}$$

Substituting this condition and the export demand function into the resource constraint, domestic output can be expressed as a function of the terms of trade (and foreign shocks):

$$y_{Dt} = (\sigma^{open}\tau_t + c_{Dt}^*)(1-g_{cy}) + g_{cy}g_{ct} \tag{24}$$

where the parameter σ^{open} is defined as:

$$\sigma^{open} = \sigma[\omega_c\ \frac{\eta_c}{\sigma} + (1-\omega_c)(1+(\omega_c+\omega_c^*)(\frac{\eta_c}{\sigma}-1))] \tag{25}$$

Finally, substituting (23) and (24) into (20), and using the production function, the labor supply schedule for an open economy may be expressed:

$$\zeta_t^s = \chi_{0t} + \chi L_t + \frac{(1-\omega_c^*\eta_c)}{\sigma^{open}}\frac{1}{1-g_{cy}}((1-\alpha)(L_t+z_t) - g_{cy}g_{ct}) + [\frac{1}{\sigma} - \frac{(1-\omega_c^*\eta_c)}{\sigma^{open}}]c_{Dt}^* \quad (26)$$

Comparing the open economy labor supply schedule (26) with its closed economy analogue (21), it is clear that the expressions are identical except for the parameter multiplying the second term involving labor hours, and the extra term involving foreign consumption in (26). Thus, the implications of openness for how domestic shocks affect labor market equilibrium must operate exclusively through effects on the slope coefficient $\frac{(1-\omega_c^*\eta_c)}{\sigma^{open}}$ in the labor supply curve. In particular, the behavior of output, the real wage, and employment in an open economy with an intertemporal elasticity of substitution of σ, trade price elasticity of η_c (same for imports and exports), trade openness of ω_c, and relative size of γ must be identical to that in a closed economy in which the intertemporal elasticity of substitution equals to $\frac{(1-\omega_c^*\eta_c)}{\sigma^{open}}$. [13]

By analogy with the closed economy, the second term involving labor hours (26) can be interpreted as capturing a wealth effect on labor supply. Tables 1 and 2 use equation (25) to quantify how this generalized wealth effect coefficient σ^{open} depends on its underlying determinants, including the degree of openness of the economy (with the first table based on a relatively low Frisch elasticity of 0.2, the latter on a high elasticity of one).

The tables help illuminate conditions under which openness can markedly influence the effects of real shocks on output, the real wage, and employment. In particular, one way in which openness can have large effects is through changing the wealth effect of shocks on labor supply, which in our model means driving a wedge between σ^{open} and σ. As can be seen from equation 25, openness dampens the wealth effects of shocks – implying a rise in σ^{open} compared with σ – provided that the trade price elasticity η_c exceeds the intertemporal

[13] Equivalently, the behavior of output under flexible prices and wages in an open economy with any given set of structural characteristics could be replicated by suitably adjusting a single parameter – the intertemporal elasticity of substitution – of the closed economy.

elasticity σ. Intuitively, to the extent this condition is satisfied, goods are more substitutable across countries, and can be reallocated through insurance arrangements to mitigate wealth effects on a small open economy. By illustration, Table 1 shows that for a calibration with an intertemporal elasticity of 0.25 and trade price elasticity of 1.5, a one percent rise in technology increases output by 0.65 percent in the highly open economy, compared with only 0.49 percent in the closed economy. It is clear from the consumption response – which is only a quarter as large in the highly open economy – that this pattern is consistent with a smaller wealth effect on labor supply as openness increases.

The second way in which openness matters is through its effect on the slope of the MRS schedule. Since the MRS depends on the sum of the wealth effect parameter and the inverse Frisch elasticity χ, changes in the wealth effect parameter σ^{open} associated with greater openness have much larger effects on the slope of the MRS schedule when the Frisch elasticity of labor supply is relatively high (i.e., low χ), as can readily be seen through comparing Tables Tables 1 and 2. Importantly, the MRS slope varies to a much greater extent under the high Frisch elasticity case in Table 2, so that openness affects not only the scale of shocks, but also how they operate on the economy. Using the same calibration of the intertemporal and trade price elasticities as in the preceding paragraph, Table 2 shows that the output and real wage responses are much more sensitive to the openness of the economy (so that output expands only 0.33 percent in the closed economy, but 0.64 percent in the highly open economy).

The implications of the two open economy channels for the effects of a technology shock are illustrated in Figure 6. For comparison, the left panel shows the response in a closed economy, while the right panel shows the response in an open economy. In each case, the MRS schedule is expressed exclusively in terms of hours and endogenous shocks, i.e., using (21) and (26) for the closed and open economy, respectively. The technology shock shifts the labor demand schedule up by one percent in both the closed and open economy (recalling that this schedule is the same in each). In the closed economy, the wealth effect is determined by the parameter σ, which for illustrative purposes is assumed to be less than

unity. Accordingly, the wealth effect on labor supply dominates the substitution effect. In the new equilibrium at point B, hours worked decline, and the real wage rises (in part because the hours decline reinforces the effect of the exogenous rise in productivity on labor's marginal product). Turning to the open economy case, the structural parameters of the open economy are assumed to imply a value of (σ^{open}) that exceeds unity (e.g., from Table 1, $\sigma = 0.25$ and $\eta_c = 6$ implies $\sigma^{open} = 3$). In this case, the open economy MRS schedule shifts inward by much less (i.e., from A to E) than its closed economy counterpart (from A to D in the left panel), reflecting that the wealth effect is damped in the open economy as consumption varies less with hours worked. Moreover, the MRS is considerably flatter in the open economy case. With the substitution effect dominating the wealth effect, labor hours expand, and although the real wage rises, it increases by less than in the closed economy (reflecting the effects of diminishing returns to labor on labor's marginal product).

This comparison provides an intuitive confirmation of the message of Table 1 that, under certain conditions, potential hours, output, and employment in an open economy may respond very differently than in a closed economy. The disparities between the two settings are most pronounced under conditions that damp the wealth effect in an open economy (higher trade price elasticity than intertemporal elasticity, high trade share, small relative size of domestic economy), and that flatten the MRS schedule (the same conditions that attenuate the wealth effect, combined with a high Frisch elasticity). In terms of Figure 6, provided that goods are highly substitutable across countries and the Frisch elasticity is very high, the effects of the technology shock on the real wage as an economy becomes more open become negligible, and all of the rise in labor demand must translate into an employment expansion (reflecting that the slope of the MRS schedule flattens, and the inward shift in the MRS becomes very small).

But while increased openness can have large effects in principle, we believe that under plausible calibrations it is likely to have less dramatic implications for flexible-price employment, output, and the real wage. As suggested by Table 1, for trade price elasticities in the neighborhood of 1 to 1.5, and a Frisch elasticity of one-half or below (both in the typical

range of macro estimates), differences between the closed and open economy responses to a technology shock are quite small, though somewhat larger in the case of a government spending shock.

Our analysis in this simplified framework proves helpful in accounting for the salient features of the output responses in the SIGMA simulations of Section 2. Thus, the smaller effects of government spending shocks in an open economy in SIGMA are basically attributable to a smaller wealth effect on labor supply. Moreover, our simplified model helps account for why technology shocks have very similar effects on output in SIGMA (although technology shocks induce a smaller inward shift in labor supply in the open economy – with the partial effect of causing output to rise by more than in the closed economy – this effect in SIGMA is small enough that it is masked by other influences, including those introduced by endogenous capital).

3.6 Sticky Prices and Wages

We next turn to analyzing the model's behavior in the presence of nominal wage and price rigidities. Toward this end, it is very useful for heuristic reasons to consider the behavior of our model under the assumption that it is a small open economy (i.e., as the relative population size converges to zero). As can be verified numerically, this turns out to be a good approximation even when the home population is a fairly substantial fraction of the world population (e.g., impulse responses are virtually unchanged from those in the small open economy case when the population size rises to 10 percent of the world, or roughly the size of Japan).

Under this small open economy assumption, the log-linearized behavioral equations can be expressed in a particularly simple form that is essentially identical to that derived in the closed economy model of Erceg, Henderson, and Levin (2000), allowing for indexation of wages and prices.

$$x_t = x_{t+1|t} - \sigma^{open}(1 - g_{cy})(i_t - \pi_{t+1|t} - r_t^N) \tag{27}$$

$$\Delta\pi_t = \beta\Delta\pi_{t+1|t} + \kappa_p(\zeta_t - mpl_t) \tag{28}$$

$$\Delta\omega_t = \beta\Delta\omega_{t+1|t} + \kappa_w(mrs_t - \zeta_t) \tag{29}$$

$$mpl_t = \zeta_t^N - \lambda_{mpl} l_t = \zeta_t^N - \frac{\lambda_{mpl}}{(1-\alpha)} x_t \tag{30}$$

$$mrs_t = \zeta_t^N + \lambda_{mrs}\ l_t = \zeta_t^N + \frac{\lambda_{mrs}}{(1-\alpha)} x_t \tag{31}$$

$$\zeta_t = \zeta_{t-1} + \omega_t - \pi_t \tag{32}$$

where x_t is the output gap (i.e., $y_t - y_t^N$), l_t is the employment gap, r_t^N is the "natural" real interest rate (i.e., under flexible prices and wages), ζ_t^N the natural rate wage, and the composite parameters are defined by $\kappa_p = \frac{(1-\xi_p)(1-\beta\xi_p)}{\xi_p}$, $\kappa_w = \frac{(1-\xi_w)(1-\beta\xi_w)}{\xi_w(1+\chi\frac{1+\theta_w}{\theta_w})}$, $\lambda_{mpl} = \alpha$, and $\lambda_{mrs} = \chi + \frac{1-\alpha}{\sigma^{open}(1-g_{cy})}$.

As in Galí and Monacelli (2005), (27) can be regarded as an open economy IS curve, with the interest sensitivity determined by $\sigma^{open}(1 - g_{cy})$, rather than by $\sigma(1 - g_{cy})$ as in a closed economy. The price-setting equation (44) specifies the change in domestic price inflation to depend on the future expected change in inflation and real marginal cost, the difference between the real wage and marginal product of labor. The wage-setting equation (29) specifies the change in wage inflation to depend on the future expected change in wage inflation and the difference between the MRS and real wage (both in product terms). The MRS and MPL equations can be specified to depend only on real wage under flexible prices ζ_t^N, and either the output or employment gap. By substitution, it is evident that the forcing variable driving price inflation can be regarded as depending directly on the output gap x_t, and inversely on the "wage gap" $\zeta_t - \zeta_t^N$; while wage inflation depends positively on both the output and wage gap.

Taken together, the formulation given by equations (27) - (32), together with the monetary policy rule, are very instructive in identifying how openness affects the response of the output gap, inflation, and real interest rates to real and nominal shocks. Clearly, the only way for the equilibrium with sticky prices and wages to be affected by openness is either through effects on the slopes of the MRS and MPL schedules, or through changes in the flexible price responses ζ_t^N and r_t^N. But as we showed in the last section, the composite parameter σ^{open} provides a summary statistic for how the flexible price equilibrium is affected by openness; and moreover, because this is also true for the slopes of the MRS and MPL schedules (λ_{mpl} and λ_{mrs}, respectively), it follows that openness can only affect the sticky price equilibrium through the parameter σ^{open}.

The immediate implication is that differences between closed and open economy responses – including of nominal variables such as inflation – can only be substantial under the same conditions that drive a significant wedge in the flexible price equilibrium. Thus, openness can create a large wedge if the trade price elasticity is significantly higher than the intertemporal substitution elasticity, and if the Frisch elasticity of labor supply is relatively high. Under these conditions, the economy changes in three important ways as it becomes more open. First, the slope of the MRS schedule flattens as the economy becomes more open, which reduces upward pressure on wages as output rises above potential. Accordingly, openness can matter by affecting the behavior of wages and real marginal cost. Second, higher openness affects the flexible price real wage response ζ_t^N, which acts as a shift variable in affecting the responses under sticky prices; for example, the previous section showed that higher openness reduced the wealth effect associated with productivity and government spending shocks, which served to damp the shift in ζ_t^N.[14] As we discuss below, this has important consequences for monetary policy tradeoffs in the presence of real wage rigidities. Finally, the IS curve "steepens," with greater openness. Thus, output becomes more sensitive to

[14] This is not true for all real shocks. For example, the real wage response would increase with greater openness in response to the labor preference shock χ_{0t}, reflecting that employment would move by more along a stable labor demand schedule.

the real interest rate, and by implication, smaller changes in interest rates are required to stabilize output. From an intuitive perspective, this steeping of the IS curve reflects that exports can be regarded as a function of the product of the trade price elasticity, and the long-term real interest rate (through the UIP condition). If the trade price elasticity exceeds the intertemporal substitution elasticity, exports will effectively be more interest-sensitive than domestic demand, so increasing the weight on the latter will increase the overall interest sensitivity of domestic output.

These considerations are useful in interpreting how impulse responses to the same three shocks considered above in our SIGMA simulations depend on the openness of the economy. Figure 7 compares responses to a 1 percentage point decline in the inflation target. It is evident that output contracts by a somewhat larger amount – and price inflation falls more sharply – in the highly open economy. The larger output contraction occurs because the target reduction causes a rise in real interest rates, and the interest-sensitivity of output rises with greater openness in our benchmark calibration (quantitatively, $\sigma^{open}(1 - g_{cy})$ rises from 0.45 under the "nearly closed" calibration to 0.86 in the high openness case). The larger output gap puts greater downward pressure on prices and wages, notwithstanding that wages are slightly less sensitive to a given-sized change in output. Nevertheless, the differences in the responses of aggregate output, inflation, and the real interest rate across alternative calibrations of openness appears small. The main difference is simply that exports drive a substantial fraction of the GDP contraction in the open economy case.

Figure 8 compares the effects of a rise in government spending across the three calibrations. The responses of output and inflation diverge noticeably with openness, with output and inflation rising much more in the closed-economy calibration. Because the Taylor rule nearly keeps output at potential, the differences in the output responses reflect that the wealth effect on labor supply is larger in a closed economy (following the discussion of the flexible price equilibrium). Moreover, with real wages adjusting downward slowly following the shock, the real wage gap is also larger and more persistent in the closed economy. As seen from equation (44), the larger real wage gap generates significantly greater upward pressure

on inflation.

In our workhorse model, the government purchases only domestic goods. However, there is probably some import content to government purchases, and Figure 9 considers an alternative in which the import content of government purchases is the same as private consumption. In this case, there is a larger difference between the response of output and domestic inflation in the closed and open economies, as more of the government spending increase falls on imports in the highly open economy. The differences are not dramatic, however, even though this alternative probably overstates the import content of government purchases.

Figure 10 compares the effects of a highly persistent rise in technology. The response of output is somewhat larger in the highly open calibration, while the response of the real wage is smaller. These effects – especially after the first few quarters – are easily understood from the discussion of the flexible price equilibrium, in which we showed how greater openness (assuming $\eta_m > \sigma$ as under our benchmark calibration) tends to flatten the slope of the labor supply schedule. Because the flexible price wage jumps a bit less in the highly open economy, the real wage gap tends to be a bit smaller (in absolute value) on average, which mainly accounts for the smaller fall in inflation.

But notwithstanding some differences, the salient feature of the foregoing results is that even substantial variation in openness seems to have fairly small effects on the responses, except in the case of the government spending shock; and even in the latter case, while output responses diverge markedly across calibrations, they are uniformly small given the size of the underlying shock (i.e., a rise in government spending of 1 percent of baseline GDP only raises output by 0.3 percent in the closed economy case). Taken together, these simulations are very helpful in understanding the main features of the SIGMA simulations considered in Section 2. In particular, for trade price elasticities in the range typically estimated in the macro literature, and for labor supply estimates below about 0.5, closed and open economy responses are very similar quantitatively as well as qualitatively. In addition, with real wages also exhibiting similar variation, the tradeoff frontier facing a monetary policymaker with the same objectives for output, domestic inflation, and possibly wage inflation are also nearly

the same, irrespective of openness.

We conclude this section by illustrating a case in which openness exerts fairly dramatic effects on the impulse responses of the model. In particular, Figure 11 shows responses to the technology shock for varying degrees of openness under an alternative calibration that imposes a very high trade price elasticity of 6, and a Frisch elasticity of labor supply of 1. As seen in Table 2, the wealth effect parameter $\sigma^{open}(1 - g_{cy})$ rises from 0.45 under the "nearly closed" calibration to 0.86 in the high openness case, consistent with roughly a halving of the slope of the MRS schedule. Because the Taylor rule nearly keeps output at potential, the differences in the output responses can again be understood in terms of the flexible price equilibrium: namely, openness considerably dampens the wealth effect of the technology shock on labor supply, so that output rises more in an open economy than in a closed (and employment rises instead of falls). The smaller rise in the real wage in the open economy case implies a much smaller real wage gap (in absolute value), and accounts for why inflation falls only about half as much on impact. Accordingly, as suggested by the figure, a policymaker concerned about the variability of domestic price inflation and the output gap would face a markedly improved tradeoff locus in the open economy. However, we emphasize that obtaining significant divergence does appear to require very extreme assumptions about the trade price and labor supply elasticities.

3.7 Variance Tradeoff Frontiers

A limitation of our preceding analysis that characterized policy as following a simple (Taylor-style) interest rate reaction function is that it is difficult to disentangle what features of the transmission channel change with trade openness. In particular, it is hard to ascertain whether differences are attributable to disparities in the "IS" block of the model, i.e., in the interest-sensitivity of the economy, or in the equations governing aggregate supply.

Toward this end, we consider an alternative formulation in which monetary policy is determined by an optimal targeting rule that minimizes the following quadratic discounted loss function:

$$\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j (\pi_{t+j}^2 + \lambda_x x_{t+j}^2), \tag{33}$$

where λ_x is the relative weight on the output gap. The policymaker is assumed to minimize the loss function subject to the behavioral equations of the "small open economy" variant of our model above given by equations (27)- (32). This case parallels related analysis in a closed economy setting (as in Clarida, Galí, and Gertler (1999) and Woodford (2003)) insofar as the optimal policy does not depend on the model's IS curve (at least given our assumption that the policymaker's loss function does not penalize interest rate variability).

The left panel of Figure 12 shows a policy tradeoff frontier between inflation and output gap variability for the case of a technology shock. The tradeoff frontier is obtained by minimizing the policymaker's loss function (33) over all possible values of λ_x subject to equations (27)- (32). For visual clarity, the tradeoff frontiers are shown only for the alternative calibrations of a highly open economy (in which the trade share is 35 percent), and the nearly closed case (with a trade share of 1 percent). Under either calibration, the standard deviation of inflation declines to zero as the policymaker's weight on the output gap λ_x declines to zero, while output gap variability declines to zero as λ_x approaches infinity.

As is familiar from closed-economy analysis, the presence of wage rigidities gives rise to an interesting tradeoff between stabilizing the output gap and inflation. However, the striking feature of the figure is that the tradeoff frontiers are virtually identical, notwithstanding very pronounced differences in trade openness. This similarity reflects that the *only* channels through which trade openness can affect the tradeoff frontier is by affecting the slope of the MRS schedule (recalling the MPL is invariant), or by affecting the potential real wage ζ_t^N; as noted above, while openness affects the slope of the IS curve and potential real interest rate r_t^N, this is inconsequential for a policymaker loss function such as (33) that does not explicitly depend on the interest rate. Thus, insofar as it is clear from Table 1 that the potential real wage and slope of the MRS show little variation with openness, it is unsurprising that the policy frontier are nearly identical.

Although the policy tradeoff frontiers are nearly identical, the right panel – which plots how interest rate volatility varies with λ_x – shows that implementation of the policy implies considerably less real interest variation in the more open economy. This simply reflects that openness markedly raises the interest sensitivity of the economy, even if not the slope of the MRS schedule (as seen from Table 1, σ_{open} rises from 0.5 in the closed economy case to 1.1 when the trade share is 35 percent). Thus, most of the relatively small differences in the transmission of the technology shock shown in Figure 10 are in fact attributable to the aggregate demand block of the model. In particular, if the Taylor rule "took account" of the lower interest sensitivity of the economy in the same manner as the optimal targeting rule, real interest rates would fall by less in response to a positive technology shock, so that the output gap and inflation responses would be even closer to those depicted in Figure 10 (this is easily verified by plotting impulse responses under the optimal rule).

Figure 13 considers how the highly open and closed economy policy frontiers shift given changes in key structural parameters that affect the slope of the MRS schedule. The upper panel shows that even adopting an extremely high value of the trade price elasticity η_c of 3, and a high Frisch elasticity of labor supply of 0.5 (i.e., $\chi = 2$), is not sufficient to induce much of a disparity between the tradeoff frontiers. This seems especially remarkable in light of the wide range of values of the trade openness parameter considered. Not surprisingly, the high trade price elasticity does drive a large wedge in the variability of the interest rate response associated with any given policy rule, i.e., value of λ_x.

The policy frontiers may show considerable more variation with openness, but only under rather extreme calibrations. Thus, the middle panel shows that the open economy tradeoff frontier would move further inside the (nearly) closed economy frontier in the case in which the Frisch elasticity of labor supply is extremely high ($\chi = .05$ corresponds to a Frisch elasticity of 20). In this case, the wealth effect dominates the behavior of the MRS slope, so that the latter flattens considerably with openness. Provided that the MPL slopes downward enough, this tends to greatly reduce variation in the potential real wage – and with real wages sticky, improves the tradeoff locus open to policymakers. However, the manner in which the

tradeoff frontier varies with openness in an environment with an extremely flat MRS tends to be highly sensitive to the slope of the MPL schedule (unlike under our benchmark, in which the frontier is much less sensitive to the slope of the MPL). As illustrated by the last panel, the open economy tradeoff frontier actually lies well outside the closed economy frontier if the MPL slope is reduced to 0.05 in absolute value.

4 Alternative Model Specifications

Our workhorse model made a number of simplifying assumptions to keep the analysis tractable. We now investigate the robustness of these conclusions to several extensions of the model widely used in the open economy literature including incomplete asset markets, imported intermediate goods, and local currency pricing.

4.1 Incomplete International Financial Markets

Our workhorse model assumes that asset markets are complete both domestically and internationally. However, there is considerable evidence that international financial markets do not provide full insurance from country-specific risks. We therefore consider an alternative in which households only have access to a non-state contingent international bond.

We denote this asset, denominated in foreign currency, as $B_{Ft+1}(h)$, and rewrite the household budget constraint as:

$$\begin{array}{c} P_{Ct}C_t\left(h\right)+\int_s \xi_{Dt,t+1}B_{Dt+1}(h)+\frac{e_t P^*_{Ft}B_{Ft+1}(h)}{\phi_{Ft}(b_{Ft+1})}=W_t\left(h\right)N_t\left(h\right)+R_{Kt}K+ \\ \Gamma_t\left(h\right)-T_t\left(h\right)+B_{Dt}(h)+e_tB_{Ft}(h). \end{array} \tag{34}$$

where $B_{Dt+1}(h)$ denotes state-contingent bonds traded amongst domestic households. We follow Turnovsky (1985) and assume there is an intermediation cost, $\phi_F(b_{Ft+1})$, paid by domestic households for purchases of the international bond to ensure that net foreign assets are stationary.[15] This intermediation cost depends on the ratio of economy wide holdings of

[15] This intermediation cost is asymmetric, as foreign households do not face this cost; rather, they collect profits on the monopoly rents associated with the intermediation costs.

net foreign assets to nominal output (b_{Ft+1}):

$$\phi_F(b_{Ft+1}) = \exp\left(-\upsilon_F \frac{e_t P^*_{Ft} B_{Ft+1}(h)}{P_{Dt} Y_t}\right) \tag{35}$$

and rises when a country is a net debtor; thus, effectively, raising the interest rate paid on foreign debt. We set υ_F to be very small ($\upsilon_F = 0.001$), which effectively implies that uncovered interest rate parity holds in our model.

Since financial markets are no longer complete internationally, the risk sharing condition (i.e., equation (22) no longer holds and the domestic economy's level of net foreign assets influences the model's dynamics. The evolution of net foreign assets can be determined from the households' budget constraints, and in our linearized economy, this expression relates the evolution of net foreign assets to an economy's trade surplus:

$$b_{Ft+1} = \frac{1}{\beta} b_{Ft} + \omega_C \left(m^*_{ct} - \tau_t - m_{ct}\right). \tag{36}$$

The panels on right side of Figure 14 show the effects of an increase in technology in the alternative version of the model in which international financial markets are incomplete. In the highly open economy, output rises a bit more than in the closed economy, while domestic inflation does not fall as much. The results are very similar to the workhorse model in which financial markets are complete (shown on the left side of Figure 14). In an open economy, as discussed in Schmitt-Grohé and Uribe (2003), consumption rises less in the complete market case than the incomplete markets case, reflecting that domestic households have effectively agreed to share the wealth increase associated with the higher technology with foreign households. However, consumption only rises a bit higher under incomplete markets given a substitutability of home and foreign goods near one, and as a result, there are not large differences in the response of the economy whether asset markets are complete or incomplete.

The above result suggests that the degree of financial integration (i.e., moving from incomplete to complete markets) does not have large effects on the transmission of domestic shocks. However, greater financial integration can in principle alter the transmission of

domestic shocks. Figure 15 shows the effects of a persistent increase in the growth rate of technology with a trade price elasticity of six and a Frisch labor supply elasticity of 1.[16] This shock boosts the expected future income of domestic households relative to their current income. Under incomplete markets, households borrow from abroad to finance their higher consumption by running a trade deficit. The wealth effect from the shock reduces a household's desired labor supply, which mitigates the expansion in output. In contrast, under complete markets, consumption does not rise as much, output expands more, and there is a trade surplus associated with the acceleration in productivity. In general, these differences between incomplete and complete markets are greater for shocks with large wealth effects, for greater substitutability between home and foreign goods, and for more elastic labor supply schedules.

4.2 Endogenous Investment

To simplify our analysis, the workhorse model assumed that the stock of capital was fixed. We now investigate the robustness of our results when we incorporate endogenous investment into the workhorse model.

We assume that households augment their stock of capital according to:

$$K_{t+1}(h) = (1-\delta)K_t(h) + I_t(h), \tag{37}$$

where $I_t(h)$ and $K_t(h)$ denote household investment and beginning of period t stock of capital, respectively. The household budget constraint is also modified to reflect investment purchases:

$$\begin{array}{c} P_{Ct}C_t\left(h\right) + P_{Ct}I_t\left(h\right) + \int_s \xi_{t,t+1}B_{t+1}(h) = W_t\left(h\right)N_t\left(h\right) + R_{Kt}K_t(h) + \\ \Gamma_t\left(h\right) - T_t\left(h\right) + B_t(h) - P_{Dt}\phi_{It}(h). \end{array} \tag{38}$$

In equation (38), ϕ_{It} denotes an adjustment cost given by:

$$\phi_{It}(h) = \frac{\phi_I}{2}\frac{\left(I_t(h) - I_{t-1}(h)\right)^2}{I_{t-1}(h)}. \tag{39}$$

[16] For this shock, we assume that technology growth follows an AR(1) with an autoregressive coefficient of 0.9.

Following Christiano, Eichenbaum, and Evans (2005) is costly to change the level of investment from the previous period. Similar to consumption, investment goods also have an import content. In particular, we assume that I_t is produced via a CES aggregator with the same share parameter, ω_C, and elasticity of substitution, $\frac{1+\rho_C}{\rho_C}$ as consumption (see equation (7)).

There are two important reasons to expect that the differences between closed and open economies observed in Section 3 would narrow in a model with endogenous investment. First, even in a closed economy, endogenous investment provides a channel for buffering consumption from the effects of shocks; thus, the ability to smooth consumption through international capital markets has a lower marginal value than in a framework that abstracts from investment (as in Section 3). Second, some of the differences in Section 3 hinge on the trade price elasticity significantly exceeding the interest sensitivity of domestic demand, so that the aggregate interest sensitivity of the economy increases with openness. Because allowing for investment markedly boosts the interest-sensitivity of domestic demand, the aggregate interest sensitivity should rise less steeply with openness (or perhaps even fall).

To illustrate these points, the upper panel of Figure 16 reexamines the reduction in the inflation target shock in the augmented model with investment. In contrast to the model with fixed capital (see Figure 7), which implied a noticeably larger output contraction in the highly open economy, the response of both output and inflation is nearly invariant to trade openness. The similar output responses reflect that the effective interest sensitivity of domestic demand and real exports is quite similar, so that putting a higher weight on the latter as trade openness rises has little effect on the overall interest sensitivity of the economy. The nearly identical inflation response reflects that greater openness has small consequences for the wage-price block of the model: roughly speaking, the Phillips Curve implied by our model is nearly invariant to openness.

The two lower panels consider alternative calibrations which show that the conditions highlighted above as potentially giving rise to large differences between closed and open economies continue to remain operative under endogenous capital accumulation. Thus, the

middle panel considers the case in which the trade price elasticity is set to 5, rather than 1.5 in our benchmark. In this case, the interest-sensitivity of trade is much higher than that of domestic demand, so that the aggregate interest-sensitivity of the economy rises with openness, and output shows a larger contraction as openness increases. The final panel combines the higher trade price elasticity with a very high Frisch elasticity of 0.05, which causes the MRS schedule to flatten considerably with greater openness. In this case, the highly open economy experiences a much larger output contraction, while inflation is nearly invariant to openness – reflecting, in essence, a noticeable flattening of the Phillips Curve as openness increases. We stress, however, that while the pronounced disparities in the lower two panels can occur in principle, rather extreme calibrations are required to elicit them.

4.3 Imported Materials

Our workhorse model treats imports as finished goods. However, many imported goods are used as intermediate inputs in production, and their use in production may alter the transmission of domestic shocks.

To investigate this possibility, we follow McCallum and Nelson (1999) and modify the production process of intermediate goods producers discussed in section 3 so that intermediate good i is produced according to the following CES gross production function:

$$Y_{Gt}(i) = \left((1-\omega_L)^{\frac{\rho_L}{1+\rho_L}} (Y_t(i))^{\frac{1}{1+\rho_L}} + \omega_L^{\frac{\rho_L}{1+\rho_L}} M_{Yt}(i)^{\frac{1}{1+\rho_L}} \right)^{1+\rho_L}. \tag{40}$$

In the above, value-added, $Y_t(i)$, is defined via the Cobb-Douglas production function given by equation (11) and $M_{Yt}(i)$ are firm i's purchases of a CES aggregate of imported goods produced by the foreign intermediate goods producers.[17] Also, the parameter ω_L determines the share of imported materials in gross production, and $\eta_L = \frac{1+\rho_L}{\rho_L}$ is the elasticity of

[17] Specifically, we assume that these foreign goods are combined using the same aggregator as final consumption goods:

$$M_{Yt} = \left[\int_0^1 M_{Yt}(j)^{\frac{1}{1+\theta_p}} dj \right]^{1+\theta_p},$$

where j indexes the foreign intermediate goods. Market clearing for M_{Yt} then requires that $M_{Yt} = \int_0^1 M_{Yt}(i)di$, where i indexes the purchases of domestic intermediate goods producers.

substitution between value-added and imported materials. We assume that capital, labor, and imported materials are perfectly mobile across firms within a country so that all firms have identical marginal costs per unit of gross output:

$$MC_{Gt} = \left((1-\omega_L) MC_t^{-\frac{1}{\rho_L}} + \omega_L P_{Mt}^{-\frac{1}{\rho_L}} \right)^{-\rho_L}, \tag{41}$$

where MC_t is marginal cost per unit of value-added defined earlier as equation (12).

As in the workhorse model, producer i sells its good to households and the government. In addition, producer i sells its good to each of the foreign intermediate goods producers so that the resource constraint for good i is

$$Y_t(i) = C_{Dt}(i) + G_t(i) + \frac{\zeta^*}{\zeta} \left(M^*_{Ct}(i) + M^*_{Yt}(i) \right). \tag{42}$$

In contrast to the workhorse model, openness can have a direct effect on the MPL schedule, as the terms of trade affect labor demand. In particular, a terms of trade appreciation increases labor demand by an amount that depends on the share parameter ω_L. In addition, the inclusion of imported materials affects labor supply through altering the wealth effect component. Quite remarkably, as shown in Appendix A, it remains possible to follow the basic logic of Section 3 to derive new composite parameter, σ_M^{open}, which captures how the wealth effect on labor supply depends on openness. More interestingly, this parameter can be related to the one obtained in the baseline model, σ^{open}, as follows: $\sigma_M^{open} = \sigma^{open}(1-\omega_L) + \omega_L \frac{(1-\omega_L^*)(1-\omega_C^*)\eta_L^*}{(1-g_{cy})}$. Using this expression, it is easy to assess the quantitative impact of openness on the slope of the labor supply schedule (similarly to our analysis in Table 1). For example, let us assume that the share of imported materials on gross production is 5 percent – ie, $\omega_L = \omega_L^* = 0.05$– and that the price elasticity gross output to materials η_L^* takes the values of the trade elasticities η_C^*. Hence, for the case of $\sigma = 0.25$, $\omega_C = 0.12$, and $\eta_C = \eta_L^* = 1.5$ then $\sigma_M^{open} = 0.52$ instead of $\sigma^{open} = 0.44$. By increasing the trade elasticities to $\eta_C = \eta_L^* = 6$, then $\sigma_M^{open} = 1.6$ instead of $\sigma^{open} = 1.4$. Thus, the differences become more relevant the higher is the value of the trade elasticities.[18]

[18] As we will later show these differences will not generate important changes to the adjustment of the economy in response to technology shocks.

We again assume that the law of one price holds and that producer i sets its price according to Calvo-style staggered contracts that are subject to indexation. However, producers are setting gross output prices in a staggered fashion rather than value-added prices, and the first order condition for goods price i is:

$$\mathbb{E}_t \sum_{j=0}^{\infty} \psi_{t,t+j} \xi_p^j \left(\frac{(1+\tau_p) V_{Dt+j} P_{Dt}(i)}{(1+\theta_p)} - MC_{Gt+j} \right) Y_{t+j}(i) = 0, \tag{43}$$

where $P_{Dt}(i)$ now has an interpretation as a gross output price and $V_{Dt+j} = \prod_{h=1}^{j} \pi_{t+h-1}$. Equation (43) can be log-linearized and rewritten as:

$$\pi_t - \pi_{t-1} = \beta(\pi_{t+1|t} - \pi_t) + \kappa_p \left[(1-\omega_L)(\zeta_t - mpl_t) + \omega_L \tau_t \right]. \tag{44}$$

where $mpl_t = (1-\alpha) z_t - \alpha L_t$, corresponds to the marginal product of labor — in terms of value added — described in section 3. In the previous expression we have written the marginal cost in terms of the value-added output to make clear that with imported materials, gross output price inflation depends on fluctuations in the terms of trade.

Relative to the workhorse model, allowing for fluctuations in imported materials has two effects on the price equation. First, the presence of materials inputs contribute to reducing the pass-through from marginal cost to prices, thus resulting in smaller price adjustments in response to higher nominal aggregate demand. Second, since a more open economy may be associated with a high fraction of imported materials in gross output production (i.e, a larger ω_L), fluctuations in the terms of trade may have a greater influence on gross output price inflation than in a closed economy. Thus, the presence of imported materials in production gives rise to an additional channel through which domestic shocks can have different effects on domestic price inflation in a closed and open economy.

To investigate the quantitative importance of imported materials, Figure 17 shows the effects of a technology shock for different degrees of openness. In each case, we set $\rho_L = \rho_C = 1.5$ and calibrated ω_C and ω_L so that material imports account for roughly 15 percent of total imports in each economy.[19] As in the workhorse model, the highly open economy experiences

[19] In the model with material imports, we vary both ω_C and ω_L to alter the ratio of imports to GDP

a larger increase in output and smaller decline in inflation. The inclusion of intermediate inputs tends to dampen the fall in inflation in response to the technology shock, reflecting that the fall in unit labor costs is offset to a greater degree by higher import prices. However, the differences between the highly open economy and the closed economy do not appear large, so that the inclusion of intermediate goods only modestly amplifies the differences evident in the workhorse model.

4.4 Pricing To Market

Our workhorse model assumed that the law of one price holds for each intermediate good. However, there is considerable empirical evidence suggesting that the law of one price does not hold. A related literature emphasizes that U.S. import prices at the point of entry respond less than one for one with a change in the exchange rate (i.e., exchange rate pass-through to U.S. import prices is incomplete). We now consider an alternative version of our model which can account for these findings.

In this alternative version, intermediate goods firms set different prices at home and abroad or 'price to market'. This pricing to market behavior arises for two reasons. First, we assume, as in Betts and Devereux (1996), intermediate goods' prices are sticky in local currency terms. We also work with aggregators for intermediate goods that have non-constant elasticities of demand as in Kimball (1995), implying that a firm may face different demand elasticities at home and abroad.

To incorporate these features, we modify the problem of the consumption goods distributor who purchases all the intermediate goods both at home and abroad to produce a final good that can be used either for private consumption, C_t, or government consumption, G_t. Using the demand aggregator discussed in Gust, Leduc, and Vigfusson (2006), the final

in each scenario; and, as a result, the more open economy is characterized by larger values of both ω_C and ω_L. However, in each scenario, the fraction of material imports to overall imports is held fixed at 15 percent, which roughly corresponds to the ratio of U.S. imports of industrial supplies and materials to total non-petroleum imports.

consumption good distributor's demand for imported and domestic good i is given by:

$$M_{Ct}(i) = \omega_C \left[\frac{1}{1-\nu} \left(\frac{P_{Mt}(i)}{P_{Mt}} \right)^{\frac{1}{1-\gamma}} \left(\frac{P_{Mt}}{P_{Ft}} \right)^{\frac{\rho}{\gamma-\rho}} - \frac{\nu}{1-\nu} \right] (C_t + G_t), \tag{45}$$

$$C_{Dt}(i) = (1-\omega_C) \left[\frac{1}{1-\nu} \left(\frac{P_{Dt}(i)}{P_{Dt}} \right)^{\frac{1}{1-\gamma}} \left(\frac{P_{Dt}}{P_{Ft}} \right)^{\frac{\rho}{\gamma-\rho}} - \frac{\nu}{1-\nu} \right] (C_t + G_t). \tag{46}$$

As in Dotsey and King (2005), when $\nu \neq 0$, these demand curves have a linear term which implies that the elasticity of demand depends on the $P_{Dt}(i)$ relative to an index of the prices of its competitors, P_{Ft}. When $\nu = 0$, the demand elasticity is constant and $\frac{1}{1-\gamma}$ has the interpretation as the elasticity of substitution between home brands (i.e., $\frac{1-\gamma}{\gamma}$ is equivalent to θ_P in the workhorse model). However, it also influences the elasticity of substitution between home and foreign goods, which is given by $\frac{\rho}{\rho-\gamma}$ when $\nu = 0$.

In these demand curves, P_{Mt}, and P_{Dt} are price indices of domestic and imported goods given by:

$$P_{Dt} = \left(\int_0^1 P_{Dt}\,(i)^{\frac{\gamma}{\gamma-1}}\, di \right)^{\frac{\gamma-1}{\gamma}} \quad \text{and} \quad P_{Mt} = \left(\int_0^1 P_{Mt}\,(i)^{\frac{\gamma}{\gamma-1}}\, di \right)^{\frac{\gamma-1}{\gamma}}, \tag{47}$$

while P_{Ft} is a price index consisting of all the prices of a firm's competitors:

$$P_{Ft} = \left[(1-\omega_C) P_{Dt}^{\frac{\gamma}{\gamma-\rho}} + \omega_C P_{Mt}^{\frac{\gamma}{\gamma-\rho}} \right]^{\frac{\gamma-\rho}{\gamma}}. \tag{48}$$

Intermediate goods producers sell their products to the consumption goods distributors and can charge different prices at home and abroad. These prices are determined according to Calvo-style contracts subject to indexation. The first order condition associated with the domestic price of intermediate good i is given by:

$$\mathbb{E}_t \sum_{j=0}^{\infty} \psi_{t,t+j} \xi_p^j \left[1 - \left(1 - \frac{MC_{t+j}}{(1+\tau_P) V_{Dt+j} P_{Dt}(i)} \right) \epsilon_{Dt+j}(i) \right] V_{Dt+j} C_{Dt+j} = 0, \tag{49}$$

where the elasticity of demand for good i in the domestic market is:

$$\epsilon_{Dt}(i) = \frac{1}{1-\gamma} \left[1 - \nu \left(\frac{P_{Dt}(i)}{P_{Dt}} \right)^{\frac{1}{1-\gamma}} \left(\frac{P_{Dt}}{P_{Ft}} \right)^{\frac{\rho}{\rho-\gamma}} \right]^{-1} \tag{50}$$

With $\nu > 0$, as in Kimball (1995), $\epsilon_{Dt}(i)$ may be an increasing function of a firm's price relative to its competitors, and a firm will not want its desired price (i.e., its optimal price in the absence of price rigidities) to deviate too far from its competitors.

Equation (49) can be log-linearized and rewritten as:

$$\pi_t - \pi_{t-1} = \beta\left(\pi_{t+1|t} - \pi_t\right) + \kappa_p\Theta\left[\zeta_t - mpl_t + \nu\mu\omega_C\eta_C(p_{Mt} - p_{Dt})\right], \tag{51}$$

where $\mu = \frac{1}{\epsilon_D - 1}$ denotes the steady state (net) markup over marginal cost, $\epsilon_D = \frac{1}{(1-\gamma)(1-\nu)}$ is the steady state value of $\epsilon_{Dt}(i)$, and $\eta_C = \frac{\rho}{(\rho-\gamma)(1-\nu)}$ denotes the aggregate elasticity between home and foreign goods in steady state. The parameter $\Theta = \frac{1}{1+\nu(1+\mu)} < 1$ reflects the degree of 'strategic' complementarity in price-setting associated with variable demand elasticity (e.g., Woodford (2003)). That is, with $\nu = 0$, a firm's demand elasticity is constant, and this expression is the same as in the workhorse model. With $\nu > 0$, there are variations in desired markups associated with changes in a firm's price relative to its competitors. In this case, inflation is less sensitive to marginal cost, and in the open economy more sensitive to foreign prices. Furthermore, the importance of foreign prices in affecting domestic inflation depends directly on the degree of openness, ω_C.

A domestic firm also sets a sticky price in the local currency of the foreign economy. These prices are also determined according to Calvo-style contracts indexed to lagged foreign import price inflation, and the log-linearized first order condition associated with the foreign price of domestic good i is:

$$\begin{aligned}\pi^*_{Mt} - \pi^*_{Mt-1} = \beta\left(\pi^*_{Mt+1|t} - \pi^*_{Mt}\right) + \kappa_p\Theta\left[(\zeta_t - mpl_t - q_{Dt}) - \right.\\ \left.(1 + \nu\mu(1-\omega^*_C)\eta_C)(p^*_{Mt} - p^*_{Dt})\right],\end{aligned} \tag{52}$$

where $q_{Dt} = p^*_{Dt} + e_t - p^*_{Dt}$ is the real exchange rate in terms of domestic prices. This expression suggests that foreign import prices will be dampened in response to changes in marginal costs and in particular changes in real exchange rates. This dampened response reflects that prices are sticky in local currency terms and the variations in desired markups. With foreign import prices remaining relatively unchanged, the response of real trade flows

will also be muted. In contrast, in the workhorse model, changes in exchange rates have a relatively large effect on import prices and thus real trade flows.

As discussed in Appendix B, we derive the analogue expression to σ^{open} for the pricing to market model. We show that for benchmark calibration this parameter is smaller than in the workhorse model. This lower value for σ^{open} reflects that the variation in desired markups mutes the responsiveness of trade prices to exchange rate changes and reduces the interest sensitivity of real trade flows. Accordingly, the difference in the response of output in a closed and open economy narrows.

To illustrate this point, Figure 18 shows the effects of a technology shock for different degrees of openness in both the workhorse model with a constant elasticity of demand and the pricing to market model with a variable elasticity. Comparing the top panels, there is a smaller difference in the response of output across the three calibrations in the pricing to market model, reflecting the lower sensitivity of aggregate demand to changes in interest rates. The response of output is also more persistent in the model, reflecting the higher degree of strategic complementarities associated with the variable desired markups.

The higher degree of strategic complementarity also implies less pass-through from marginal cost to domestic prices. Hence, there is a smaller response of inflation in the pricing to market model than the workhorse model, regardless of the degree of openness. In addition, there are relatively large difference in the response of domestic inflation across the three calibrations in the pricing to market model. These differences reflect a rise in import prices that through the complementarity in price setting between domestic and foreign firms tends to mitigate the fall in inflation. Since this pricing complementarity is relatively more important in the highly open economy, inflation in this case only falls 0.2 percentage point compared to the 0.35 percentage point fall in the nearly closed economy.

5 Conclusion

In this paper, we used an open economy DSGE model to explore how trade openness affects the transmission of domestic shocks. Our results indicate that increased trade openness and international linkages are likely to have fairly modest implications for real activity and inflation, though more pronounced effects on the composition of expenditure and the wedge between consumer and domestic prices. Accordingly, to the extent that openness changes the behavior of the domestic economy, it seems plausible that the main effects would occur through an increased role of foreign shocks.

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Appendix

This appendix describes the flexible price and wage equilibrium for the models with imported materials and variable desired markups.

A Flexible Price and Wage Equilibrium: Imported Materials

We proceed in three steps.

First, relative to the baseline model, the consideration of imported materials implies that the labor demand schedule is directly affected by fluctuations in the terms of trade. This straightforwardly follows from the firm's price setting optimality condition:

$$\zeta_t^d = (1-\alpha)z_t - \alpha L_t - \frac{\omega_L}{1-\omega_L}\tau_t \tag{A.1}$$

so that the demand real wage now varies inversely with hours and the terms of trade. For a given level of hours worked, an increase in the terms of trade (i.e. a real depreciation of domestic currency) put downward pressures on demand (product) real wages. From the previous expression (A.1) it also follows that the lower the share of imported materials on gross production, $\omega_L = 0$, the closer is the current model to the baseline one.

Second, to understand the effects of imported materials on the labor supply schedule we can obtain, after simple algebraic manipulations, a relationship among domestic output, the terms of trade, and domestic and foreign shocks:

$$\begin{aligned} y_{Dt} = (\sigma^{open}\tau_t - c^*_{Dt})(1-g_{cy})(1-\omega_L) + \omega_L(1-\omega_L^*)(1-\omega_C^*)\eta_L^*\tau_t \\ +(1-\omega_L)g_{gy}g_{Ct} + \omega_L f_t^* \end{aligned} \tag{A.2}$$

where f_t^* represents a combination of foreign variables. Relative to the benchmark model, the previous expression makes clear that fluctuations in imported materials introduce an additional effect of the terms of trade on domestic output whose intensity depends upon the share of imported materials on gross production (ω_L), the share of imports of the foreign economy (ω_C^*) and the elasticity of substitution of materials (η_L^*) and value added in the gross production. The previous expression (A.2) can be rearranged as follows:

$$y_{Dt} = (\sigma_M^{open}\tau_t - (1-\omega_L)c^*_{Dt})(1-g_{cy}) + (1-\omega_L)g_{gy}g_{Ct} + \omega_L f_t^* \tag{A.3}$$

where σ_M^{open} is given by:

$$\sigma_M^{open} = \sigma^{open}(1-\omega_L) + \omega_L\frac{(1-\omega_L^*)(1-\omega_C^*)\eta_L^*}{(1-g_{cy})} \tag{A.4}$$

which generalizes the expression of the benchmark model (i.e. if $\omega_L = 0$ we go back to the expression of the baseline model).

Third, as described in section 3, we might use expression (A.3) and the marginal rate of substitution to obtain a generalization of the expression of the product real wages as follows:

$$\zeta_t^s = \chi_{0t} + \chi L_t + \frac{(1-\omega_C^*\eta_C)}{\sigma_M^{open}}\frac{1}{1-g_{cy}}(y_{Dt} - g_{gy}g_{Ct}) \tag{A.5}$$
$$+(\frac{1}{\sigma} - \frac{(1-\omega_C^*\eta_C)(1-\omega_L)}{\sigma_M^{open}})c_{Dt}^* - \omega_L\frac{(1-\omega_C^*\eta_C)}{\sigma_M^{open}}\frac{1}{1-g_{cy}}f_t^*.$$

The second term of expression (A.4), the consideration of imported materials incorporates an extra *wealth effect* on the labor supply schedule. As previously noticed, the slope coefficient,$\frac{(1-\omega_C^*\eta_C)}{\sigma_M^{open}}$ might be smaller or larger than in the benchmark economy. In addition, taking into account the role of imported materials introduce an additional relative price (term of trade) effect into the product real wages due to fluctuations in the demand of imported materials. Formally, recall that the gross production is given by:

$$y_{Dt} = (1-\omega_L)(1-\alpha)(z_t + L_t) + \omega_L M_{yt} \tag{A.6}$$

and the demand for imported materials:

$$M_{yt} = (1-\alpha)(z_t + L_t) - \eta_L(\tau_t + z_t - \zeta_t^s) \tag{A.7}$$

Thus, combining (A.6) and (A.7) yields:

$$y_{Dt} = (1-\alpha)L_t - \omega_L\eta_L\tau_t + \omega_L\eta_L\zeta_t^s + [(1-\alpha) - \omega_L\eta_L]z_t \tag{A.8}$$

and substituting (A.8) into expression (A.5) yields

$$\zeta_t^s = \frac{\chi + \vartheta(1-\alpha)}{1-\omega_L\eta_L\vartheta}L_t - \frac{\omega_L\eta_L\vartheta}{1-\omega_L\eta_L\vartheta}\tau_t + \Psi_t$$

with $\vartheta = \frac{(1-\omega_C^*\eta_C)}{\sigma_M^{open}}\frac{1}{1-g_{cy}}$ and Ψ_t is a combination of domestic and foreign shocks that shift the mrs schedule.

B Flexible Price and Wage Equilibrium: Variable Desired Markups

We now turn to the model that incorporates changes in the desired markups. Relative to the baseline model, this model introduces variations in the marginal costs and relative prices that are unrelated to the presence of nominal rigidities. Thus, this framework allows the exchange rate to exert a fairly direct influence on domestic pricing decisions since domestic producers care about their price relative to that of foreign competitors. More formally, it is straightforward to see that from the main text expression (51), domestic price setters' marginal costs can be written as follows:

$$mc_{Dt} = \zeta_t - mpl_t = -\nu\mu\omega_C\eta_C(p_{Mt} - p_{Dt}), \tag{B.1}$$

and from the main text expression (52), it is possible to write the exporters' marginal costs as follows:

$$mc_{Dt} - q_{Dt} = (1 + \nu\mu(1 - \omega_C^*)\eta_C)(p_{Mt}^* - p_{Dt}^*) \tag{B.2}$$

where $q_{Dt} = p_{Dt}^* + e_t - p_{Dt}$ represents the real exchange rate in terms of domestic price goods.

Notice that, by symmetry, the marginal costs of the foreing producers can be written as follows:

$$mc_{Dt}^* + q_{Dt} = (1 + \nu\mu(1 - \omega_C)\eta_C)(p_{Mt} - p_{Dt}) \tag{B.3}$$

where the real exchange rate, q_t, defined in terms of consumer prices. Thus, it follows the following relationship between the real exchange rate in term of consumer prices, the real exchange rate in terms of domestic prices and the relative price of imported goods:

$$q_t = q_{Dt} - \omega_C(p_{Mt} - p_{Dt}) + \omega_C^*(p_{Mt}^* - p_{Dt}^*) \tag{B.4}$$

Also notice that the following relationship holds:

$$(p_{Ct} - p_{Dt}) = \omega_C(p_{Mt} - p_{Dt}) \tag{B.5}$$

Using previous expressions (B.2) and (B.3) into expression (B.4) we can write the real exchange rate as follows:

$$q_t = (1 - \omega_C\kappa_M - \omega_C^*\kappa_M^*)q_{Dt} + \omega_C\kappa_M mc_{Dt} - \omega_C^*\kappa_M^* mc_{Dt}^* \tag{B.6}$$

where $\kappa_M = (1 + \nu\mu(1 - \omega_C)\eta_C)^{-1}$.

We now use the relative demand for domestic consumption and imported goods, i.e.

$$c_{Dt} = \eta_C(p_{Ct} - p_{Dt}) + c_t \tag{B.7}$$

$$m_{Ct} = -\eta_C(p_{Mt} - p_{Ct}) = -\eta_C\left[(p_{Mt} - p_{Dt}) - (p_{Ct} - p_{Dt})\right] + c_t \tag{B.8}$$

From expressions (B.7), (B.5) and (B.3) it follows that:

$$c_t = c_{Dt} - \omega_C\eta_C\kappa_M\ q_{Dt} - \omega_C\eta_C\kappa_M\ mc_{Dt}^* \tag{B.9}$$

Using the previous expression for private consumption and the corresponding of the foreign economy it is possible to write the relative private consumption as follows:

$$c_t - c_t^* = (c_{Dt} - c_{Dt}^*) - \eta_C(\omega_C\kappa_M + \omega_C^*\kappa_M^*)q_{Dt} + \omega_C^*\eta_C\kappa_M^* mc_{Dt} - \omega_C\eta_C\kappa_M mc_{Dt}^* \tag{B.10}$$

Using expressions (B.6) and (B.10) into the prefect risk sharing condition yields:

$$\Lambda q_{Dt} = \sigma^{-1}(c_{Dt} - c_{Dt}^*) - \omega_C^*\kappa_M^*(1 - \sigma^{-1}\eta_C)mc_{Dt} + \omega_C\kappa_M(1 - \sigma^{-1}\eta_C)mc_{Dt}^* \tag{B.11}$$

where $\Lambda = 1 - \omega_C\kappa_M(1 - \sigma^{-1}\eta_C) + \omega_C^*\kappa_M^*(1 - \sigma^{-1}\eta_C)$. Notice that under $v = 0$, i.e. $\kappa_M = \kappa_M^* = 1$, the previous expression corresponds to the one of the baseline model.

From the equivalent expressions (B.7) and (B.8) for the foreing economy it follows that

$$m^*_{Ct} - c^*_{Dt} = -\eta_C (p^*_{Mt} - p^*_{Dt})$$

We can use the previous expression and the aggregate resource constraint of the domestic economy to write domestic output as follows:

$$y_{Dt} = (1-\omega_C)(c_{Dt} - c^*_{Dt}) - \omega_C \eta_C (p^*_{Mt} - p^*_{Dt}) + c^*_{Dt} \tag{B.12}$$

We now use expressions (B.2) and (B.11) into the previous expression to obtain

$$\begin{aligned} y_{Dt} &= \sigma \left[(1-\omega_C)\Lambda + \sigma^{-1}\omega_C \eta_C \kappa^*_M \right] q_{Dt} + \\ &\quad \sigma \left[(1-\omega_C)\omega^*_C \kappa^*_M (1-\sigma^{-1}\eta_C) - \sigma^{-1}\omega_C \kappa^*_M \eta_C \right] mc_{Dt} + \Theta^*_t \end{aligned} \tag{B.13}$$

where Θ^*_t represents a proper combination of external variables. Finally we use expressions (B.1) and (B.3) to write the marginal costs in terms of the exchange rate, i.e.

$$mc_{Dt} = -\nu\mu\omega_C \eta_C \kappa_M (mc^*_{Dt} - q_{Dt}),$$

which we use to substitute out mc_{Dt} in the previous expression (B.13). This yields the following relationship between domestic output and the real exchange rate:

$$y_{Dt} = \sigma^{open}_{VM} q_{Dt} + \widetilde{\Theta}^*_t$$

where

$$\begin{aligned} \sigma^{open}_{VM} &= \sigma \left[(1-\omega_C)\Lambda + \sigma^{-1}\omega_C \eta_C \kappa^*_M - \nu\delta \right], \\ \delta &= \mu\omega_C \eta^C \kappa_M \left[(1-\omega_C)\omega^*_C \kappa^*_M (1-\sigma^{-1}\eta_C) - \sigma^{-1}\omega_C \kappa^*_M \eta_C \right], \end{aligned}$$

and $\widetilde{\Theta}^*_t$ represents a proper combination of external variables. When $\nu = 0$, then $\sigma^{open}_{VM} = \sigma^{open}$, i.e. collapses to the expression of the baseline model.

Table 1: Slope of Reduced Form MRS Schedule for Alternative Calibrations

Benchmark Frisch Elasticity ($\chi^{-1} = 0.2$)

Parameters					Flexible Price Responses to:						
					Technology Shock				Government Spending Shock		
ω_C	σ	η_C	σ^{open}	MRS Slope	C_t	Y_t	L_t	ζ_t	C_t	Y_t	ζ_t
0	0.25	–	0.25	12	0.55	0.49	-0.25	0.74	-0.75	0.33	-0.18
	0.5	–	0.5	9.7	0.65	0.59	-0.098	0.68	-0.89	0.2	-0.11
	1	–	1	8.7	0.72	0.65	0	0.65	-0.99	0.11	-0.058
0.12	0.25	1	0.42	10	0.33	0.56	-0.13	0.7	-0.45	0.22	-0.12
	0.25	1.5	0.53	9.6	0.27	0.59	-0.088	0.68	-0.37	0.19	-0.1
	0.25	6	1.5	8.4	0.11	0.67	0.038	0.64	-0.15	0.074	-0.04
	0.5	1	0.61	9.3	0.48	0.61	-0.064	0.67	-0.66	0.17	-0.089
	0.5	1.5	0.72	9.1	0.42	0.62	-0.039	0.66	-0.58	0.14	-0.077
	0.5	6	1.7	8.3	0.19	0.68	0.048	0.63	-0.26	0.066	-0.035
	1	1	1	8.7	0.63	0.65	0	0.65	-0.87	0.11	-0.058
	1	1.5	1.1	8.6	0.58	0.66	0.011	0.65	-0.79	0.098	-0.053
	1	6	2.1	8.2	0.32	0.69	0.061	0.63	-0.43	0.054	-0.029
0.35	0.25	1	0.68	9.2	0.16	0.62	-0.049	0.67	-0.22	0.15	-0.082
	0.25	1.5	0.96	8.7	0.12	0.65	-0.0047	0.65	-0.16	0.11	-0.061
	0.25	6	3.3	8	0.035	0.7	0.082	0.62	-0.048	0.035	-0.019
	0.5	1	0.79	9	0.29	0.63	-0.028	0.66	-0.39	0.13	-0.072
	0.5	1.5	1.1	8.6	0.22	0.65	0.0074	0.65	-0.3	0.1	-0.055
	0.5	6	3.6	8	0.069	0.7	0.084	0.62	-0.094	0.033	-0.018
	1	1	1	8.7	0.47	0.65	0	0.65	-0.64	0.11	-0.058
	1	1.5	1.3	8.5	0.37	0.67	0.025	0.64	-0.51	0.086	-0.046
	1	6	3.8	8	0.13	0.71	0.087	0.62	-0.18	0.031	-0.017

Table 2: Slope of Reduced Form MRS Schedule for Alternative Calibrations

Higher Frisch Elasticity ($\chi^{-1} = 1$)

Parameters					Flexible Price Responses to:						
					Technology Shock				Government Spending Shock		
ω_C	σ	η_C	σ^{open}	MRS Slope	C_t	Y_t	L_t	ζ_t	C_t	Y_t	ζ_t
0	0.25	–	0.25	5.5	0.37	0.33	-0.49	0.82	-0.38	0.66	-0.35
	0.5	–	0.5	3.5	0.55	0.49	-0.25	0.74	-0.57	0.49	-0.26
	1	–	1	2.5	0.72	0.65	0	0.65	-0.75	0.33	-0.17
0.12	0.25	1	0.42	3.9	0.26	0.45	-0.31	0.76	-0.27	0.53	-0.29
	0.25	1.5	0.53	3.4	0.23	0.5	-0.22	0.73	-0.24	0.48	-0.26
	0.25	6	1.5	2.2	0.11	0.73	0.12	0.61	-0.12	0.24	-0.13
	0.5	1	0.61	3.2	0.43	0.54	-0.17	0.71	-0.45	0.44	-0.24
	0.5	1.5	0.72	2.9	0.39	0.58	-0.11	0.69	-0.4	0.4	-0.21
	0.5	6	1.7	2.1	0.21	0.75	0.16	0.59	-0.22	0.22	-0.12
	1	1	1	2.5	0.63	0.65	0	0.65	-0.66	0.33	-0.17
	1	1.5	1.1	2.4	0.59	0.67	0.034	0.64	-0.61	0.3	-0.16
	1	6	2.1	2	0.36	0.78	0.21	0.58	-0.37	0.19	-0.1
0.35	0.25	1	0.68	3	0.15	0.56	-0.13	0.7	-0.15	0.42	-0.22
	0.25	1.5	0.96	2.6	0.12	0.64	-0.014	0.65	-0.12	0.33	-0.18
	0.25	6	3.3	1.8	0.042	0.84	0.29	0.55	-0.044	0.13	-0.068
	0.5	1	0.79	2.8	0.27	0.6	-0.081	0.68	-0.28	0.38	-0.2
	0.5	1.5	1.1	2.5	0.22	0.66	0.022	0.64	-0.23	0.31	-0.17
	0.5	6	3.6	1.8	0.083	0.85	0.3	0.54	-0.086	0.12	-0.064
	1	1	1	2.5	0.47	0.65	0	0.65	-0.48	0.33	-0.17
	1	1.5	1.3	2.3	0.39	0.7	0.078	0.62	-0.41	0.27	-0.15
	1	6	3.8	1.8	0.16	0.86	0.32	0.54	-0.16	0.11	-0.06

Figure 1: Permanent Reduction in the Inflation Target in SIGMA
(Deviation from Steady State)

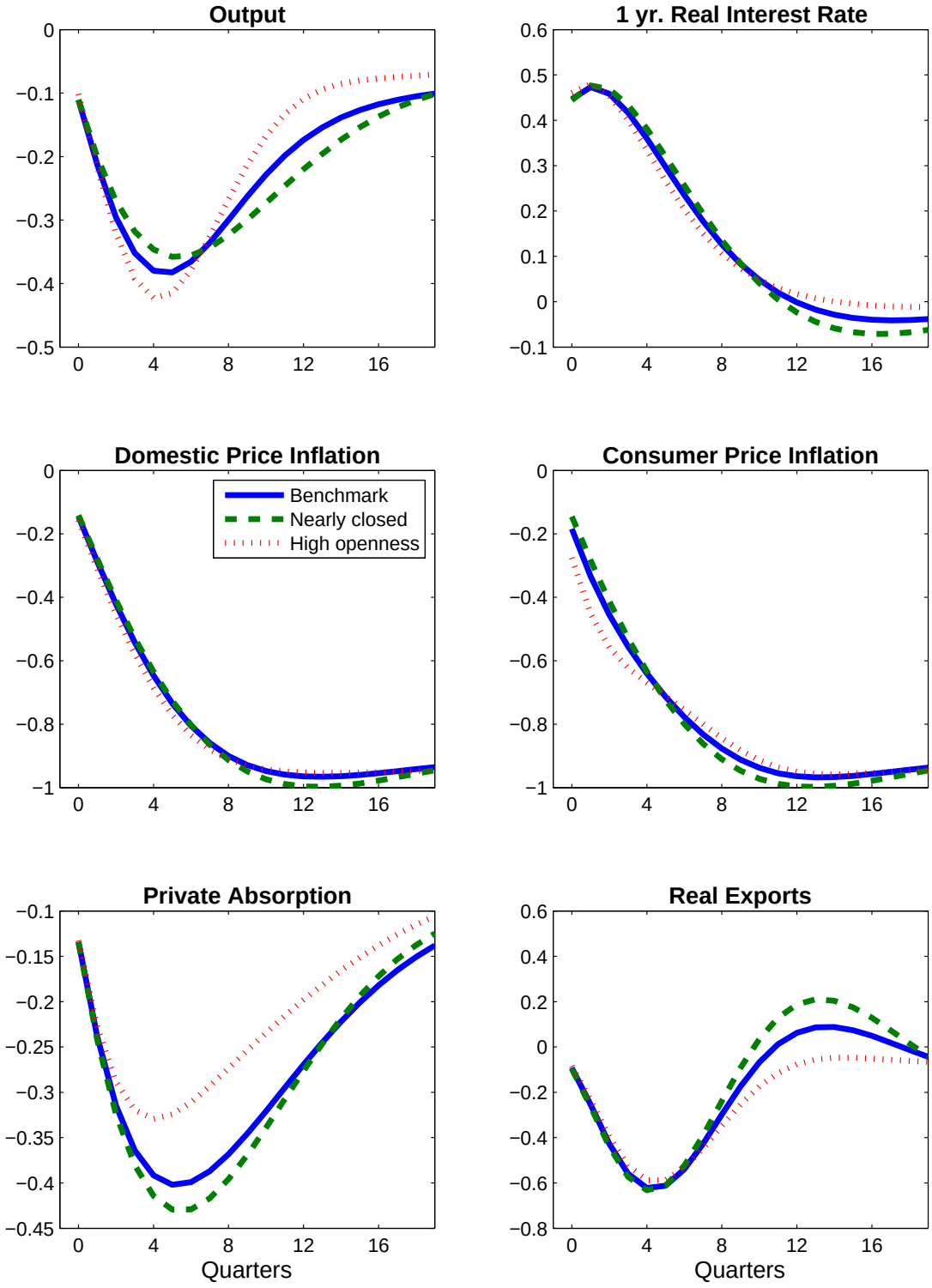


Figure 2: Disinflation Episodes in U.S., Canada, and the U.K.

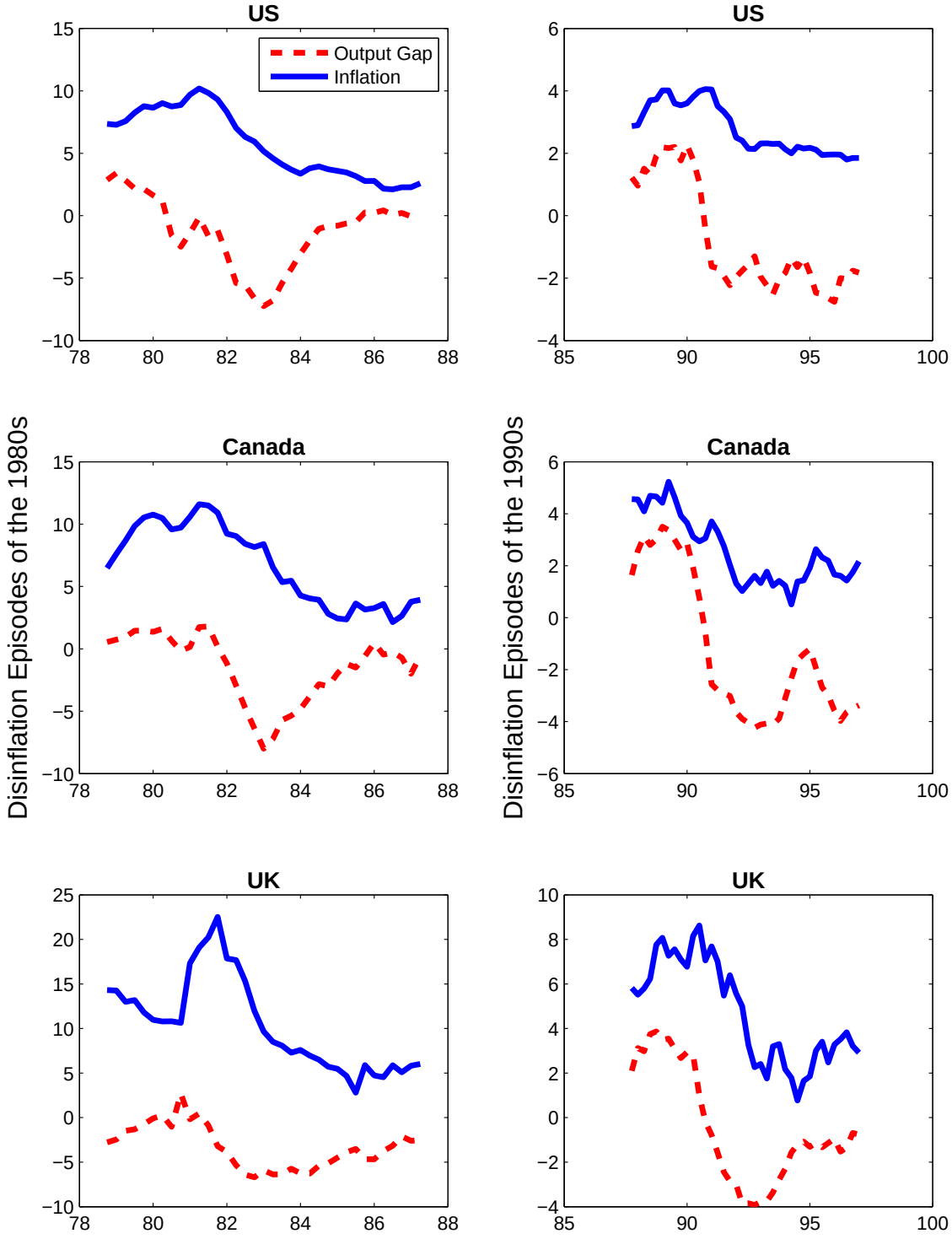


Figure 3: Increase in Government Spending in SIGMA
(Deviation from Steady State)

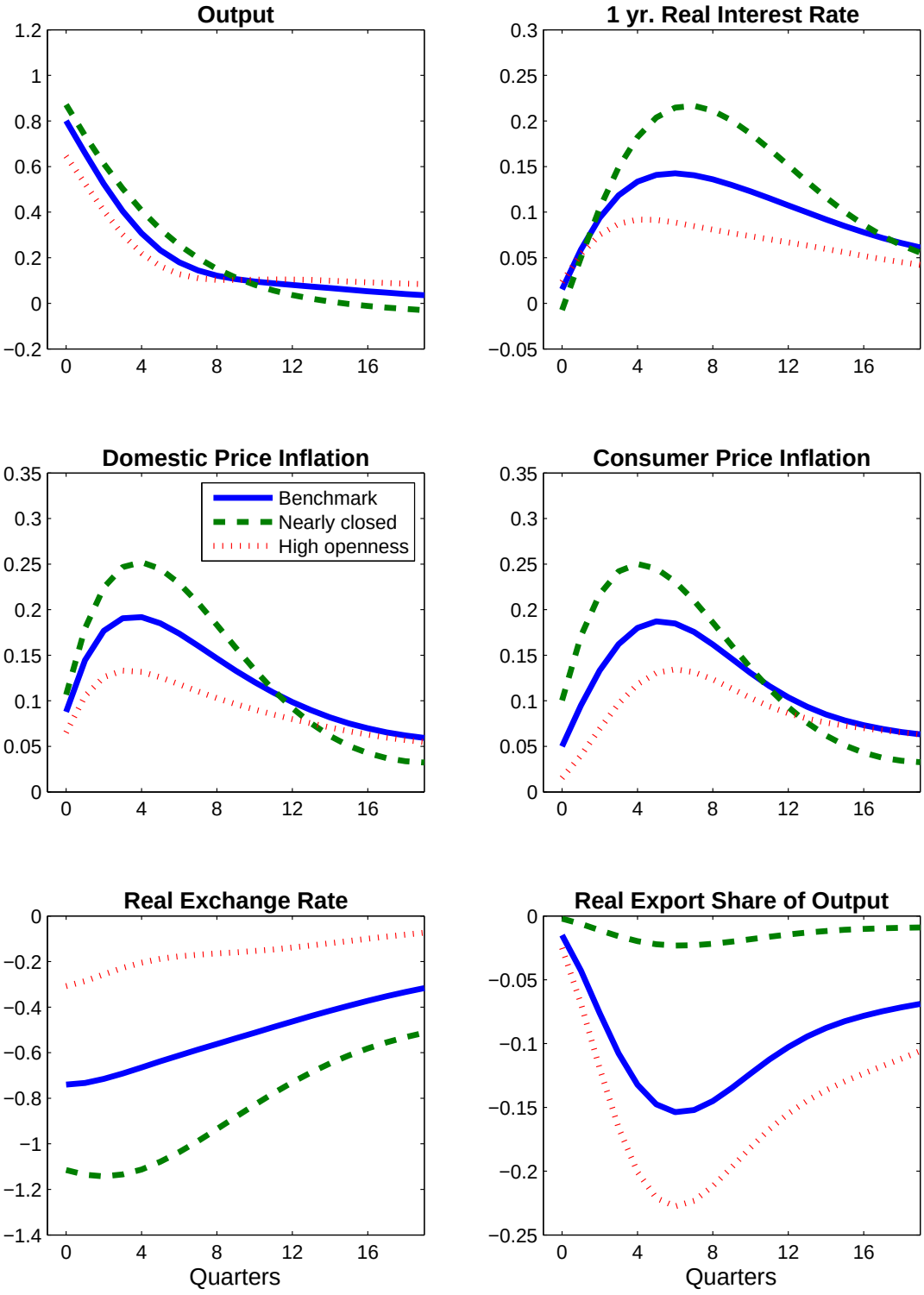


Figure 4: Increase in Technology in SIGMA
(Deviation from Steady State)

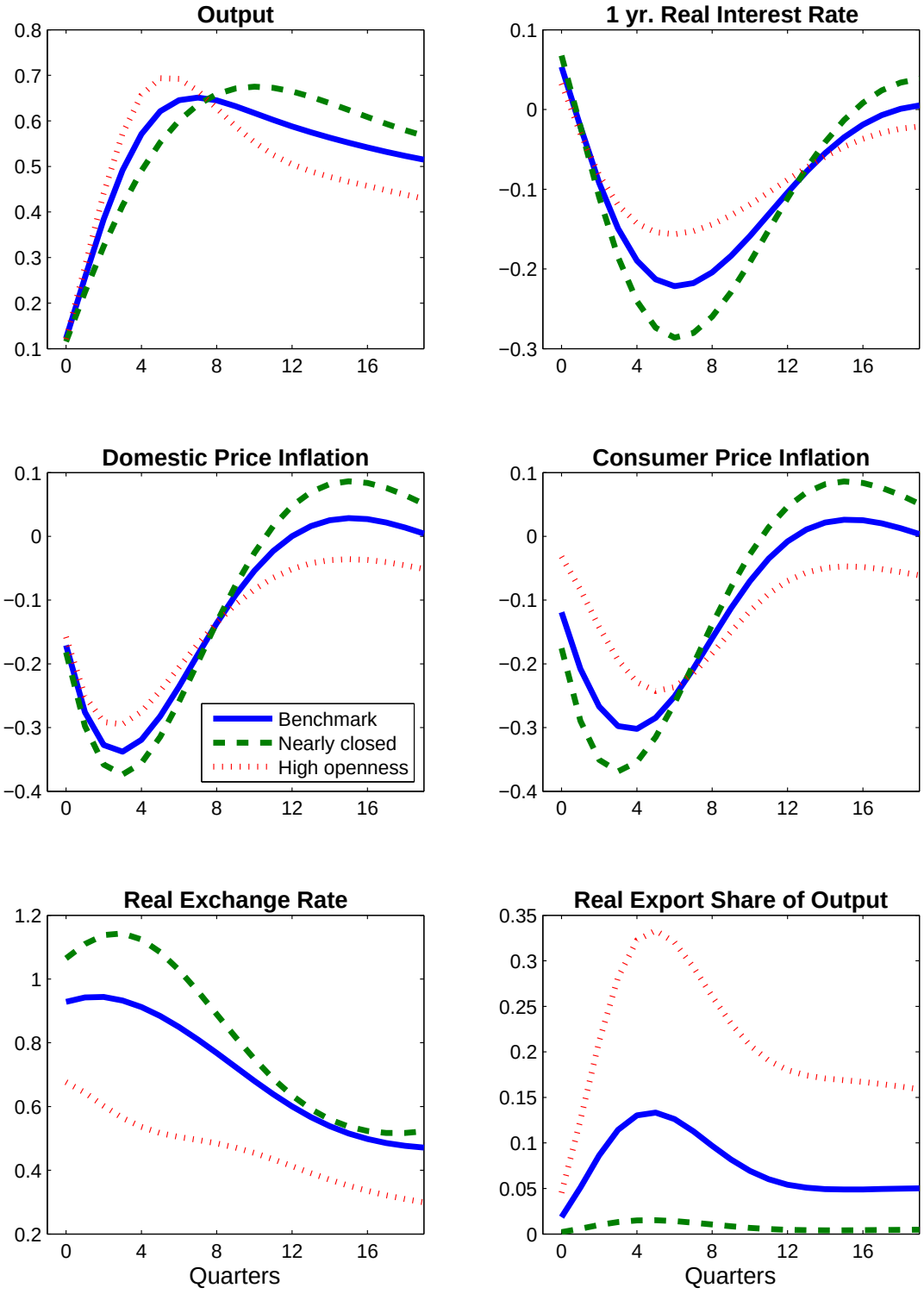


Figure 5: Rise in Government Spending: Closed vs. Open
Labor Market Equilibrium under Flexible Prices and Wages

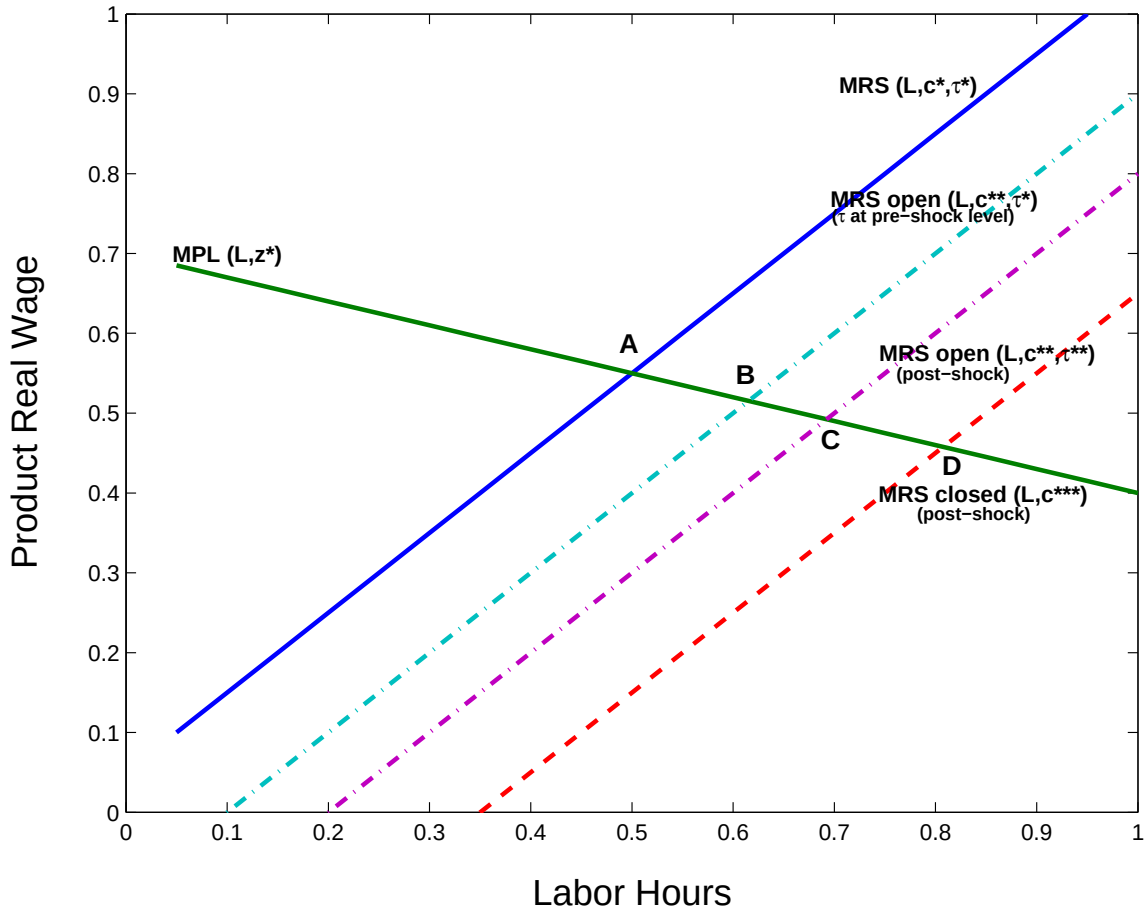


Figure 6: Rise in Technology: Closed vs. Open

Labor Market Equilibrium under Flexible Prices and Wages

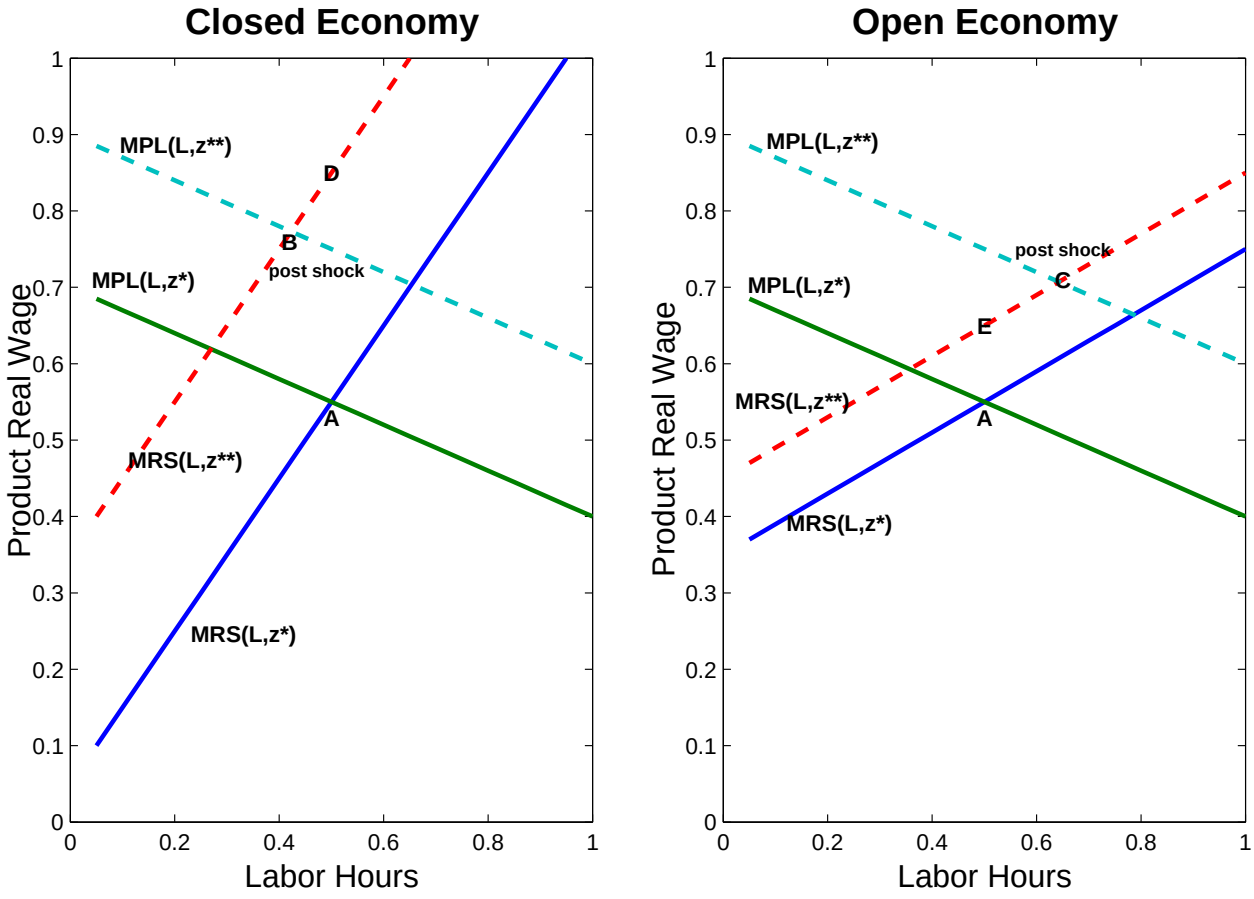


Figure 7: Increase in Inflation Target in Workhorse Model
(Deviation from Steady State)

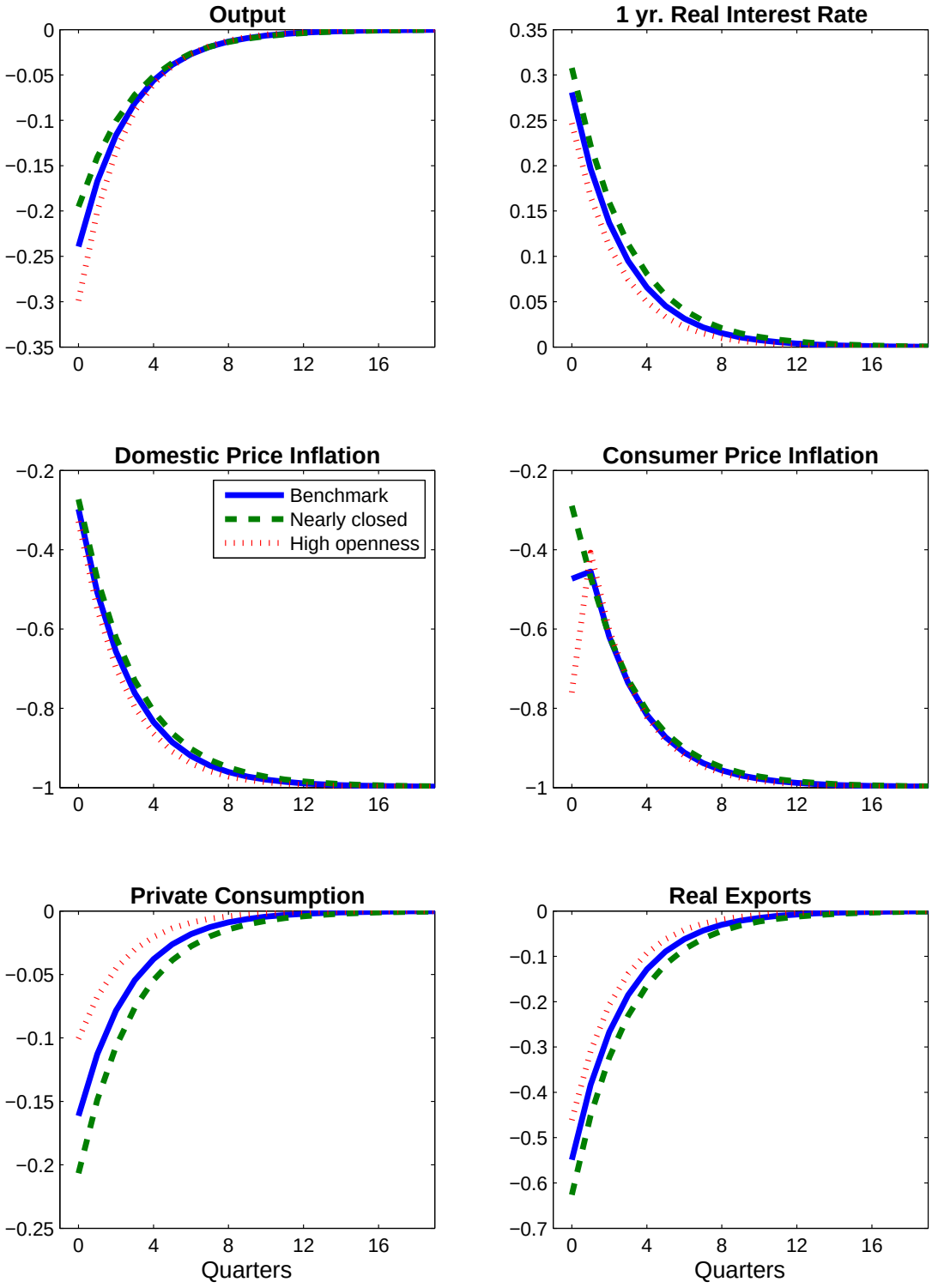


Figure 8: Increase in Government Spending in Workhorse Model
(Deviation from Steady State)

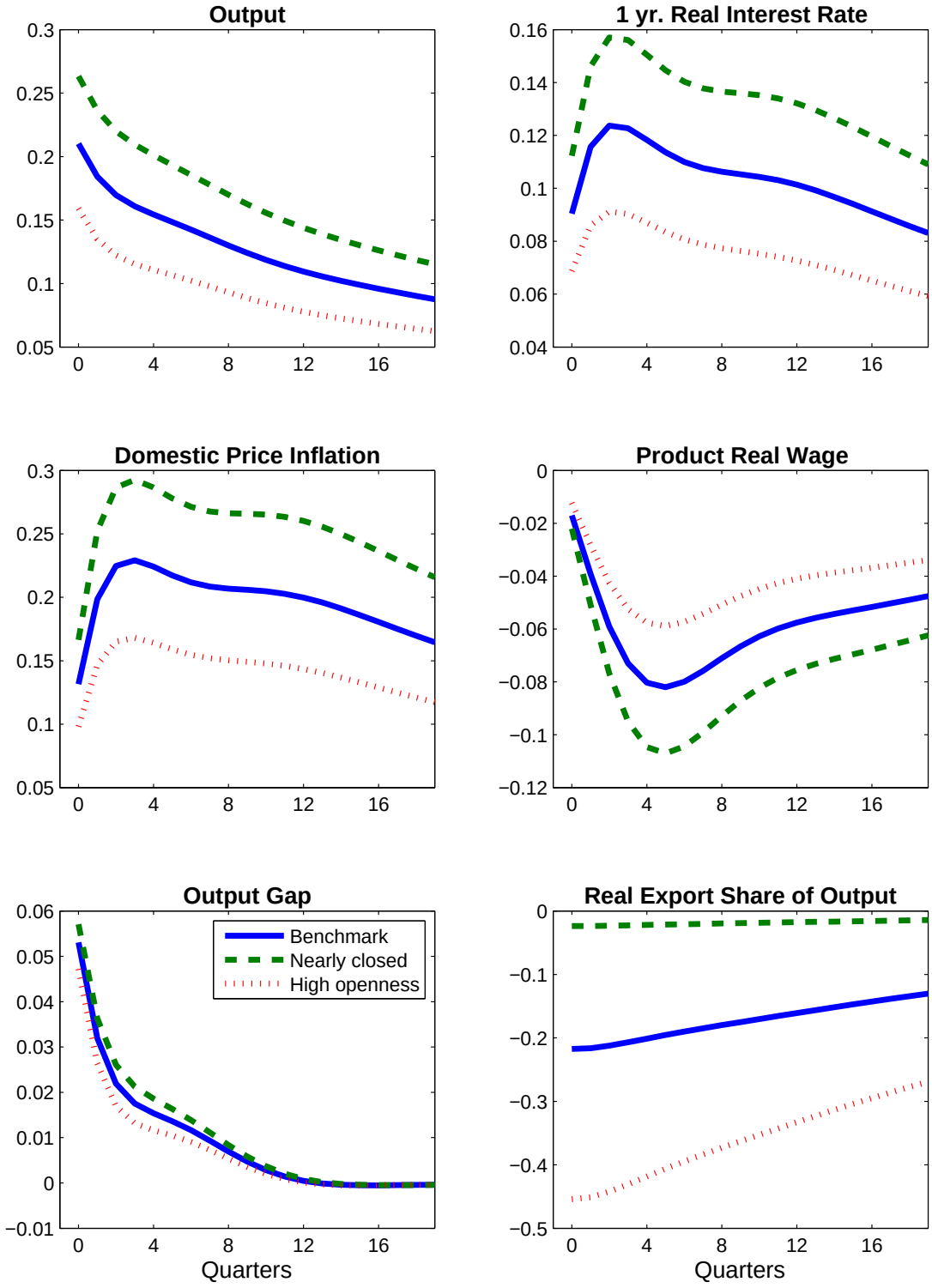


Figure 9: Increase in Government Spending (Gov't Spending Requires Imports)
(Deviation from Steady State)

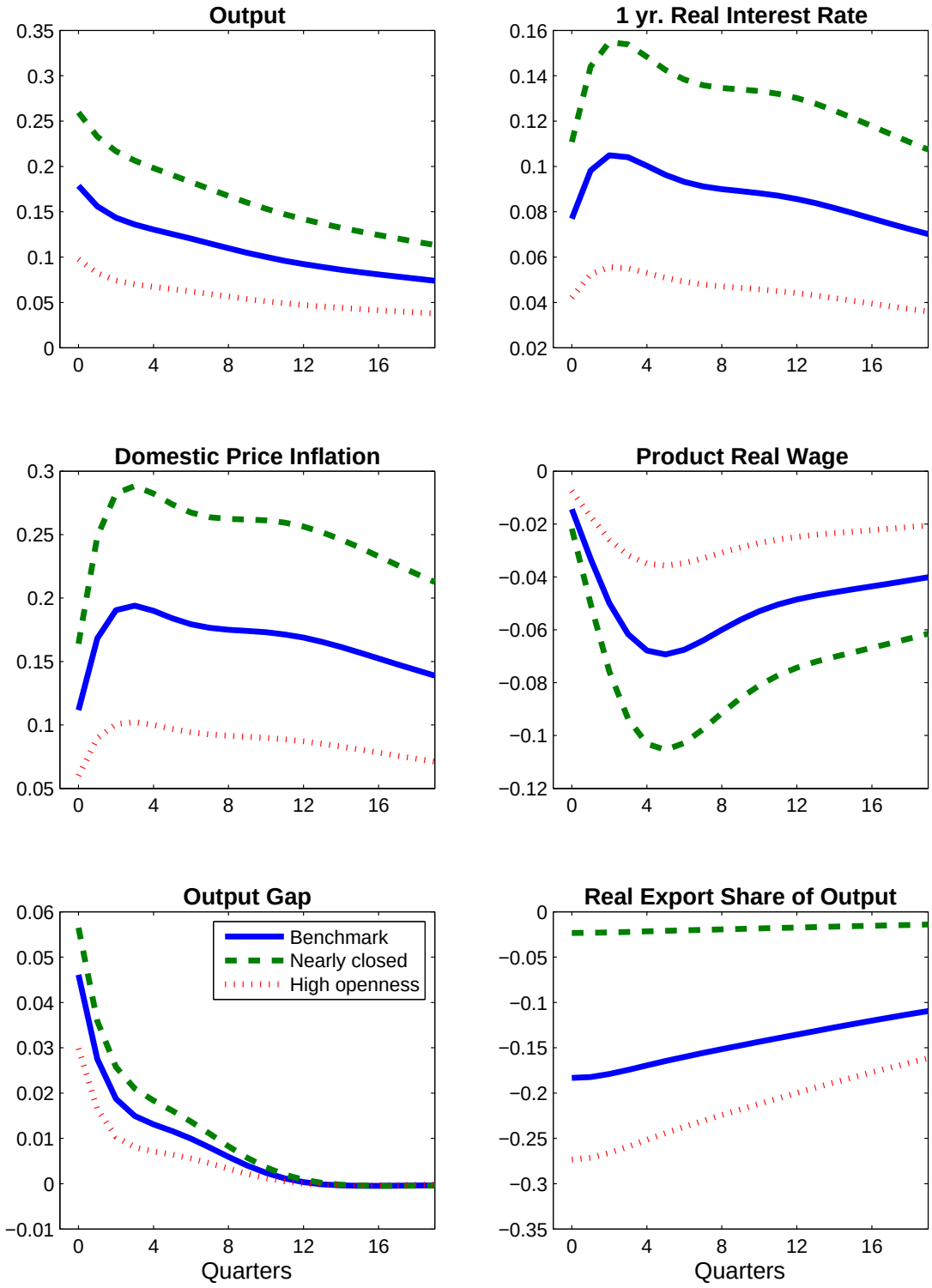


Figure 10: Increase in Technology in Workhorse Model
(Deviation from Steady State)

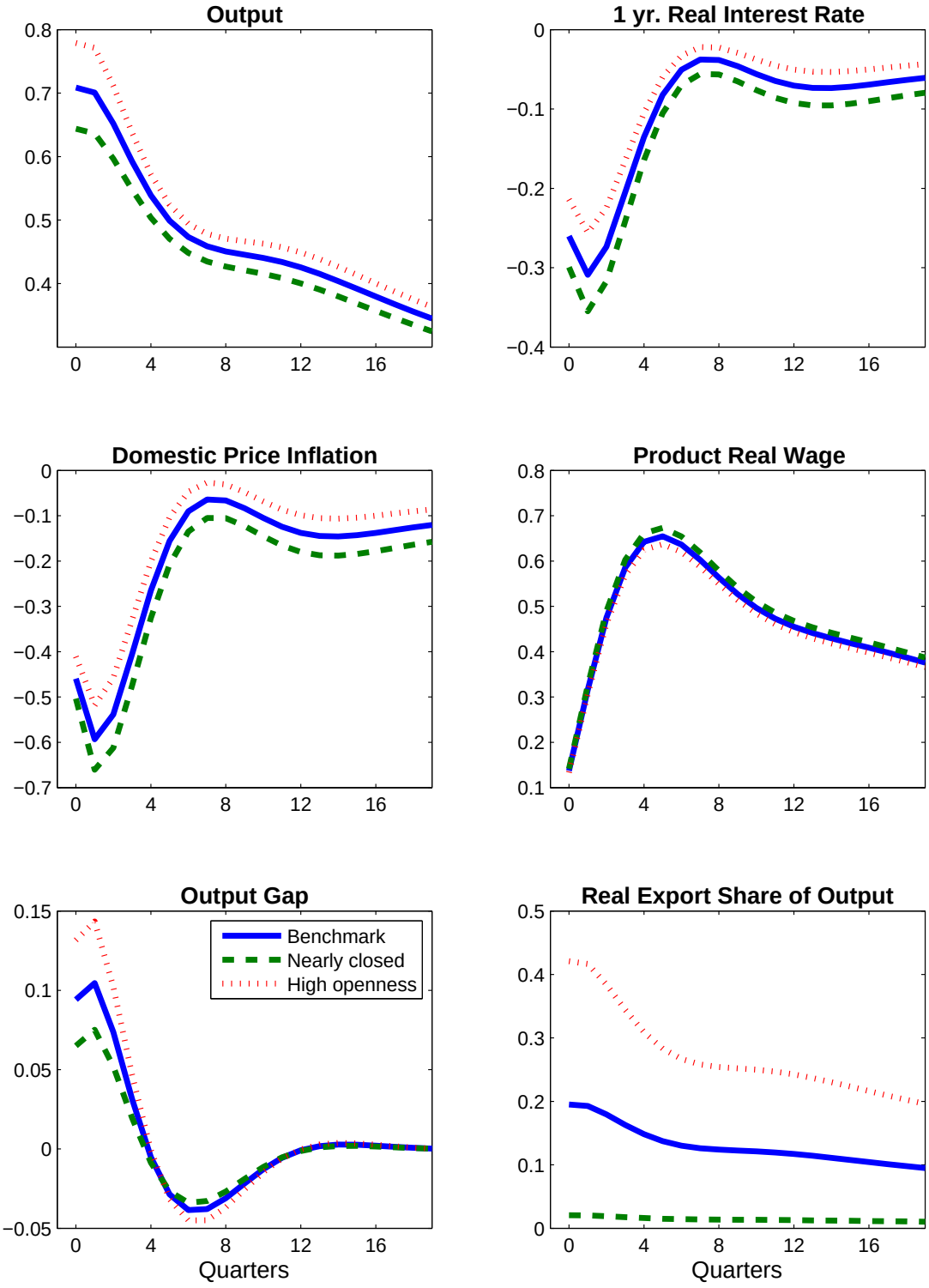


Figure 11: Increase in Technology in Workhorse Model
(Alternative Calibration: $\eta = 6$ and $\chi^{-1} = 1$)

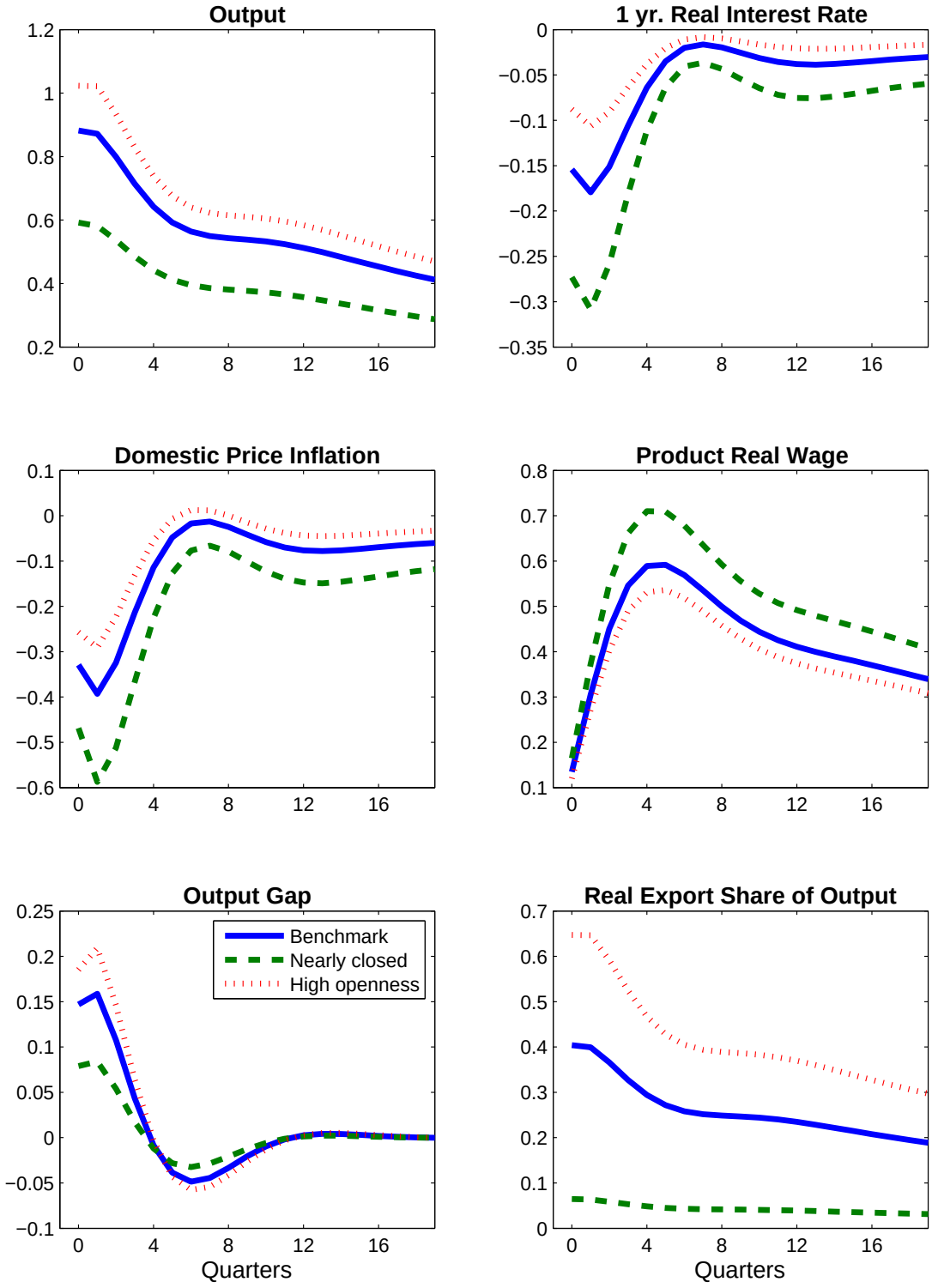


Figure 12: Policy Tradeoff Frontier for Technology Shock

Benchmark Calibration

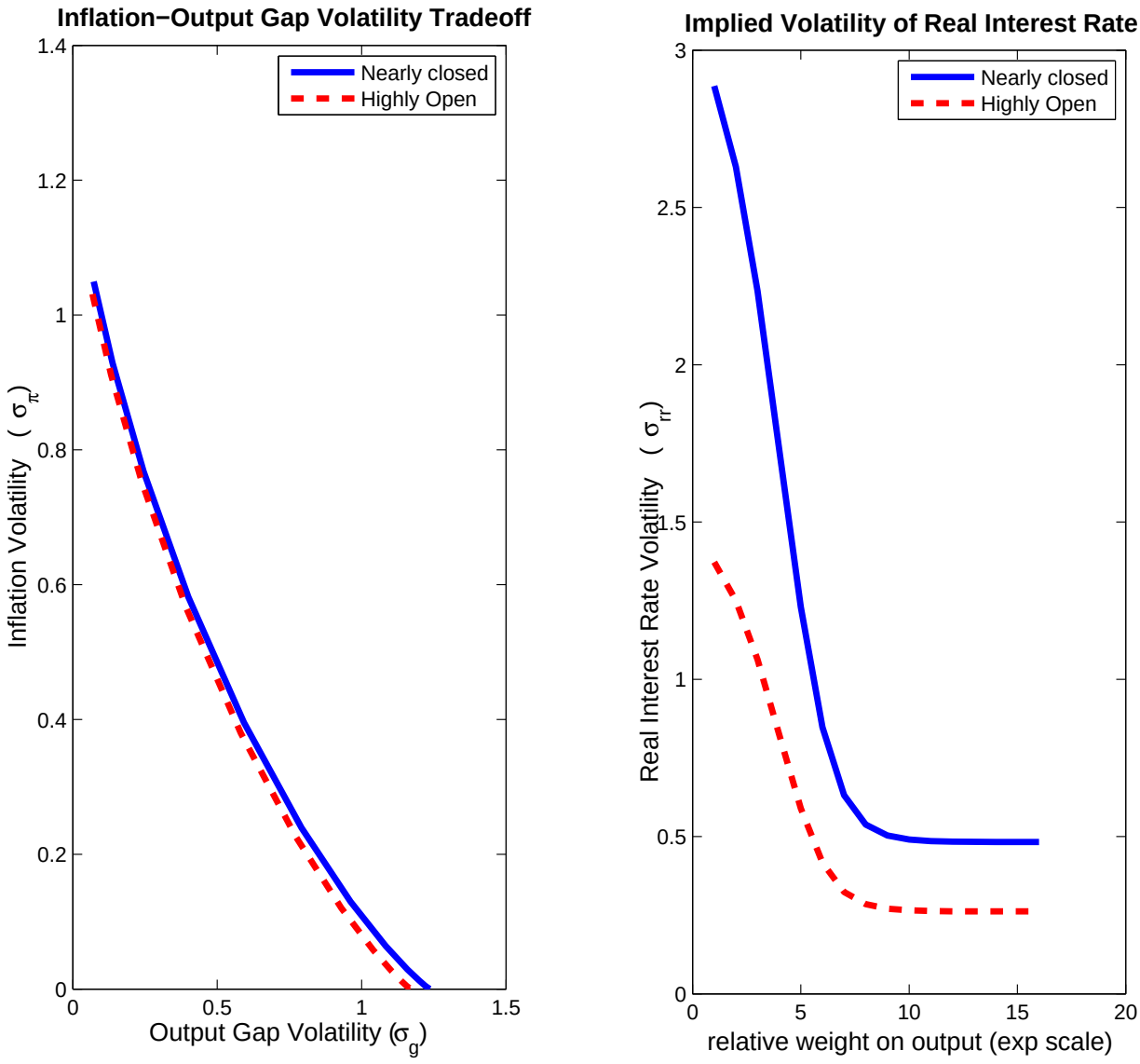


Figure 13: Policy Tradeoff Frontier for Technology Shock

Alternative Calibrations

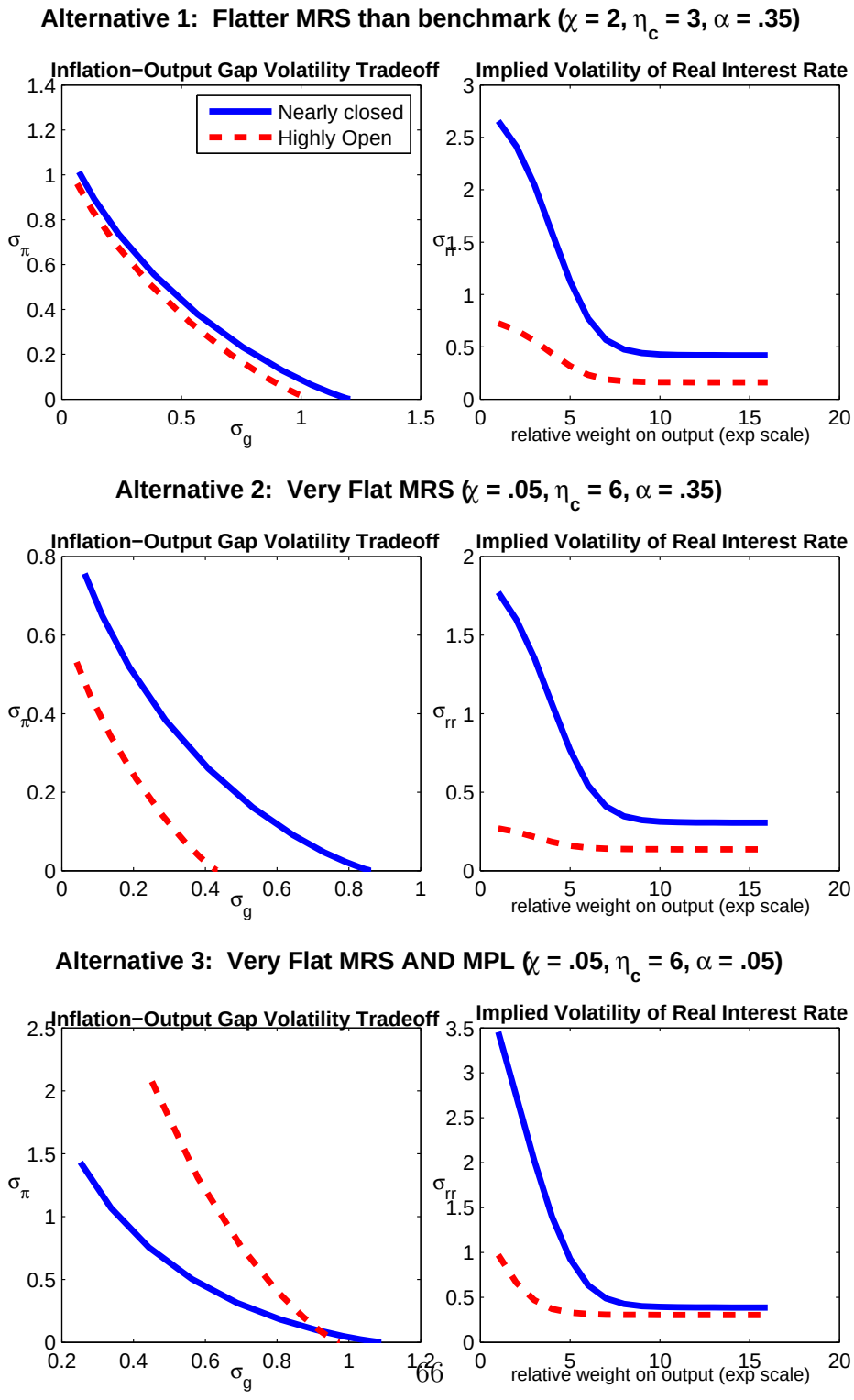


Figure 14: Increase in Technology: Complete vs. Incomplete Markets

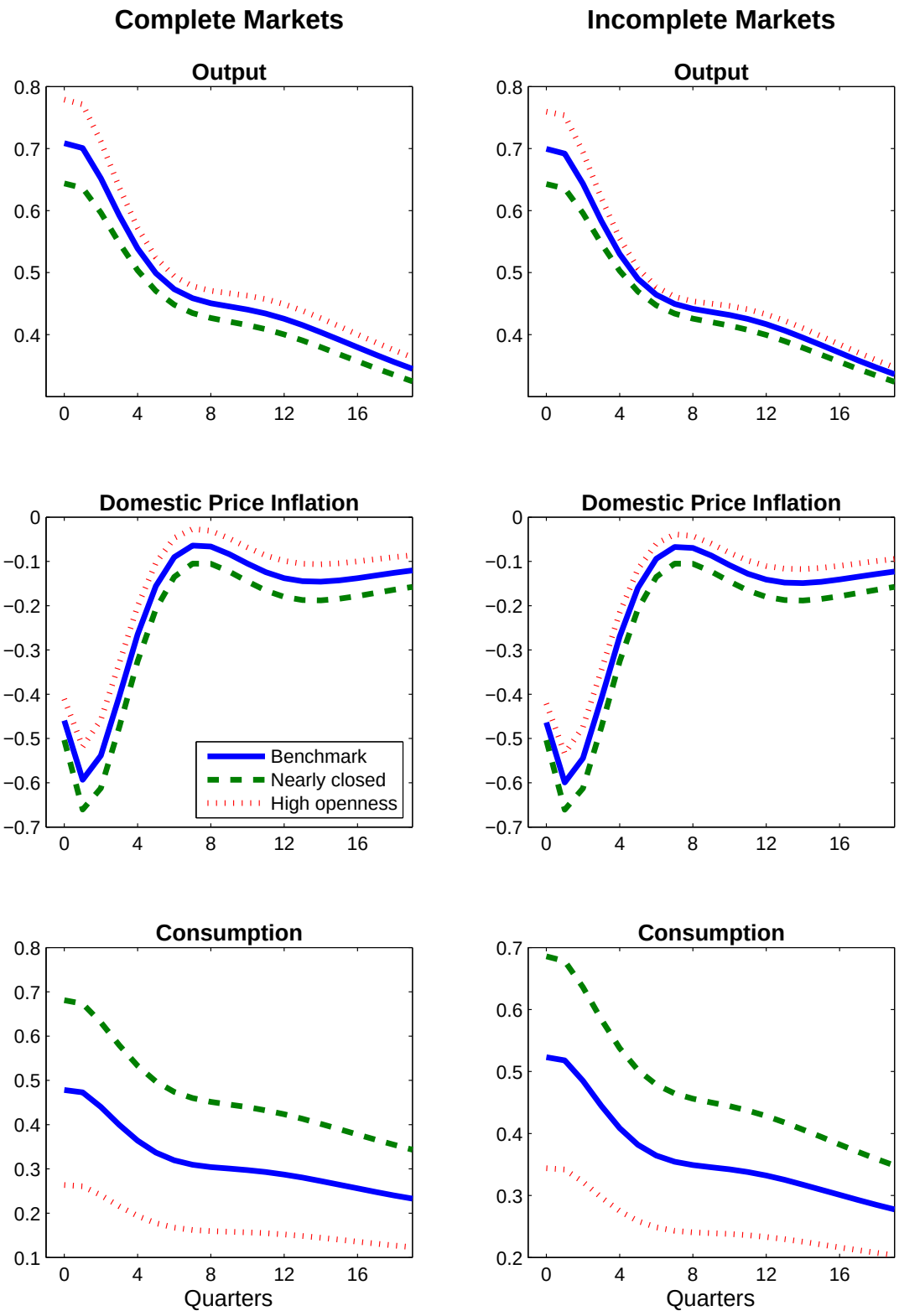


Figure 15: Increase in Technological Growth: Complete vs. Incomplete Markets (Alternative Calibration: $\eta = 6$ and $\chi^{-1} = 1$)

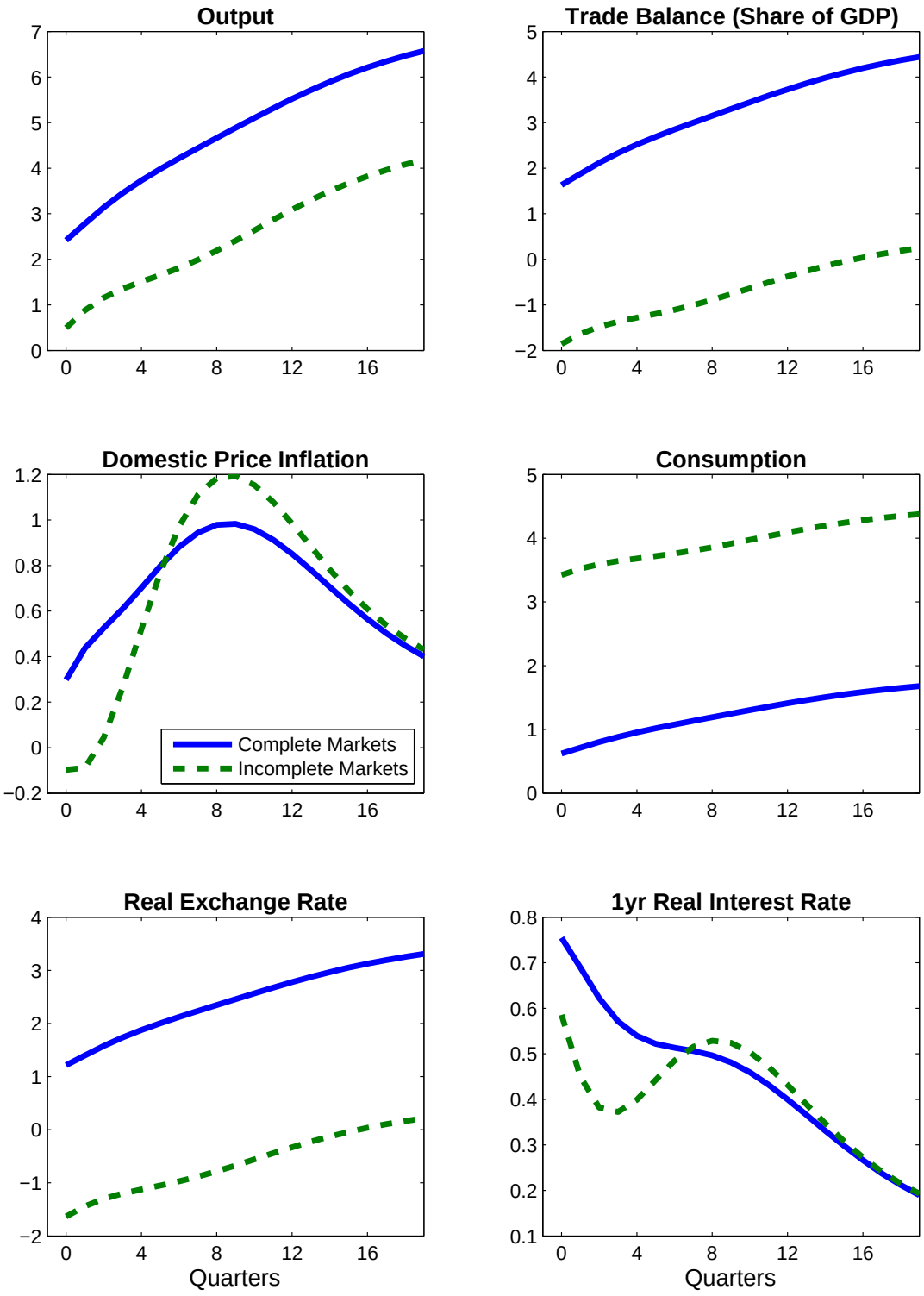


Figure 16: Reduction in Inflation Target in Endogenous Investment Model

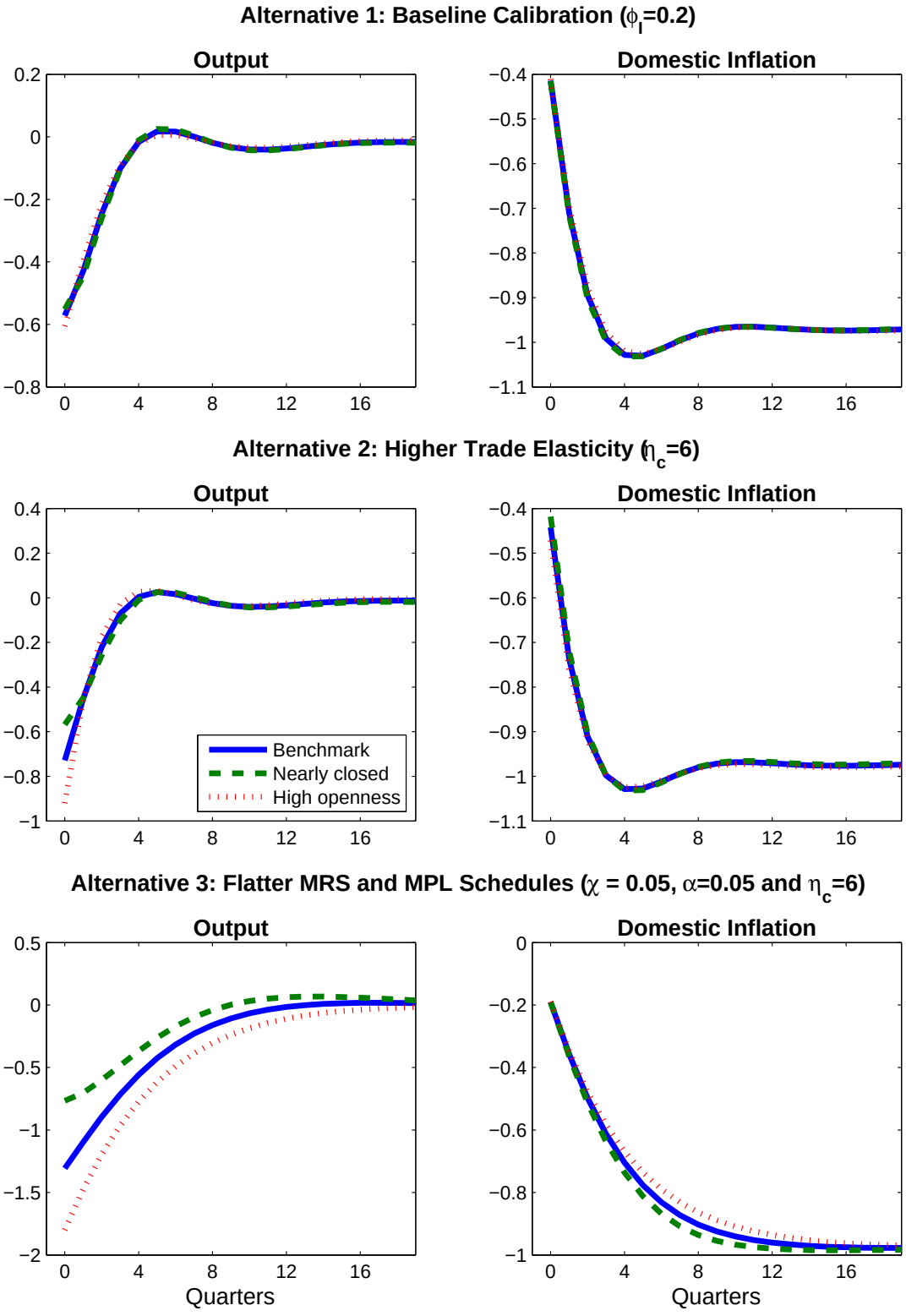


Figure 17: Increase in Technology: Workhorse Model vs. Imported Materials Model

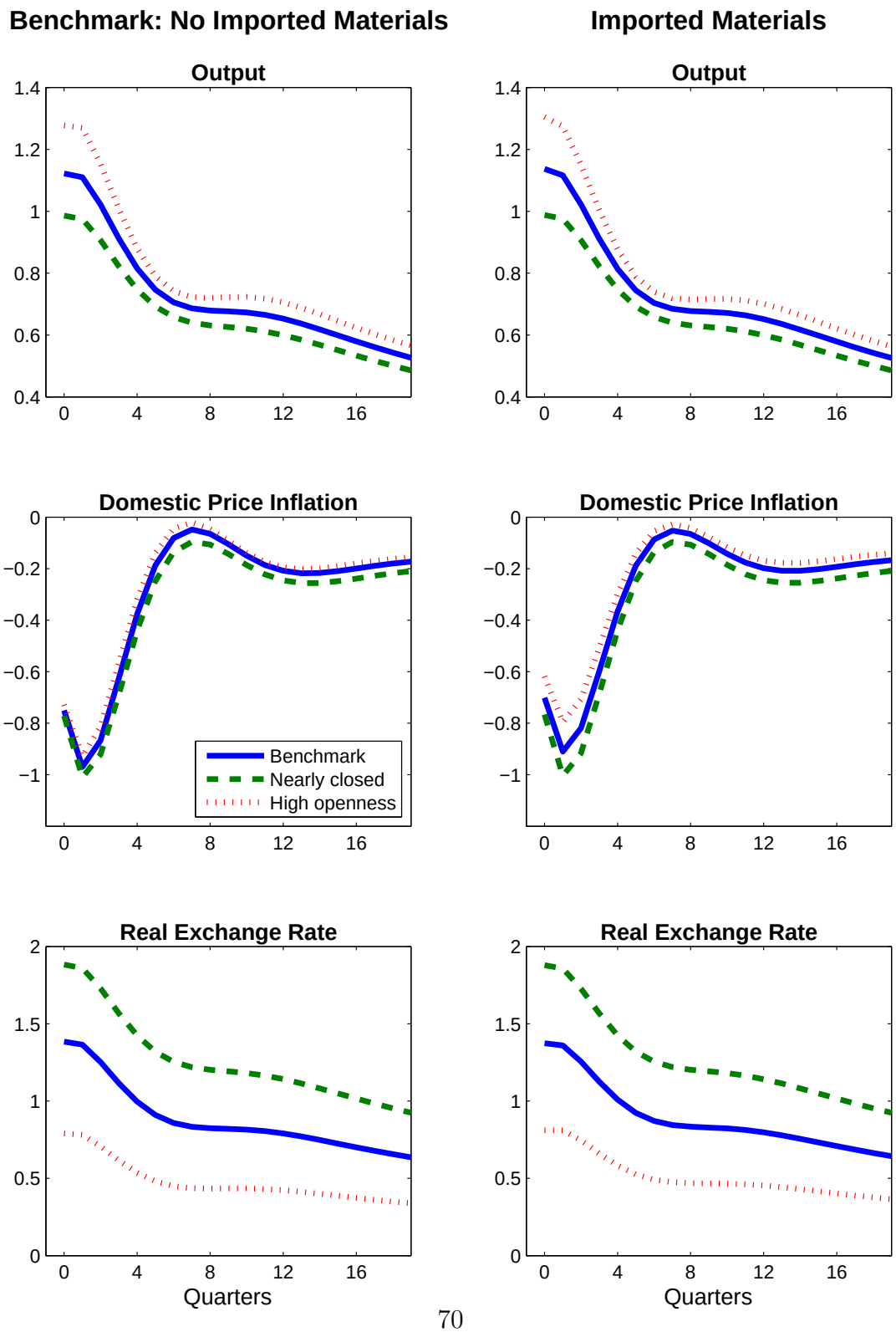


Figure 18: Increase in Technology: Workhorse Model vs. Variable Desired Markups Model

