

# Openness, imported commodities and the Phillips curve

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## **Abstract**

This paper derives a Phillips curve with imported commodities as an additional input in the production process. Given greater reliance on exogenously priced imported commodities in production then changes in output lead to a reduced impact on marginal costs and prices. The Phillips curve becomes flatter relative to the benchmark New Keynesian case. Empirical evidence supports the hypothesis that greater imported commodity intensity in production increases the sacrifice ratio. Econometrically controlling for imported commodity intensity also doubles the explanatory power of openness in determining the sacrifice ratio, as conjectured by Romer (1993).

JEL classifications: E31, E32, F41

Keywords: openness, imported commodities, sacrifice ratio

# 1 Introduction

This paper investigates the effects of imported materials costs and trade openness on the slope of the Phillips curve. The Phillips curve represents the feasible set of combinations of output growth and inflation in the short-run; a flatter slope means less inflation for a given real expansion and equivalently, disinflation becomes more costly in terms of reduced output. Romer (1993) conjectures that the negative relation between inflation and openness is driven by steeper Phillips curves in more open economies, but the subsequent empirical literature has been far from supportive of this hypothesis.

To resolve theory and data we put forward a new explanation of the link between the slope of the Phillips curve and openness. In particular, we consider the impact of imported commodities in the production process. In the standard New Keynesian model increased output increases marginal costs because of upward sloping labour supply. Given the fixed markup of monopolistically-competitive firms, increased prices and inflation eventually ensue. However, marginal production costs also depend on inputs other than labour. Imported commodities such as oil and gas, natural resources in general, and intermediate production goods such as iron, steel, chemicals and textiles can all play an important role in determining marginal production costs, and the prices of these commodities are plausibly exogenous for most countries unlike wages. In small open economies, changes in production will not change the prices of these commodities. It is also the case that real commodity costs have risen in recent years, and that producers have pointed to these as important drivers of their day-to-day pricing and output decisions. The crucial point is that when imported commodities are important in the production process then the link between increased output and marginal

production costs weakens. If firms markup at a constant rate, and there is price rigidity, the resulting Phillips curve is flatter.

Ostensibly the arguments of this paper and that of Romer (1993) point in different directions. Romer's mechanism (described below) has openness steepening the Phillips curve. The mechanism proposed in this paper has increased imported commodity intensity flattening the Phillips curve. However, the two mechanisms are not mutually exclusive, and a principal objective of this paper is to separate out the two effects. Previous empirical work has been far from decisive in confirming the relationship between openness and the slope of the Phillips curve, and the research presented here suggests a reconciliation of this literature. Just including one measure of openness falls foul of omitted variable bias. Given a positive correlation between imported commodity intensity and openness, omitting the former will bias inference concerning the latter towards insignificance. When separate measures for openness and imported commodities are both included in a regression analysis, the data are supportive of both hypotheses.

In the next section the literature addressing the relationship between openness and the Phillips curve is briefly reviewed. Section 3 presents a formal theoretical analysis of the effects of imported commodities on the Phillips curve slope in a standard New Keynesian macro model. Section 4 contains an empirical analysis of the effects of commodity imports as well as openness on the Phillips curve slope as measured by sacrifice ratios and section 5 concludes.

## 2 Literature Review

Romer (1993) documents a negative correlation between the level of inflation and the degree of openness. A potential explanation of this finding could be from time-inconsistency inflation-bias type arguments as in Kydland and Prescott (1977) and Barro and Gordon (1983). At low levels of inflation the policymaker has an incentive to expand the economy, moving rightward along the feasible inflation-output set defined by the Phillips Curve. The flatter this curve, the greater the ratio of increased output to increased inflation, and the greater the temptation to inflate. The private sector rationally anticipates this and hence Nash equilibrium entails greater mean inflation. Because of the empirical regularity that inflation is negatively associated with openness, Romer (1993) conjectures that the Phillips curve is steeper in open economies. His theoretical rationale is that in more open economies unanticipated monetary expansions lead to real depreciation and this translates into higher inflation through higher import prices. The inflation originating through the exchange rate channel does not add to output and consequently, under discretionary policy, the policymaker has less incentive to inflate.

An alternative and more straightforward mechanism leading to the same conclusion is provided by Lane (1997). In his model there are non-tradeable and tradeable sectors and as normal the non-traded sector increases output following a monetary shock. However, the smaller the non-traded sector, the smaller the benefits from the surprise inflation. The more open the economy, the lower the incentives for the central bank to inflate.

The empirical evidence has been far from supportive of the Romer (1993) hypothesis. In earlier work, Ball, Mankiw and Romer (1988) (BMR) estimated output-inflation trade-off

measures for 43 countries, notably finding robust evidence that it is affected by the level of inflation. Yet, the openness measure, when included in their regressions, turned out to be not statistically significant. Similarly Temple (2002) found no evidence of a link with openness using either BMR's trade-off measures or Ball's (1994) estimates of the sacrifice ratio.

Daniels et al. (2005) correctly criticize this literature for failing to control for central bank independence. The inflation-bias story requires discretionary policy, and at least in principle greater central bank independence should ameliorate the effect of openness on the sacrifice ratio. However, when they include the interaction of openness and measures of central bank independence, they find a positive effect of openness upon the sacrifice ratio, that is openness flattens the Phillips curve rather than steepening it.

In response to this slew of negative evidence, Razin and Huen (2002) and Daniels and VanHoose (2006) propose alternative theoretical reasons underpinning flatter Phillips Curves in more open economies. In Razin and Huen (2002) openness is also associated with greater capital mobility, enabling greater consumption smoothing through the cycle and increased strategic complementarity among producers and stickier prices; the end result is a flatter Phillips curve. In Daniels and VanHoose openness reduces the income elasticity of spending on domestic goods, and anticipating this, domestic price-setters do not increase prices as much when output expands. As Bowdler (forthcoming) discusses, both of these contributions rely on fairly specific microeconomic arguments to generate the required result. We would certainly not argue against these explanations, as it is difficult to test or evaluate the key mechanisms in both cases. It is quite possible that these explanations go some way in resolving the theory with the data, but we argue that the theory proposed in this paper is

considerably simpler, and has the additional advantage of being easier to test.

Finally Bowdler (forthcoming) makes a substantial contribution to the literature by updating the BMR inflation-output measures and Ball's sacrifice ratios for a later time period. We agree with Bowdler that his sample (1981-1998) is preferable to the older data (1961-88) in that the shocks in the later sample are more plausibly generated by monetary shocks. The earlier period is likely to be contaminated by supply-side shocks, rendering accurate estimation of the Phillips curve slope difficult. Bowdler also argues that the extant empirical work is flawed in that it fails to control adequately for the exchange rate regime. The key component in Romer's hypothesis is that a real depreciation follows a monetary shock. Clearly the extent to which a depreciation occurs will depend on the exchange rate regime. Using the newer data, Bowdler estimates the impact of openness on the sacrifice ratio, allowing the impact to vary with measures of the fixity of the exchange rate regime. He finds some evidence of a negative relationship between the alternative measure of the Phillips curve slope and openness.

### **3 Theory**

In this section we extend the standard New Keynesian framework as summarized in Gali (2008) to analyze formally the impact on the Phillips curve of imported commodities in the production process. It may be simpler to think of this commodity throughout this section as a single input such as oil, though the argument generalizes to all imported intermediate goods. As noted in the introduction these commodities may take many forms, and have come to represent an increasing fraction of producer costs in recent years. Here the novel

elements are outlined but the full details are presented in the appendix.

There is a continuum of firms indexed by  $i \in [0, 1]$  all facing the same production function:

$$Y_t(i) = A_t N_t(i)^{1-\alpha} O_t^{1-\gamma} \quad (1)$$

where  $Y_t(i)$  is firm-level output,  $N_t(i)$  is firm-level employment,  $A_t$  is technology,  $O_t$  represents the imported commodity input into the production process and  $\alpha$  and  $\gamma$  are parameters. When  $\gamma$  is equal to unity the production function reduces to the standard case considered by Galí and others. As a simplification it is assumed that all firms have the same imported commodity requirement. Without this simplification it would not be possible to generate an analytical solution and it is not at all clear that allowing idiosyncratic commodity demand would alter the main argument. In the appendix a first order approximation to the aggregate production function is given by

$$y_t = a_t + (1 - \alpha) n_t + (1 - \gamma) o_t$$

with lower case variables denoting logs and  $y_t$  and  $n_t$  denoting aggregate output and employment. Demand for imported commodities depends on their price and is given by

$$o_t = \log(1 - \gamma) + y_t - (p_t^o - p_t)$$

where  $p_t^o - p_t$  is the real price of imported commodities.

Adding these ingredients to the standard New Keynesian model of Calvo (1983) price-



setters yields a Phillips curve

$$\pi_t = \beta E_t \{\pi_{t+1}\} + \kappa \tilde{y}_t + \zeta u_t$$

where  $\tilde{y}_t$  is deviation of output from the natural rate,  $u_t = (p_t^o - p_t) - r^o$  where  $r^o$  are long-run real commodity prices,  $\kappa$  and  $\zeta$  are composite parameters. This is our modified Phillips Curve and represents a generalization of the benchmark case - equation (21) in chapter 3 of Gali (2008). The cost-push shock term  $u_t$  is formally derived from the process governing commodity prices, and the economy's sensitivity to these shocks is given by the structural parameters in  $\zeta$ . Mathematically the slope of the Phillips curve may be steeper or flatter than under the benchmark case, with the condition for this given by

$$\kappa_o \gtrless \kappa_b$$

where  $\kappa_o$  corresponds to  $\kappa$  derived in the general case, and  $\kappa_b$  is the value of  $\kappa$  when  $\gamma = 1$  (the benchmark case).

**Proposition 1** *The greater the importance of imported commodities in the production process, the flatter the Phillips Curve.*

**Proof.** See Appendix 2. ■

The intuition for this proposition is reasonably straightforward. When imported commodities are important in the production process, and the economy is small, then marginal costs do not increase by as much for given output increases. Commodity prices are exogenous, and increasing production doesn't feed into higher marginal production costs to

the extent when the key (or only) margin is additional labor. When firms markup at a constant rate (depending on their market power), then following output increases optimal prices correspondingly do not increase by as much and the resultant inflation is dampened.

## 4 Empirical Evidence

This section asks two questions following from the theory above. Firstly, whether greater imported commodity intensity in the production process flattens the Phillips curve, or equivalently increases the sacrifice ratio. Secondly, whether incorporating commodity intensity affects inference concerning the impact of openness as conventionally defined upon the Phillips curves slope. Our prior is that a more robust negative relationship between openness and the sacrifice ratio should appear once commodity intensity is controlled for. Data for commodity intensity come from the World Trade Organization who provide annual merchandise trade by commodity data for most of its members from 1980. To capture exogenously priced commodity imports used in production we sum the series for fuel and mining, iron and steel, machinery and transport products, chemicals and textiles, and divide by GDP:

$$INPUTS_{it} = (\text{fuel and mining} + \text{iron and steel} + \text{machinery} \\ \text{and transport products} + \text{chemicals} + \text{textiles imports}) / \text{GDP}.$$

Because these data are only available from 1980 we utilize Bowdler's updated series for the sacrifice ratio. This dataset consists of estimated sacrifice ratios for 71 disinflations in 38 countries over the period 1981-1998. As noted above these data have the additional advantage

of being constructed during a period of time when it was more likely that movements in inflation and output were driven by monetary shocks rather than from the supply side.

The estimation strategy also follows Bowdler. Each disinflation corresponds to a particular time period and country and, following previous research, the explanatory variables are measured as averages over the corresponding period. Thus openness is measured as total imports as a share of GDP using data from the IMF and averaged over the relevant disinflation period ( $OPEN_i$ ). Other control variables used are constructed in exactly the same way as in Bowdler, though we augment his specification to include average imported commodities over the relevant subperiod. In particular we estimate

$$\begin{aligned}
 SR_i = & \phi_0 + \phi_1 OPEN_i + \phi_2 OPENEX_i + \phi_3 INPUTS_i + \phi_4 LENGTH_i \\
 & + \phi_5 INFLOSS_i + \phi_6 PEAK_i + \phi_7 CBI_i + \phi_8 OPENCBI_i
 \end{aligned} \tag{2}$$

where the sacrifice ratio is denoted by  $SR_i$ , and  $OPENEX_i$  is the product of  $OPEN_i$  and the Reinhart and Rogoff (2004) exchange rate measure ( $EX_i$ ).  $LENGTH_i$  is the disinflation length in years,  $INFLOSS_i$  is the reduction in inflation during the disinflation,  $PEAK_i$  is the inflation rate in the year in which the disinflation started,  $CBI_i$  is an index of central bank independence and  $OPENCBI_i$  is the interaction of openness and central bank independence included following the argument of Daniels et al. (2005).

Before reporting the results of the regression analysis it is worth taking a closer look at the key explanatory variables. Figure 1 depicts a scatter plot of  $INPUTS_i$  against  $OPEN_i$ . As expected there is a fairly strong positive correlation between the two variables. Countries

which are open tend to rely on imported commodities to a greater extent. If it is the case that the mechanism proposed by Romer (1993) and that proposed here both contribute to variation in the Phillips curve slope then putting openness by itself into the regression analysis commits omitted variable bias. In particular a regression which includes openness alone will be biased towards rejecting Romer's hypothesis.

Table 1 presents the regression results. Column 1 replicates Bowdler's column 2 in Table 1. The results are similar to his and the minor differences can be attributed to primary data revisions. The sign of the openness coefficient is negative, consistent with Romer's hypothesis, but is not statistically significant. This is also the case with the interaction of openness and the exchange rate regime. Indeed the only statistically significant term is *LENGTH* as in Bowdler. Column 2 drops the CBI terms, allowing for a bigger sample, and in this regression *OPEN* is negative and significant at the 5% level though as in Bowdler *OPENEX* is insignificant. We interpret this as evidence pointing towards the mechanism put forward by Lane (1997) rather than that of Romer (1993). Romer's theory relies on depreciation, whereas Lane's does not. Clearly the interaction term is not significant, and so it is difficult to conclude that mechanisms involving movements in the exchange rate explain the link between openness and the Phillips curve.

Column 3 includes the new variable *INPUTS*. The new variable itself exhibits a positive sign, consistent with the theory above, and is significant at the 10% level. The sample is slightly reduced due to data availability, but nonetheless the results support the argument that greater imported commodity intensity in the production process increases the sacrifice ratio and flattens the Phillips curve. Given the coefficient estimate and holding all else constant, a one-standard-deviation increase (0.06) in imported commodity intensity increases

the sacrifice ratio by 0.5, which represents a meaningful change in the feasible outcome set faced by policymakers.

Also noteworthy from column 3 is the fact that the estimated coefficient for the variable *OPEN* more than doubles in magnitude, and becomes significant at almost the 1% level once *INPUTS* is included. Given a one-standard-deviation change in openness (0.13) the sacrifice ratio increases by 1.0 almost exactly. The increase in size and significance confirms the possibility of an omitted variable bias problem when the role of imported commodities is ignored. Omission of imported commodity intensity in the regression analysis leads to serious underestimation of the explanatory power of openness.

## 5 Conclusion

This paper presents a new theory explaining the link between the slope of the Phillips curve and openness. The channel is through imported commodities in the production process. When production is reliant upon imported commodities, which as opposed to wages are priced exogenously, then changes in production levels have less impact on marginal costs. In the New Keynesian literature this means less impact on optimal prices and inflation: the Phillips curve is flatter, and sacrifice ratios are larger.

Using data for imported commodities that are plausibly inputs in the production process we find that there is a positive association between imported commodity intensity and the sacrifice ratio, at least significant at the 10% level.

Previous econometric work has been far from decisive in supporting Romer's original hypothesis of steeper Phillips curves in more open economies, although Bowdler (forthcoming)

does find evidence of a weak negative relationship between openness and the sacrifice ratio. The evidence presented here is in contrast much more supportive of Romer's hypothesis. Once commodity intensity is controlled for, the impact of openness on the steepness of the Phillips curve doubles.

# Appendix 1 Derivation of the Phillips Curve

## Households

As in Gali (2008, chapter 3, section 1) idiosyncratic demand is given by:

$$C_t(i) = \left( \frac{P_t(i)}{P_t} \right)^{-\epsilon} C_t,$$

i.e. demand for good  $i$  depends on aggregate demand ( $C_t$ ) and relative prices ( $\frac{P_t(i)}{P_t}$ ) with elasticity determined by  $\epsilon$ . Labor supply and the Euler equation are respectively given in (3) and (4):

$$w_t - p_t = \sigma c_t + \varphi n_t \tag{3}$$

where  $w_t$  is the log of wages,  $p_t$  is the log of the price level,  $c_t$  is the log of consumption (in this section a single good) and  $n_t$  is the log of employment and  $\sigma$  and  $\varphi$  are parameters from the utility function. The consumption Euler equation is given by

$$c_t = E_t \{c_{t+1}\} - \frac{1}{\sigma} (i_t - E_t \{\pi_{t+1}\} - \rho) \tag{4}$$

where  $E_t \{\}$  is the expectations operator,  $i_t$  is the nominal interest rate,  $\pi_{t+1} = p_{t+1} - p_t$  is the inflation rate and  $\rho$  is the discount rate.

## Firms

Firms have production functions as given by (1) in the main text.

## Price Setting and Price Dynamics

Given Calvo pricing aggregate price dynamics are described by

$$\Pi_t^{1-\epsilon} = \theta + (1 - \theta) \left( \frac{P_t^*}{P_{t-1}} \right)^{1-\epsilon}$$

where  $\Pi_t \equiv \frac{P_t}{P_{t-1}}$  is the gross inflation rate between  $t - 1$  and  $t$  and  $P_t^*$  is the price set in period  $t$  by firms reoptimizing their price in that period. In a steady state with zero inflation ( $\Pi = 1$ ) we must have  $P_t^* = P_{t-1} = P_t$  for all  $t$ . A log-linear approximation to the aggregate price index around that steady state yields

$$\pi_t = (1 - \theta) (p_t^* - p_{t-1}).$$

The optimal price itself is a constant markup on marginal costs depending on the elasticity of substitution of consumption. Given Calvo price-setting, then

$$p_t^* - p_{t-1} = (1 - \beta\theta) \sum_{k=0}^{\infty} (\beta\theta)^k E_t \{ \widehat{mc}_{t+k|t} + (p_{t+k} - p_{t-1}) \} \quad (5)$$

## Equilibrium

Market clearing in the goods market requires that

$$Y_t(i) = C_t(i)$$



Defining aggregate output as the Dixit-Stiglitz aggregator then

$$Y_t = C_t.$$

The IS curve is

$$y_t = E_t \{y_{t+1}\} - (i_t - E_t \{\pi_{t+1}\} - \rho).$$

Labour market equilibrium requires that

$$N_t = \int_0^1 N_t(i) di$$

and using the production function (1)  $Y_t(i) = A_t N_t(i)^{1-\alpha} O_t^{1-\gamma}$

$$\begin{aligned} N_t &= \int_0^1 \left( \frac{Y_t(i)}{A_t O_t^{1-\gamma}} \right)^{\frac{1}{1-\alpha}} di \\ &= \left( \frac{Y_t}{A_t O_t^{1-\gamma}} \right)^{\frac{1}{1-\alpha}} \int_0^1 \left( \frac{Y_t(i)}{Y_t} \right)^{\frac{1}{1-\alpha}} di \\ &= \left( \frac{Y_t}{A_t O_t^{1-\gamma}} \right)^{\frac{1}{1-\alpha}} \int_0^1 \left( \frac{P_t(i)}{P_t} \right)^{\frac{-\epsilon}{1-\alpha}} di \end{aligned}$$

and taking logs,

$$(1 - \alpha) n_t = y_t + (1 - \gamma) o_t + d_t$$

where  $d_t \equiv (1 - \alpha) \log \int_0^1 \left( \frac{P_t(i)}{P_t} \right)^{\frac{-\epsilon}{1-\alpha}} di$  is equal to zero up to a first-order approximation around a zero inflation steady state. Therefore an approximate log-linear aggregate produc-

tion relation is

$$y_t = a_t + (1 - \alpha) n_t + (1 - \gamma) o_t$$

Economy-wide average real marginal costs are defined by

$$MC_t = \frac{W_t N_t}{(1 - \alpha) P_t Y_t} + \frac{P_t^o O_t}{(1 - \gamma) P_t Y_t}$$

The first term can be written as

$$MC_t^1 = \exp \{w_t + n_t - (p_t + y_t) - \log(1 - \alpha)\}.$$

Define the labour share  $s_t^l \equiv w_t + n_t - (p_t + y_t)$  and note that in the steady state  $s^{l*} = \log(1 - \alpha)$ . A first-order approximation of the first term is therefore

$$MC_t^1 \approx 1 + w_t + n_t - (p_t + y_t) - \log(1 - \alpha).$$

Similarly the second term can be written as

$$MC_t^2 = \exp \{p_t^o + o_t - (p_t + y_t) - \log(1 - \gamma)\}$$

with the steady state oil share  $s^{o*} = \log(1 - \gamma)$ , hence

$$MC_t^2 \approx 1 + p_t^o + o_t - (p_t + y_t) - \log(1 - \gamma).$$

Given that for  $x, z$  close to zero (i.e. small deviations from steady state income shares), then

for  $v = (1 + x) + (1 + z)$ ,  $\log(v) \approx x + z$  hence

$$mc_t \approx w_t + n_t - (p_t + y_t) - \log(1 - \alpha) + p_t^o + o_t - (p_t + y_t) - \log(1 - \gamma)$$

and substituting in economy-wide oil demand,  $p_t^o - p_t = \log(1 - \gamma) + y_t - o_t$ , then

$$mc_t \approx w_t - p_t + n_t - y_t - \log(1 - \alpha).$$

Substituting in  $n_t$  from the production function,  $n_t = \frac{y_t - a_t - (1 - \gamma)o_t}{1 - \alpha}$  then

$$\begin{aligned} mc_t &\approx w_t - p_t + \frac{y_t - a_t - (1 - \gamma)o_t}{1 - \alpha} - y_t - \log(1 - \alpha) \\ &\approx w_t - p_t - \frac{1}{1 - \alpha} \{a_t - \alpha y_t + (1 - \gamma)o_t\} - \log(1 - \alpha) \end{aligned}$$

and substituting in for  $o_t$  again then

$$\begin{aligned} mc_t &\approx w_t - p_t - \frac{1}{1 - \alpha} \{a_t - \alpha y_t + (1 - \gamma)[\log(1 - \gamma) + y_t - (p_t^o - p_t)]\} - \log(1 - \alpha) \\ &\approx w_t - p_t + \frac{\alpha - (1 - \gamma)}{1 - \alpha} y_t - \frac{a_t}{1 - \alpha} - \frac{1 - \gamma}{1 - \alpha} [\log(1 - \gamma) - (p_t^o - p_t)] - \log(1 - \alpha) \\ &\approx w_t - p_t + \frac{\alpha - (1 - \gamma)}{1 - \alpha} y_t - \frac{a_t}{1 - \alpha} + \left(\frac{1 - \gamma}{1 - \alpha}\right) (p_t^o - p_t) \\ &\quad - \log(1 - \alpha) - \left(\frac{1 - \gamma}{1 - \alpha}\right) \log(1 - \gamma). \end{aligned}$$

For a firm in period  $t + k$  which last reset its price in period  $t$

$$\begin{aligned}
mc_{t+k|t} &= w_t - p_t + \frac{\alpha - (1 - \gamma)}{1 - \alpha} y_{t+k|t} - \frac{a_t}{1 - \alpha} + \left( \frac{1 - \gamma}{1 - \alpha} \right) (p_{t+k}^o - p_{t+k}) \\
&\quad - \log(1 - \alpha) - \left( \frac{1 - \gamma}{1 - \alpha} \right) \log(1 - \gamma) \\
&= mc_{t+k} + \frac{\alpha - (1 - \gamma)}{1 - \alpha} (y_{t+k|t} - y_{t+k}) \\
&= mc_{t+k} - \frac{\epsilon [\alpha - (1 - \gamma)]}{1 - \alpha} (p_t^* - p_{t+k}) \tag{6}
\end{aligned}$$

which is analogous to equation (14) in Chapter 3 of Galí. Notice there is an additional term  $(-(1 - \gamma))$  making the responsiveness of marginal costs to output flatter. In the traditional New Keynesian case increasing output necessarily increases marginal costs. The only input into the production process is labour and increasing the labour input necessarily increases the real wage rate which is endogenous for the economy as a whole. When part of the costs of production (i.e. energy inputs) are exogenous then the relationship between marginal costs and economic activity flattens.

Substituting (6) into (5)

$$\begin{aligned}
p_t^* - p_{t-1} &= (1 - \beta\theta) \sum_{k=0}^{\infty} (\beta\theta)^k E_t \{ \widehat{mc}_{t+k|t} + (p_{t+k} - p_{t-1}) \} \\
p_t^* - p_{t-1} &= (1 - \beta\theta) \sum_{k=0}^{\infty} (\beta\theta)^k E_t \left\{ \widehat{mc}_t - \frac{\epsilon [\alpha - (1 - \gamma)]}{1 - \alpha} (p_t^* - p_{t+k}) + (p_{t+k} - p_{t-1}) \right\} \\
p_t^* &= (1 - \beta\theta) \sum_{k=0}^{\infty} (\beta\theta)^k E_t \left\{ \widehat{mc}_t - \frac{\epsilon [\alpha - (1 - \gamma)]}{1 - \alpha} (p_t^* - p_{t+k}) + p_{t+k} \right\} \\
p_t^* &= (1 - \beta\theta) \sum_{k=0}^{\infty} (\beta\theta)^k E_t \left\{ \widehat{mc}_t - \frac{\epsilon [\alpha - (1 - \gamma)]}{1 - \alpha} p_t^* + \frac{1 - \alpha + \epsilon [\alpha - (1 - \gamma)]}{1 - \alpha} p_{t+k} \right\}
\end{aligned}$$

$$\begin{aligned}
p_t^* + \frac{\epsilon[\alpha - (1 - \gamma)]}{1 - \alpha} p_t^* &= (1 - \beta\theta) \sum_{k=0}^{\infty} (\beta\theta)^k E_t \left\{ \widehat{m}c_t + \frac{1 - \alpha + \epsilon[\alpha - (1 - \gamma)]}{1 - \alpha} p_{t+k} \right\} \\
\frac{1 - \alpha + \epsilon[\alpha - (1 - \gamma)]}{1 - \alpha} p_t^* &= (1 - \beta\theta) \sum_{k=0}^{\infty} (\beta\theta)^k E_t \left\{ \widehat{m}c_t + \frac{1 - \alpha + \epsilon[\alpha - (1 - \gamma)]}{1 - \alpha} p_{t+k} \right\} \\
p_t^* &= (1 - \beta\theta) \sum_{k=0}^{\infty} (\beta\theta)^k E_t \left\{ \left( \frac{1 - \alpha}{1 - \alpha + \epsilon[\alpha - (1 - \gamma)]} \right) \widehat{m}c_t + p_{t+k} \right\} \\
&= (1 - \beta\theta) \sum_{k=0}^{\infty} (\beta\theta)^k E_t \{ \Theta \widehat{m}c_t + p_{t+k} \}
\end{aligned}$$

hence

$$\pi_t = \beta E_t \{ \pi_{t+1} \} + \lambda \widehat{m}c_t \quad (7)$$

where  $\lambda = \frac{(1-\theta)(1-\beta\theta)}{\theta} \Theta$  and  $\Theta = \frac{1-\alpha}{1-\alpha+\epsilon[\alpha-(1-\gamma)]}$ .

Using the above result, that

$$m c_t \approx w_t - p_t + \frac{\alpha - (1 - \gamma)}{1 - \alpha} y_t - \frac{a_t}{1 - \alpha} + \frac{1 - \gamma}{1 - \alpha} (p_t^o - p_t) - \log(1 - \alpha) - \left( \frac{1 - \gamma}{1 - \alpha} \right) \log(1 - \gamma)$$

and substituting in the household's optimality condition,

$$\begin{aligned}
m c_t &\approx \sigma y_t + \varphi n_t + \frac{\alpha - (1 - \gamma)}{1 - \alpha} y_t - \frac{a_t}{1 - \alpha} + \frac{1 - \gamma}{1 - \alpha} (p_t^o - p_t) \\
&\quad - \log(1 - \alpha) - \left( \frac{1 - \gamma}{1 - \alpha} \right) \log(1 - \gamma) \\
&\approx \varphi n_t + \frac{\sigma(1 - \alpha) + \alpha - (1 - \gamma)}{1 - \alpha} y_t - \frac{a_t}{1 - \alpha} + \frac{1 - \gamma}{1 - \alpha} (p_t^o - p_t) \\
&\quad - \log(1 - \alpha) - \left( \frac{1 - \gamma}{1 - \alpha} \right) \log(1 - \gamma).
\end{aligned}$$

Now substituting in  $n_t$  from the production function,  $n_t = \frac{y_t - a_t - (1-\gamma)o_t}{1-\alpha}$

$$\begin{aligned}
mc_t &\approx \varphi \frac{y_t - a_t - (1-\gamma)o_t}{1-\alpha} + \frac{\sigma(1-\alpha) + \alpha - (1-\gamma)}{1-\alpha} y_t - \frac{a_t}{1-\alpha} \\
&\quad + \frac{1-\gamma}{1-\alpha} (p_t^o - p_t) - \log(1-\alpha) - \left(\frac{1-\gamma}{1-\alpha}\right) \log(1-\gamma) \\
&\approx \frac{\varphi + \sigma(1-\alpha) + \alpha - (1-\gamma)}{1-\alpha} y_t - \left(\frac{1+\varphi}{1-\alpha}\right) a_t - \varphi \left(\frac{1-\gamma}{1-\alpha}\right) o_t \\
&\quad + \frac{1-\gamma}{1-\alpha} (p_t^o - p_t) - \log(1-\alpha) - \left(\frac{1-\gamma}{1-\alpha}\right) \log(1-\gamma)
\end{aligned}$$

and finally substituting in the oil demand equation  $p_t^o - p_t = \log(1-\gamma) + y_t - o_t$

$$\begin{aligned}
mc_t &\approx \frac{\varphi + \sigma(1-\alpha) + \alpha - (1-\gamma)}{1-\alpha} y_t - \left(\frac{1+\varphi}{1-\alpha}\right) a_t \\
&\quad - \varphi \left(\frac{1-\gamma}{1-\alpha}\right) [\log(1-\gamma) + y_t - (p_t^o - p_t)] \\
&\quad + \frac{1-\gamma}{1-\alpha} (p_t^o - p_t) - \log(1-\alpha) - \left(\frac{1-\gamma}{1-\alpha}\right) \log(1-\gamma) \\
&\approx \frac{\varphi + \sigma(1-\alpha) + \alpha - (1+\varphi)(1-\gamma)}{1-\alpha} y_t - \left(\frac{1+\varphi}{1-\alpha}\right) a_t \\
&\quad + (1+\varphi) \frac{1-\gamma}{1-\alpha} (p_t^o - p_t) - \log(1-\alpha) - (1+\varphi) \left(\frac{1-\gamma}{1-\alpha}\right) \log(1-\gamma) \quad (8)
\end{aligned}$$

which is a generalization of equation (17) in chapter 3 of Gali. Note that the coefficient linking economy-wide marginal costs and aggregate production has reduced. The intuition is similar to that for the discussion following equation (6). Increased production does not impact upon marginal costs in the aggregate as well as for individual firms when oil intensity is higher.

Steady-state marginal costs are constant and given by the markup parameter,  $-\mu$ . In

the steady-state output is at its steady state level and real oil prices are at their long-run equilibrium value  $r^o$ :

$$mc \approx \frac{\varphi + \sigma(1 - \alpha) + \alpha - (1 + \varphi)(1 - \gamma)}{1 - \alpha} y_t^n - \left( \frac{1 + \varphi}{1 - \alpha} \right) a_t + (1 + \varphi) \frac{1 - \gamma}{1 - \alpha} r^o - \log(1 - \alpha) - (1 + \varphi) \left( \frac{1 - \gamma}{1 - \alpha} \right) \log(1 - \gamma). \quad (9)$$

The flexible prices (natural rate) level of output is thus given as

$$y_t^n = v_y + \psi_{ya} a_t - \psi_{yo} r^{o*}$$

where  $v_y = \frac{(1 - \alpha)[\log(1 - \alpha) - \mu] + (1 - \gamma)(1 + \varphi) \log(1 - \gamma)}{\alpha + \sigma(1 - \alpha) + \varphi - (1 - \gamma)(1 + \varphi)}$ ,  $\psi_{ya} = \frac{(1 + \varphi)}{\alpha + \sigma(1 - \alpha) + \varphi - (1 - \gamma)(1 + \varphi)}$  and

$\psi_{yo} = \frac{(1 - \gamma)(1 + \varphi)}{\alpha + \sigma(1 - \alpha) + \varphi - (1 - \gamma)(1 + \varphi)}$  which can be compared with the outcome under flexible prices and perfect competition described above. The only difference is that the constant term is reduced due to the market power the firms have under the monopolistically competitive market structure.

Subtracting (9) from (8) yields

$$\widehat{mc}_t = \frac{\varphi + \sigma(1 - \alpha) + \alpha - (1 + \varphi)(1 - \gamma)}{1 - \alpha} (y_t - y_t^n) + \frac{(1 + \varphi)(1 - \gamma)}{1 - \alpha} [(p_t^o - p_t) - r^o] \quad (10)$$

Equation (10) shows that marginal costs deviate from their long-run equilibrium when output is above its natural level and when the oil price is above its natural level.

Finally, combining (10) with (7) yields

$$\pi_t = \beta E_t \{ \pi_{t+1} \} + \kappa \tilde{y}_t + \zeta u_t$$

where  $\tilde{y}_t = y_t - y_t^n$ ,  $u_t = (p_t^o - p_t) - r^o$ ,  $\kappa = \lambda \left[ \frac{\varphi + \sigma(1-\alpha) + \alpha - (1+\varphi)(1-\gamma)}{1-\alpha} \right]$  and  $\zeta = \lambda \frac{(1+\varphi)(1-\gamma)}{1-\alpha}$ .

## Appendix 2 Proof of proposition

For proposition 1 to obtain we need  $\kappa_b > \kappa_o$ . i.e.,

$$\begin{aligned} \lambda_o \left[ \frac{\varphi + \sigma(1-\alpha) + \alpha - (1+\varphi)(1-\gamma)}{1-\alpha} \right] &\geq \lambda_b \left[ \frac{\varphi + \sigma(1-\alpha) + \alpha}{1-\alpha} \right] \\ \Theta_o \left[ \frac{\varphi + \sigma(1-\alpha) + \alpha - (1+\varphi)(1-\gamma)}{1-\alpha} \right] &\geq \Theta_b \left[ \frac{\varphi + \sigma(1-\alpha) + \alpha}{1-\alpha} \right] \end{aligned}$$

because  $\lambda = \frac{(1-\theta)(1-\beta\theta)}{\theta} \Theta$  and  $\Theta = \frac{1-\alpha}{1-\alpha+\epsilon[\alpha-(1-\gamma)]}$ .

$$\begin{aligned} \frac{\varphi + \sigma(1-\alpha) + \alpha - (1+\varphi)(1-\gamma)}{1-\alpha + \epsilon[\alpha - (1-\gamma)]} &\geq \frac{\varphi + \sigma(1-\alpha) + \alpha}{1-\alpha + \epsilon\alpha} \\ \frac{\varphi + \sigma(1-\alpha) + \alpha - (1+\varphi)(1-\gamma)}{\varphi + \sigma(1-\alpha) + \alpha} &\geq \frac{1-\alpha + \epsilon[\alpha - (1-\gamma)]}{1-\alpha + \epsilon\alpha} \\ 1 - \frac{(1+\varphi)(1-\gamma)}{\varphi + \sigma(1-\alpha) + \alpha} &\geq 1 - \frac{\epsilon(1-\gamma)}{1-\alpha + \epsilon\alpha} \\ \frac{(1+\varphi)}{\varphi + \sigma(1-\alpha) + \alpha} &\geq \frac{\epsilon}{1-\alpha + \epsilon\alpha} \end{aligned}$$

Note that the condition for whether or not  $\kappa_o \geq \kappa_b$  is independent of oil intensity ( $\gamma$ ) (though for given values of other parameters, increased oil intensity will magnify the difference).

Given plausible parameter values, it is likely to be the case that  $\kappa_b > \kappa_o$ . For example, if we take the case of log utility ( $\varphi = \sigma = 1$ ) then the condition reduces to  $\kappa_b > \kappa_o \implies \epsilon > 1$ .

The elasticity of demand parameter must be greater than unity otherwise the firm could



simply increase profits by reducing output. Furthermore the elasticity of demand parameter determines the markup. In the steady state the markup is given by  $\mu = \log\left(\frac{\epsilon}{\epsilon-1}\right)$ , and we would typically only expect these profits to be in the order of a few percent e.g. Gali (2002) sets  $\epsilon = 11$ , a value which is consistent with a 10% markup. Thus we conclude that in general we would expect that  $\kappa_b > \kappa_o$ , hence a steeper Phillips curve in the benchmark case, and a flatter Phillips curve for greater imported commodity intensity.

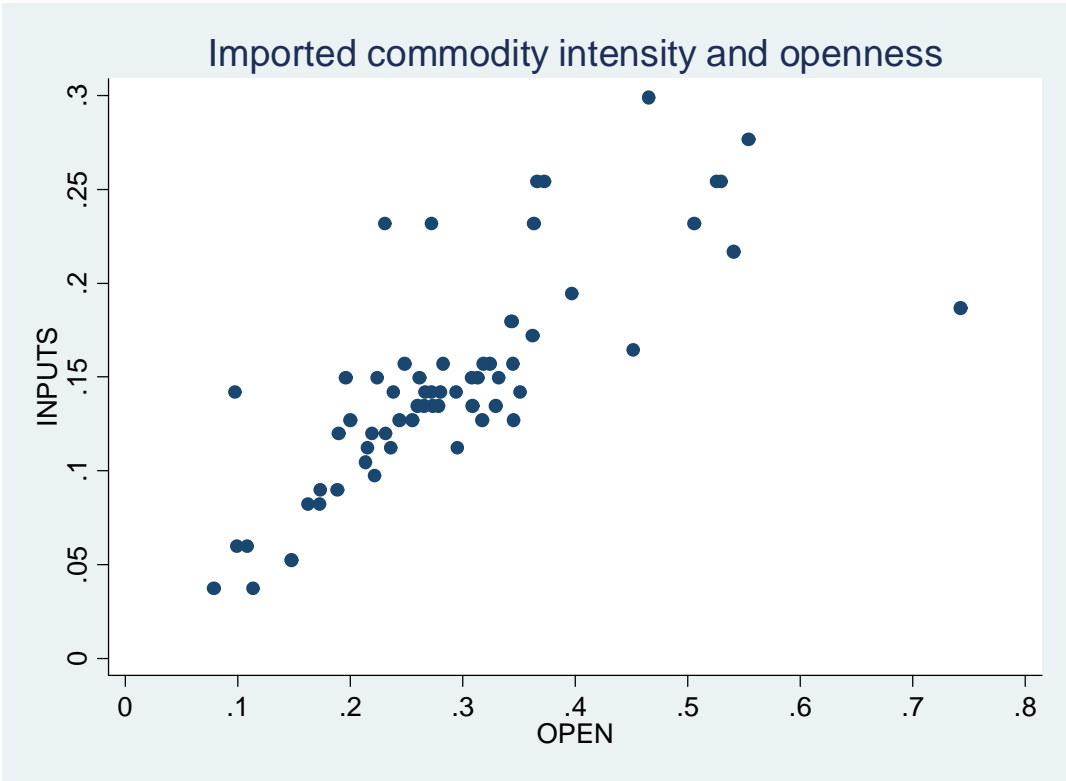


Figure 1: Scatter plot imported commodity intensity against openness

	1	2	3
<i>OPEN</i>	-3.540 (3.001)	-3.388 (1.555)**	-7.384 (2.903)**
<i>OPENEX</i>	-0.703 (0.986)	-0.145 (0.660)	-0.231 (0.771)
<i>LENGTH</i>	0.444 (0.135)***	0.463 (0.106)***	0.524 (0.129)***
<i>INFLOSS</i>	-0.102 (2.519)	-1.856 (1.979)	-3.952 (2.960)
<i>PEAK</i>	-0.874 (1.354)	-0.388 (1.100)	0.438 (1.605)
<i>CBI</i>	0.764 (1.217)		
<i>OPENCBI</i>	-11.08 (14.03)		
<i>INPUTSY</i>			9.505 (5.619)*
Observations	53	69	63
$R^2$	0.34	0.38	0.40

**Table 1: Regression Results**

The dependent variable is the sacrifice ratio. All data are constructed following Bowdler (forthcoming). Figures in parentheses are heteroscedasticity consistent standard errors.

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