Does trade integration alter monetary policy transmission?*

Tobias Cwik
Goethe University Frankfurt

Gernot J. Müller
University of Bonn and CEPR

Maik H. Wolters
Goethe University Frankfurt

September 13, 2010

Abstract

This paper explores the role of trade integration—or openness—for monetary policy transmission in a medium-scale new Keynesian model. Allowing for strategic complementarities in price-setting, we highlight a new dimension of the exchange rate channel by which monetary policy directly impacts domestic inflation: a monetary contraction which appreciates the exchange rate lowers the local currency price of imported goods; this, in turn, induces domestic producers to lower their prices too. We pin down key parameters of the model by matching impulse responses obtained from a vector autoregression on time series for the US relative to the euro area. Our estimation procedure yields plausible parameter values and suggests a strong role for strategic complementarities. Counterfactual simulations show that openness alters monetary transmission significantly. While the contractionary effect of a monetary policy shock on inflation and output tends to increase in openness, we find that monetary policy's control over inflation increases, as the output decline which is necessary to bring about a given reduction of inflation is smaller in more open economies.

Keywords: monetary policy transmission, open economy, trade integration, exchange rate channel, strategic complementarity

JEL-Codes: F41, F42, E52

*We thank Zeno Enders, Michel Juillard (the editor), Philip Jung, Keith Kuester, Volker Wieland, and two anonymous referees for very useful comments. We also gratefully acknowledge helpful discussions with participates of 39th Konstanz Seminar on Monetary Theory and Policy and with our discussant Boris Hofmann. The usual disclaimer applies. Please address correspondence to cwik@wiwi.uni-frankfurt.de, gernot.mueller@uni-bonn.de or wolters@wiwi.uni-frankfurt.de.

1 Introduction

Recent research on the monetary transmission mechanism has focused on the quantitative performance of dynamic stochastic general equilibrium (DSGE) models. Specifically, interest has centered on their ability to account for the dynamic effects of monetary policy shocks as apparent from estimated vector autoregression (VAR) models. In a seminal study, Christiano, Eichenbaum, and Evans (2005) show that a medium scale new Keynesian model mimics quite closely the VAR-responses to a monetary policy shock of as many as nine variables. This result is obtained while abstracting from external trade altogether. Taken at face value, it suggests that trade integration, or openness, plays no important role for monetary policy transmission—at least as far as a large open economy such as the US is concerned.[1]

There is, however, a secular trend in trade integration, suggesting that economies are becoming considerably more open over time. In the US, imports, as a fraction of GDP, have risen from about 6 percent in 1973 to about 15 percent to date. In fact, as this trend has been accelerating over the last decade, some observers have identified increasing trade integration as an important manifestation of globalization.[2] In this paper, we investigate more systematically the role of trade integration for monetary policy transmission, where we measure trade integration by the import-to-GDP ratio. Specifically, we assess how increasing openness alters quantitatively the effects of monetary policy shocks on inflation and economic activity.

Taking an analytical perspective, earlier work by Clarida, Galí, and Gertler (2001) and Galí and Monacelli (2005) has stressed the similarity between open and closed economy versions of the new Keynesian baseline model. In fact, apart from being a source of additional shocks, 'openness' merely alters some of the reduced-form coefficients of the canonical representation of the model which is, in fact, shown to be isomorphic in closed and open economies. These results are important for optimal monetary policy design in open economy models. In the special case where the intertemporal elasticity of substitution equals the trade price elasticity, targeting domestic inflation, rather than CPI inflation or the exchange rate is the optimal policy. De Paoli (2009) shows how this result changes in the more general case where elasticities differ. Taking a positive perspective, Erceg, Gust, and López-Salido (2010) analyze how differences in the transmission mechanism across closed and open economies hinge on the relative size of these elasticities. These authors argue that—for plausible

[1] Other studies which employ this approach find similarly satisfactory results for variants of the new Keynesian model. Rotemberg and Woodford (1997), Amato and Laubach (2003), Bovin and Giannoni (2006) and Meier and Müller (2006) are examples. These studies also assume counterfactually closed economy models. Other studies have explored the empirical performance of open economy DSGE models; yet these studies have typically not been particularly concerned with monetary transmission, see, e.g., Lubik and Schorfheide (2006) and Adolfson, Laséen, Lindé, and Villani (2007).

[2] The consequences of globalization for monetary policy are widely discussed both in academia and among policy makers. Most commentators, taking a fairly general perspective, have argued that globalization does not fundamentally affect the central bank's ability to control the economy, see, e.g., Mishkin (2007) and Bernanke (2007). Changes brought about by globalization may nevertheless require, as Yellen (2006) puts it, "some recalibration of policy responses".

calibrations—increasing openness is unlikely to alter the transmission of monetary policy shocks in a quantitatively important way.

However, taking up the question within the new Keynesian baseline model twists the analysis towards finding little ‘openness effects’. A key assumption underlying the derivation of the new Keynesian Phillips curve and, hence, its isomorphism in closed and open economies, is that the demand functions faced by intermediate goods firms are characterized by a constant elasticity of substitution. This, in turn, implies that the desired markup is independent of the price of competitors, i.e. there are no strategic complementarities in price setting. Such complementarities arise under a more general formulation of the demand functions, or, rather, the underlying aggregation technology. In this case, the isomorphism of the new Keynesian Phillips curve in closed and open economies breaks down. Intuitively, strategic complementarities arise not only with respect to domestic, but also with respect to foreign competitors. Hence, the domestic currency price charged by foreign competitors enters the decision problem of domestic firms and eventually the new Keynesian Phillips curve. Recently, Guerrieri, Gust, and López-Salido (2008) have highlighted the importance of this mechanism in accounting for inflation dynamics.[3] More generally, Chen, Imbs, and Scott (2009) provide evidence suggesting that increased exposure to foreign trade has a competitive effect which is reflected in firms’ price setting decisions.

In this paper, we take price-setting complementarities into account when exploring the role of openness for monetary transmission. As a result, a new dimension of the exchange rate channel emerges. Traditionally, monetary policy is thought to directly impact CPI-inflation and to indirectly impact domestic inflation via exchange rate changes, where the latter effect comes about through changes in demand induced by ‘expenditure-switching’. In contrast, with strategic price-setting complementarities, changes in the exchange rate, which alter the domestic currency price charged by foreign competitors, directly influence domestic inflation. The quantitative importance of this effect increases with the openness of an economy.

Our analysis is based on a medium-scale two-country DSGE model. It features an aggregation technology which allows to combine domestically produced and imported goods and gives rise to strategic complementarities in price-setting; in addition, the aggregation technology determines trade integration by giving unequal weight to domestically produced and imported intermediate goods. The model also features a number of frictions which the literature has found to increase the empirical success of this class of models. Overall, the model structure is rich enough to provide a quantitatively realistic account of the monetary transmission mechanism.

As a benchmark, we compute impulse responses to a monetary policy shock within a VAR model estimated on quarterly time-series data for the US relative to the euro area (EA) for the period 1973–

[3] Specifically, they estimate the resulting variant of the new Keynesian Phillips curve on the basis of single equation techniques. Importantly, in contrast to our analysis, they assume that all firms engage in local currency pricing.

2006. In addition to standard ‘closed-economy’ variables, the VAR model also includes CPI-inflation as well as US net exports vis-à-vis the EA. We treat the impulse responses as a characterization of the actual monetary transmission mechanism and estimate the structural parameters of the DSGE model by matching the impulse response functions of relative variables, i.e. the response of a domestic variable relative to its foreign counterpart. The domestic and the foreign economy in our two-country model are meant to represent the US and the EA, respectively. As trade with the EA accounts only for a small fraction of US trade, we assume, while estimating the model on US-EA data, that imports and exports account on average for two percent of GDP, respectively.

We limit ourselves to these data, because economic structures and trade relationships with the US have been less stable in most other regions of the world economy during our sample period. Instead, we rely on counterfactual simulations relative to the baseline scenario and analyze how a higher degree of openness alters the effects of a monetary policy shock. Put differently, we use our structural model to make up for the lack of long and stable time series. In a first step, we assume that imports account for 15 percent of GDP, a value close to the actual value for the US during the last few years. In a second step, we consider an average import share of 30 percent in order to assess the likely consequences of a further increase in openness.

Relative to the baseline economy we find considerable differences in the dynamic adjustment of the economy to a contractionary monetary policy shock. In more open economies domestic absorption tends to fall less, but overall activity tends to decline more strongly, reflecting a stronger reduction in real net exports. We also find the dynamics of inflation altered by openness. While CPI inflation generally falls in response to the shock, because the appreciation of the exchange rate is gradually passed-through into consumer prices, this effect grows stronger, as the economy becomes more open. Openness similarly affects the response of domestic inflation. For this result, strategic complementarities in price setting—which our estimates suggest to be sizeable—are crucial. Lastly, we find that monetary policy’s control over inflation (both of domestic inflation and CPI inflation) increases in the sense that the reduction in output which is necessary to bring about a given reduction in inflation declines in more open economies.

The remainder of this paper is organized as follows. In section 2 we introduce the details of the model economy. Section 3 presents time-series evidence from the estimated VAR model and discusses the estimation of the DSGE model. In section 4, we take a closer look at the role of trade integration for monetary transmission. Section 5 concludes.

2 Model

In this section we outline a two-country DSGE model which we use to study monetary policy transmission in open economies. Most of the model features are standard and familiar from so-called medium scale DSGE models as put forward, for instance, in Christiano et al. (2005) or Smets and Wouters (2007) in a closed economy context.[4] There is a representative household in each country which owns the capital stock and rents it out together with labor services to intermediate goods producers on a period-by-period basis. Adjusting the level of investment is costly. International financial markets are assumed to be complete.

We assume that each country specializes in the production of a specific set of intermediate goods which are manufactured by a continuum of monopolistic competitive firms. These intermediate good firms are constrained in price setting à la Calvo and invoice exports in their own currency. Within each country, perfectly competitive firms combine domestically produced and imported goods in order to produce wholesale goods which are not traded across countries. The aggregation technology employed by wholesale goods firms determines, for any given relative price, how many imported goods are used to produce a unit of the wholesale good—thereby determining the degree of openness. In addition, the aggregation technology induces demand functions for intermediate goods which are characterized by a non-constant price elasticity of substitution (NCES). Such an aggregation technology has recently been advocated by Gust, Leduc, and Vigfusson (2006), and Guerrieri et al. (2008) in an open economy context. Importantly, it induces strategic complementarities in price-setting among intermediate good firms not only with respect to domestic, but also with respect to foreign competitors.[5] This model feature allows us to account for a dimension of the exchange rate channel, which is absent from the baseline new Keynesian open economy model. Exchange rate changes which alter the domestic currency price of imported goods affect the pricing decision of domestic intermediate goods producers directly within our setup. This matters for the international transmission mechanism to the extent that pass-through of exchange rate changes into the domestic currency price of imported goods is sizeable. In our baseline setup we assume that pass-through is complete at the level of wholesale goods production, because exports are invoiced in producer currency. This assumption captures, in a stylized manner, the observation that pass-through at the border is typically much higher than the pass-through of border prices into consumer prices, see Goldberg and Campa (2010) for a recent evidence.[6]

We assume that pass-through of border prices into consumer prices is limited, because of a imperfectly competitive retail sector. In this sector a continuum of monopolistically competitive firms

[4]In setting up the model we also draw on earlier work on open economies by Chari, Kehoe, and McGrattan (2002), Kollmann (2002), Galí and Monacelli (2005) and Corsetti and Pesenti (2005), among others.

[5]The original closed economy formulation goes back to Dotsey and King (2005) or, more generally, to Kimball (1995). Sbordone (2007) uses a similar technology when discussing the consequences of firm entry for the slope of the new Keynesian Phillips curve. While Gust et al. (2006) and Guerrieri et al. (2008) focus on pass-through and inflation dynamics, respectively, we explore the implications for monetary transmission. Melitz and Ottaviano (2008) develop an alternative setup where consumer preferences imply a "love of variety" such that an increase in openness due to an increased number of goods alters the elasticity of demand. Hence, openness also alters the price setting decisions of domestic producers. For reasons of tractability we consider variations in openness only along the intensive margin.

[6]We conduct a sensitivity analysis exploring to the consequences of limiting the extent of exchange rate pass-through.

repackages and distributes wholesale goods to final consumers. As in Devereux and Engel (2002) retailers use no resources in order to distribute wholesale goods; they are also constrained in price setting à la Calvo, such that changes in the price of wholesale goods (due to exchange rate changes) are not fully passed-through into consumer prices, but partly absorbed by time-varying markups.[7]

In the following we give a formal exposition of the model, discussing, in turn, the problems of the firms and the representative household. We close the model with a feedback rule to characterize monetary policy. As both countries are symmetric, of equal size, and have isomorphic structures, we focus on the domestic economy, i.e. on the 'home' country. When necessary we refer to foreign variables by means of a star superscript.

2.1 Final goods

Domestic absorption of final goods is given as the sum of domestic consumption C_t, investment X_t, and government spending G_t. We assume that final goods are an aggregate of differentiated retail goods, $F_t(i)$, with $i \in [0, 1]$, which are bundled according to a standard CES aggregation technology. Specifically, we have

$$C_t + X_t + G_t = \left[\int_0^1 F_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}}, \quad \varepsilon > 1. \tag{1}$$

Expenditure minimizing implies a demand function for a generic retail good

$$F_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\varepsilon} (C_t + X_t + G_t), \tag{2}$$

where $P_t(i)$ denotes the price of good i and $P_t = \left[\int_0^1 P_t(i)^{1-\varepsilon} di\right]^{\frac{1}{1-\varepsilon}}$ denotes the price index of final goods (CPI).

2.2 Retail firms

We assume that retail goods are sold to final good consumers by monopolistically competitive firms. These retail firms repackage and redistribute a homogenous wholesale good which they purchase at price P_t^W. Retail firms adjust prices infrequently, as they are constrained exogenously à la Calvo. Specifically, each retail firm has the opportunity to change its price with a given probability $1 - \xi_R$. Moreover, we assume that when a retailer has the opportunity to do so, it sets the new price in order to maximize the expected discounted value of net profits before the realization of shocks in a given

[7] We model retailers as distinct from wholesale goods producers. While retailers are assumed to be monopolistically competitive, wholesale producers operate under perfect competition. Under this assumption, the aggregation problem faced by wholesale producers remains managable. Note also that in the present model nominal rigidities are critical for limiting the extent of exchange rate pass-through. Corsetti and Dedola (2005) and Gust et al. (2006), in contrast, develop real models of limited exchange rate pass-through.

period.[8] Retailers that do not reoptimize in a certain period, index their price to last period's CPI inflation, $\Pi_{t-1} = P_{t-1}/P_{t-2}$, as in Christiano et al. (2005). In setting the new price $\widetilde{P}_t(i)$, a generic retailer solves

$$\max \sum_{k=0}^{\infty} \xi_R^k E_{t-1} \left(\frac{Q_{t,t+k} F_{t+k}(i)}{P_{t+k}} \left[\widetilde{P}_t(i) \prod_{s=1}^{k} (\Pi_{t+s-1}) - P_{t+k}^W \right] \right), \tag{3}$$

subject to the demand function (2). Profits are discounted with the stochastic discount factor, $Q_{t,t+1}$, implicitly defined below. Each retailer uses an amount of wholesale goods equal to the demand for her retail good such that the total amount of wholesale goods processed by retail firms is given by $F_t = \int_0^1 F_t(i)di$.[9]

2.3 Wholesale good firms

The wholesale good consists of a continuum of intermediate goods produced domestically, $A_t(j)$, and imported from abroad, $B_t(j)$. We use $j \in [0,1]$ to index intermediate good firms as well as their products and prices. Wholesale goods are produced by perfectly competitive firms and are not traded across countries.

Letting $P_t^A(j)$ denote the domestic price of a domestically produced intermediate good and $P_t^B(j)$ the domestic price of an imported intermediate good, the problem of the representative wholesale goods firm is to produce F_t while minimizing expenditures given by

$$\int_0^1 P_t^A(j) A_t(j) dj + \int_0^1 P_t^B(j) B_t(j) dj \tag{4}$$

subject to

$$\left[V_{Dt}^{\frac{\sigma-1}{\sigma}} + V_{Mt}^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} - \left[\frac{1}{(1+\eta)\upsilon} - 1 \right] = 1, \tag{5}$$

where V_{Dt} and V_{Mt} are defined as follows

$$V_{Dt} = \int_0^1 \omega^{\frac{\sigma}{\sigma-1}} \frac{1}{(1+\eta)\upsilon} \left[\frac{(1+\eta)}{\omega} \frac{A_t(j)}{F_t} - \eta \right]^{\upsilon} dj, \tag{6}$$

$$V_{Mt} = \int_0^1 (1-\omega)^{\frac{\sigma}{\sigma-1}} \frac{1}{(1+\eta)\upsilon} \left[\frac{(1+\eta)}{(1-\omega)} \frac{B_t(j)}{F_t} - \eta \right]^{\upsilon} dj. \tag{7}$$

The aggregation technology given by (5), (6) and (7) is set up as in Gust et al. (2006). A few remarks concerning parameters are in order. First, the elasticity of substitution across domestically produced intermediate goods generally differs from the elasticity of substitution across domestically produced

[8] In other words, period t prices are set conditional on the information in period $t-1$, see Christiano et al. (2005). This assumption restricts the impact response of inflation to a monetary policy shock to be zero. We also impose this restriction to achieve identification in our estimated VAR model below.

[9] Due to price dispersion $F_t = C_t + X_t + G_t$ does not generally hold, but up to a first order approximation.

and imported goods. The elasticity of substitution across goods produced within the same country is generally time varying. In steady state it is constant and given by

$$\epsilon = \frac{1}{1-\upsilon}\frac{1}{1+\eta}. \tag{8}$$

For given values of υ and η, the parameter σ governs the trade price elasticity, which determines the extent of substitution from home to foreign produced goods for a given change of the terms of trade. It is a key parameter for the international transmission mechanism and given by

$$\tilde{\sigma} = \frac{-\sigma}{(\sigma(\upsilon-1)-\upsilon)(1+\eta)}. \tag{9}$$

The parameter η plays a crucial role for both elasticities. It provides a measure of how strongly our setup deviates from the special case where the elasticity of substitution is constant (CES), which is nested in our model for $\eta = 0$. Finally, the parameter ω measures the weight of domestically produced goods in final goods in steady state. $1-\omega$ measures the fraction of imports in wholesale goods in steady state and thus corresponds to the import-GDP-ratio.

Optimization behavior of domestic and foreign wholesale goods firms gives rise to demand functions for domestically produced intermediate goods

$$A_t(j) = \frac{\omega}{1+\eta}\left[\left(\frac{P_t^A(j)}{P_t^A}\right)^{\frac{1}{\upsilon-1}}\left(\frac{P_t^A}{\Gamma_t}\right)^{\frac{\sigma}{\sigma(\upsilon-1)-\upsilon}}+\eta\right]F_t, \tag{10}$$

$$A_t^*(j) = \frac{1-\omega}{1+\eta}\left[\left(\frac{P_t^{A*}(j)}{P_t^{A*}}\right)^{\frac{1}{\upsilon-1}}\left(\frac{P_t^{A*}}{\Gamma_t^*}\right)^{\frac{\sigma}{\sigma(\upsilon-1)-\upsilon}}+\eta\right]F_t^*. \tag{11}$$

P_t^A and P_t^B are price indices for domestically and imported goods, respectively. Expenditure minimization implies

$$P_t^A = \left(\int_0^1 P_t^A(j)^{\frac{\upsilon}{\upsilon-1}}dj\right)^{\frac{\upsilon-1}{\upsilon}}, \quad P_t^B = \left(\int_0^1 P_t^B(j)^{\frac{\upsilon}{\upsilon-1}}dj\right)^{\frac{\upsilon-1}{\upsilon}}, \tag{12}$$

and

$$\Gamma_t = \left[\omega(P_t^A)^{\frac{(\sigma-1)\upsilon}{\sigma(\upsilon-1)-\upsilon}} + (1-\omega)(P_t^B)^{\frac{(\sigma-1)\upsilon}{\sigma(\upsilon-1)-\upsilon}}\right]^{\frac{\sigma(\upsilon-1)-\upsilon}{(\sigma-1)\upsilon}}. \tag{13}$$

The price index for wholesale goods is given by

$$P_t^W = \frac{1}{1+\eta}\Gamma_t + \frac{\eta}{1+\eta}\omega\int_0^1 P_t^A(j)dj + \frac{\eta}{1+\eta}(1-\omega)\int_0^1 P_t^B(j)dj. \tag{14}$$

Letting S_t denote the nominal exchange rate and assuming that the law of one price holds, we have

$$P_t^B(j) = S_t P_t^{B*}(j); \quad P_t^A(j) = S_t P_t^{A*}(j). \tag{15}$$

Global demand for a generic good j is then given by

$$Y_t(j) = A_t(j) + A_t^*(j). \tag{16}$$

Note that the demand function includes an additive term if $\eta \neq 0$. As a result, price elasticities of demand and the desired markup of intermediate goods firms will be time-varying, or, in other words, price-setting behavior at the level of intermediate goods firms is characterized by strategic complementarities.

2.4 Intermediate good firms

The production of intermediate goods, $Y_t(j)$, is governed by a Cobb-Douglas production function

$$Y_t(j) = K_t(j)^{\theta} H_t(j)^{1-\theta}, \tag{17}$$

where $H_t(j)$ and $K_t(j)$ denote labor and capital employed by firm j. Letting W_t and R_t denote the nominal wage rate and the rental rate of capital, respectively, minimizing costs implies for (nominal) marginal costs

$$MC_t(j) = \frac{W_t H_t(j)}{(1-\theta)Y_t(j)} = \frac{R_t K_t(j)}{\theta Y_t(j)}. \tag{18}$$

We assume that price setting is constrained in the same way as for retail firms. An intermediate good firm has the opportunity to change its price with a given probability $1-\xi_I$. Moreover, we assume that when an intermediate good firm has the opportunity to do so, it sets the new price in order to maximize the expected discounted value of net profits before the realization of shocks in a given period.[10] Firms that do not reoptimize in a certain period index their price to last period's producer price inflation.[11] In setting the new price $\widetilde{P}_t^A(j)$, a generic intermediate good firm solves

$$\max \sum_{k=0}^{\infty} \xi_I^k E_{t-1} \left(\frac{Q_{t,t+k} Y_{t+k}(j)}{P_{t+k}} \left[\widetilde{P}_t^A(j) \prod_{s=1}^{k} \left(\Pi_{t+s-1}^A\right) - MC_{t+k} \right] \right), \tag{19}$$

subject to the demand function (16), the production function (17) and the optimality condition on factor inputs (18).[12] $\Pi_t^A = P_t^A / P_{t-1}^A$ denotes price inflation of domestically produced goods. We will refer to it as 'domestic inflation' in what follows.

2.5 Households

A representative household allocates consumption expenditures intertemporally on final goods and supplies labor, H_t, to intermediate good firms. The preferences of the household are given by

$$\sum_{t=0}^{\infty} \beta^t \frac{[(C_t - bC_{t-1})^{\mu}(1-H_t)^{1-\mu}]^{1-\gamma}}{1-\gamma}, \tag{20}$$

[10] In other words, period t prices are set conditional on the information period $t-1$, see Christiano et al. (2005). This assumption restricts the impact response of domestic inflation to a monetary policy shock to be zero. We also impose this assumption to achieve identification in our estimated VAR model below.

[11] Assuming that intermediate goods producers index to past intermediate goods price inflation, while retails index to the past CPI inflation allows us to capture the persistence of the estimated inflation response to a monetary policy shock. We also estimated variants of the model allowing for incomplete indexation, but typically found estimates at the upper bound of full indexation.

[12] In our formulation we implicitly assume that demand for intermediate good j is met at all times.

where β is a time discount factor and $b \in [0, 1)$ measures the extent of consumption habits. The parameters γ and μ are positive constants characterizing preferences.

Households own the domestic capital stock, K_t, which is internationally immobile as are labor services. As in Christiano et al. (2005) it may be costly to adjust the level of investment. Specifically, the law of motion for capital is given by

$$K_{t+1} = (1 - \delta)K_t + [1 - \Phi(X_t/X_{t-1})]X_t, \tag{21}$$

where δ denotes the depreciation rate; restricting $\Phi(1) = \Phi'(1) = 0$ ensures that the steady state capital stock is independent of investment adjustment costs captured by $\chi = \Phi''(1) > 0$.

A complete set of state-contingent securities is traded at an international level. Letting Ξ_{t+1} denote the period $t+1$ payoff of the portfolio held at the end of period t, the gross short-term nominal interest rate, $(1 + i_t)$, is implicitly defined by $(1 + i_t)^{-1} = E_t Q_{t,t+1}$, while the budget constraint reads as follow:

$$W_t H_t + R_t K_t + \Upsilon_t + T_t - P_t (C_t + X_t) = E_t \{Q_{t,t+1}\Xi_{t+1}\} - \Xi_t. \tag{22}$$

Υ_t denotes nominal profits earned by monopolistic firms and transferred to households and T_t denotes lump-sum taxes. We assume that government spending is financed entirely through lump-sum taxes: $T_t = P_t G_t$.

We assume that the household decides on consumption and investment expenditures in period t before period-t uncertainty is revealed. Subject to this additional constraint as well as to (21) and (22), the household maximizes the expected value of (20).

2.6 Monetary Policy

To close the model, we assume that monetary policy is characterized by an interest rate feedback rule similar to the one put forward by Clarida, Galí, and Gertler (2000). Specifically, we assume for the interest rate

$$i_t = \rho i_{t-1} + (1 - \rho)\left(i + \beta^{-1}\phi_\pi (\Pi_t - \Pi) + (4F\beta)^{-1}\phi_y (Y_{t-1} - Y)\right) + \nu_t, \tag{23}$$

where variables without time subscript refer to steady state values. The parameter $\rho \in [0, 1]$ captures interest rate smoothing, while ϕ_π captures the long-run adjustment of the interest rate to CPI inflation. ϕ_y measures the response to lagged output, Y_{t-1}, in terms of deviations from steady state. We assume that monetary policy responds to output with a lag only as it is hardly observable in real time.[13] Finally, ν_t represents a zero-mean shock to the short-term interest rate not accounted for by the systematic feedback rule. It thus represents a monetary policy shock.

[13] Under these assumptions the interest rate is predetermined with respect to output. This is consistent with the identification assumption imposed on the VAR below where we exclude a response of the policy rate to net exports within the quarter. In specifying (23), we scale parameters so as to allow a direct comparison which the values obtained in the empirical literature on interest rate rules where inflation and interest rate are typically annualized.

2.7 Model solution

We solve the model numerically by applying standard techniques. Specifically, we use (23) together with the linearized first order conditions and constraints of the firms' and household problem as well as their foreign counterparts to determine the equilibrium allocation near the deterministic and symmetric steady state. We use the approximate solution of the model to investigate the effects of monetary policy shocks on the economy. To simplify the analysis, we focus on country differences, i.e. the behavior of a domestic variable relative to its foreign counterpart. Before discussing our strategy to assign parameter values, we briefly turn to the implications of strategic price-setting complementarities for the exchange rate channel of monetary policy transmission.

2.8 Inflation dynamics and the exchange rate channel

Strategic complementarities in price-setting may alter monetary policy transmission in open economies by adding a new dimension to the exchange rate channel. Traditionally, two dimensions of the exchange rate channel have been distinguished (see, for instance, Svensson, 2000). First, under sticky prices, nominal exchange rate changes translate into real exchange rate changes that in turn induce an expenditure switching effect. As a result, exchange rate changes alter the demand for domestic goods and thus affect domestic producer prices. Note that in this case, the exchange rate impacts only indirectly—via demand—on domestic inflation. Second, nominal exchange rate changes may feed directly into the prices of imported goods and hence into CPI-inflation.

Strategic price-setting complementarities add a new dimension to the exchange rate channel. In order to show this formally, we derive a variant of the new Keynesian Phillips curve as an approximation of the intermediate goods firms' price setting problem around a deterministic, zero inflation steady state:

$$E_{t-1}\pi_t = \beta E_{t-1}\pi_{t+1} + \lambda(1-\Psi)E_{t-1}mc_t + \lambda\Psi(1-\omega)\frac{2\omega\tilde{\sigma}}{\epsilon}E_{t-1}q_t^B. \tag{24}$$

Here π_t denotes percentage points of domestic inflation, mc_t measures the percentage deviation of marginal costs from steady state and q_t^B denotes the percentage deviation of the relative price of imports expressed in domestic currency.[14] The coefficient $\lambda = (1-\beta\xi_I)(1-\xi_I)\xi_I^{-1}$ is familiar from the new Keynesian baseline model and provides a measure for the pass-through of marginal costs into domestic inflation. The coefficient Ψ depends on the extent of strategic complementarities in price-setting and other structural parameters of the model: $\Psi = -\eta\epsilon(\epsilon(1-\eta)-1)^{-1}$.

The relationship (24) governs the dynamics of domestic inflation. Note that if $\eta = 0$, we have $\Psi = 0$ and the term q_t^B disappears from the Phillips curve. In fact, in this case the Phillips curve takes the form which is well-known from the closed-economy new Keynesian baseline model. Clarida et al.

[14]Expression (24) abstracts from indexation, appendix B provides details. Note that Guerrieri et al. (2008) provide a derivation under the assumption of local currency pricing.

(2001) and Galí and Monacelli (2005) have stressed this isomorphism, i.e. the fact that the form of the Phillips curve for the open economy corresponds to that of the closed economy. This case is nested in our model.

Turning to the case where complementarities are present ($\eta < 0 \rightarrow \Psi > 0$), we observe that the relative price of imports directly matters for domestic inflation. Consider, for instance, a decrease in the domestic currency price of imports resulting from an exchange rate appreciation. In this case, given strategic price-setting complementarities, domestic producers will find it optimal to lower their prices, because the price charged by foreign competitors is reduced: domestic inflation falls. In addition to the coefficient Ψ, two more parameters govern the strength of this effect. First, the larger the trade price elasticity relative to the elasticity of substitution across domestically produced goods ($\tilde{\sigma}/\epsilon$), the stronger the impact of import prices on domestic inflation. Second, the impact will also be stronger, the more open an economy. This follows from imports making up for a larger fraction of the wholesale goods, measured by $1 - \omega$.

As a consequence, monetary policy may *directly* impact *domestic* inflation via the exchange rate. A monetary contraction which appreciates the nominal exchange rate and lowers the price of imports reduces domestic inflation. This adds a new dimension to the exchange rate channel, which is not present in models without price-setting complementarities.

3 Estimation

Our model is agnostic as to what drives the business cycle fluctuations as it only allows for monetary policy shocks. Accordingly, by bringing the model to the data, we isolate fluctuations in actual time series which can be attributed to monetary policy shocks. Specifically, we focus on the empirical impulse response functions obtained from an estimated VAR model. We use these statistics to pin down the values of key parameters of the DSGE model.[15] To the extent that our model is able to account for the empirical response functions, it provides an empirically plausible account of the monetary transmission mechanism.

3.1 Empirical impulse response functions

We estimate the VAR on quarterly time series data for the period 1973–2006. We consider relative variables as, for instance, in Clarida and Gali (1994) and Rogers (1999), and compute the difference of a variable for the US and its counterpart for the EA. While the EA accounts only for a limited amount of US foreign trade today, we limit ourselves to US-EA data, because changes in economic

[15]A natural alternative to our limited information approach is to estimate the model using full information techniques. This would require to take a stand of all possible sources of business cycle fluctuations, which we can avoid for the purpose of the present study.

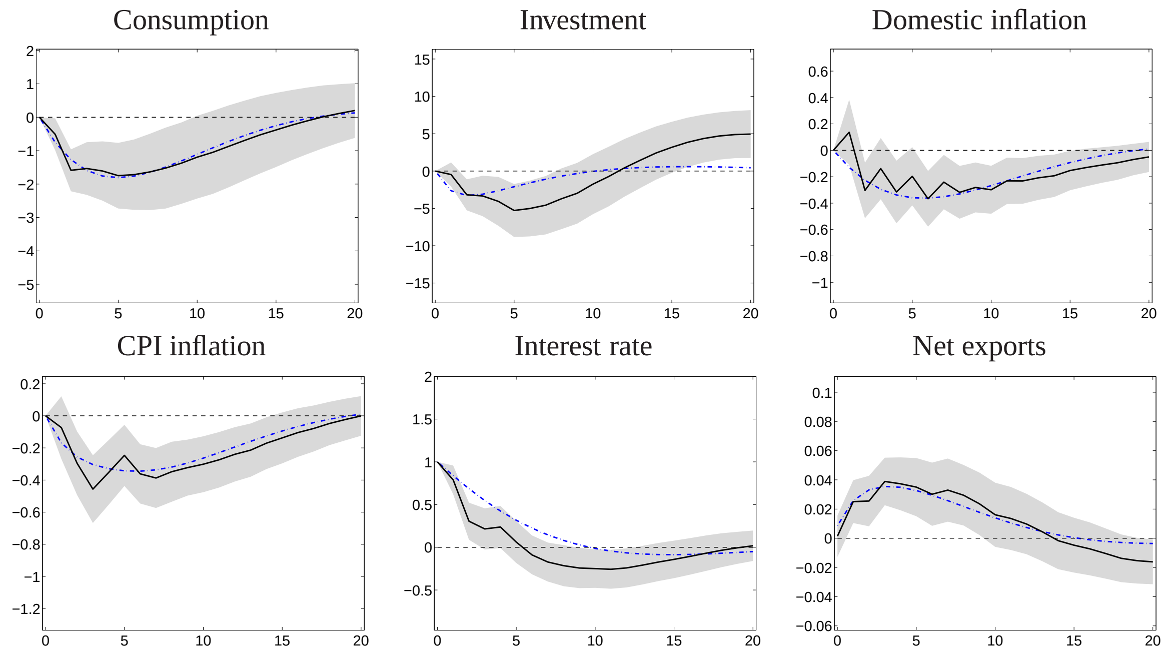

Figure 1: Effects of a monetary policy shock. Notes: Shock and responses are in relative terms (US vs EA); solid lines: point estimate of VAR model; shaded areas: bootstrapped 90 percent confidence intervals; dashed-dotted line: responses of estimated DSGE model; Vertical axes: percentage deviation from trend (consumption and investment), quarterly percentage points (inflation and interest rate) and percent of output (net exports). Horizontal axes: quarters.

structures have been less severe in these currency areas than in other regions of the world economy during our sample period. Specifically, we consider the log of relative consumption, the log of relative investment, the domestic inflation rates (computed on the basis of the GDP deflator), CPI-inflation rates, short-term interest rates, as well as US net exports, measured in percent of GDP, vis-à-vis the EA. Interest rates and inflation rates are measured at quarterly rates.[16] Letting Y_t denote the vector of endogenous variables, we estimate the structural VAR model

$$A(L)Y_t = u_t, \tag{25}$$

where $A(L) = \sum_{i=0}^{4} A_i L^i$, $LY_t = Y_{t-1}$ and $E(u_t u_t') = I$.

In order to identify (relative) monetary policy shocks, we assume that A_0 is lower triangular, i.e. we impose the recursive identification scheme which is frequently employed to study the effects of monetary policy shocks, see Kim (2001) for an open economy context. We attach a structural interpretation only to the innovation in relative short-term interest rates. Hence, what matters for identification is how the other variables in Y_t are ordered relative to this variable, see Christiano, Eichenbaum, and

[16]We treat CPI-inflation as the empirical counterpart of the DSGE model's inflation rate for final goods. A detailed description of the data is given in appendix C. We remove a constant linear trend from consumption and investment before computing relative variables.

Evans (1999). We order relative consumption, relative investment as well as the inflation differentials before and net exports after the short-term interest rate differential. The implied identification assumptions are consistent with our DSGE model: consumption, investment and inflation are predetermined relative to monetary policy shocks, while net exports are free to adjust immediately. At the same time, our identification scheme rules out a contemporaneous response of interest rates to net exports.[17]

Figure 1 displays the impulse responses to a monetary policy shock which we normalize to an increase by 100 basis points of the US short rate relative to the short rate in the EA (quarterly interest rate). The solid line represents the point estimate, while the shaded areas indicate 90 percent confidence bounds obtained from bootstrap sampling. The upper row shows the responses of consumption and investment in relative terms; for both we find a protracted and hump-shaped decline. While consumption falls by roughly 1.5 percent, investment falls by about five percent, with the maximum effect occurring between three and five quarters after the shock.

Domestic inflation responds somewhat sluggishly; the maximum decline of about 40 basis points is observed six quarters after the shock. According to our point estimate, it takes another 3 to 4 years for inflation to return to its pre-shock level. The response of CPI-inflation is fairly similar to that of domestic inflation, both from a quantitative and a qualitative point of view. The response of the interest rate differential to the exogenous innovation is mildly persistent, with the short rate returning to its pre-shock level after about one year. Finally, US net exports display a hump-shaped increase with the maximum effect of about 0.04 percent of output occurring after about a year.

3.2 Estimation of general equilibrium model

The second step of the analysis consists in matching empirical and theoretical impulse responses in order to obtain estimates for the parameters of the DSGE model. This approach has gained popularity in closed economy studies of monetary policy transmission following the pioneering work of Rotemberg and Woodford (1997) and Christiano et al. (2005).

To illustrate this approach, define IR^e to be the empirical impulse response function characterizing the data. The model itself assigns to each admissible vector of structural parameters θ a theoretical impulse response function $IR = IR(\theta)$. We obtain an estimate for the parameter vector of interest, $\widehat{\theta}$, by minimizing the weighted distance between empirical and theoretical impulse response functions,

[17] Alternative approaches to identify monetary policy shocks in open economy frameworks consider monetary aggregates and non-recursive identification schemes, see Eichenbaum and Evans (1995), Cushman and Zha (1997) and Kim and Roubini (2000). More recently, Faust and Rogers (2003) and Scholl and Uhlig (2008) use sign restrictions to achieve identification. These studies have typically been concerned with the behavior of the exchange rate in the face of monetary policy shocks and focused on the importance of the latter to account for fluctuations in the former. In the present paper, we are not taking up these issues. Instead, we use the VAR responses as a key statistic to pin down parameter values of our DSGE model.

i.e., IR^e and IR:

$$\widehat{\theta} = \arg\min \left(IR^e - IR(\theta)\right)' W \left(IR^e - IR(\theta)\right), \tag{26}$$

where W represents a diagonal matrix whose entries are the reciprocal values of the variance of the empirical impulse responses. Using this weighting matrix ensures that the theoretical impulse responses are made to be as close to the empirical ones as possible, in terms of point-wise standard deviations. Regarding the length of the impulse response functions, we consider 20 quarters starting from the second quarter as most variables return to their steady state within 5 years.

The relationship between structural parameters and the implied impulse response functions is non-linear; we therefore obtain theoretical impulse response functions by applying standard numerical techniques. Note that our procedure only admits solution which are saddle-path stable and thus rules out by construction any parameterization of the model which would give rise to equilibrium indeterminacy. Standard errors for $\widehat{\theta}$ are computed using the following expression for the asymptotic variance of our estimator, taken from Wooldridge (2002):

$$\widehat{Avar}\left(\widehat{\theta}\right) = \left(G'WG\right)^{-1}\left(G'W\widehat{\Sigma}WG\right)\left(G'WG\right)^{-1}. \tag{27}$$

where $G = \nabla_{\theta} IR$ represents the Jacobian of the impulse response function generated from the model and $\widehat{\Sigma}$ denotes the variance matrix of the impulse responses obtained from bootstrap sampling.

3.3 Parametric setup

In practice, given the number of the structural parameters, it is not possible to identify all of them simultaneously. We therefore fix those parameters prior to the estimation which are either given by first moments of the data or are fairly uncontroversial.

First we set $\omega = 0.98$ which implies an import-to-GDP ratio of 2 percent, the average value for the US vis-à-vis EA in our sample period, see also Chari et al. (2002) who target a value of 1.6 percent. Moreover, we set, as, for instance, in Backus, Kehoe, and Kydland (1994) $\beta = 0.99$, $\gamma = 2$ and $\mu = 0.34$ as well as $\theta = 0.36$ and $\delta = 0.025$. In addition, we assume that government spending accounts for 20 percent of GDP, close to the average in our sample period. Regarding price rigidities in the intermediate goods sector, we set $\xi_I = 0.75$, which implies an average duration of prices of four quarters. This value, if somewhat high, is still consistent with evidence reported by micro studies such as Nakamura and Steinsson (2008). We set υ such that the markup earned by intermediate goods firms in steady state is 50 percent, in line with estimates by Smets and Wouters (2007).[18]

We are thus left with eight parameters for which we seek to obtain estimates by solving (26). We estimate a value for the trade price elasticity, $\tilde{\sigma}$, by adjusting σ according to the relationship (9). In

[18] We set $\varepsilon = 100$. ε does not affect the dynamics of the model, because the production function of retailers is linear. Assuming a high value for ε ensures that the markup in the retail sector is close to zero so that in steady state final good output is equal in size to the output in the retail sector.

Table 1: Estimated parameter values of DSGE model

Parameter	Description	
$\tilde{\sigma}$	Trade price elasticity	0.479 (0.035)
χ	Investment adjustment costs	0.751 (0.388)
b	Habits	0.842 (0.056)
ϕ_π	Inflation coefficient in policy rule	1.000 (0.740)
ϕ_y	Output coefficient in policy rule	0.006 (0.242)
ρ	Interest rate smoothing	0.861 (0.068)
η	NCES-parameter	-12.499 (8.797)
ξ_R	Calvo-parameter (retail firms)	0.457 (0.362)

Notes: Parameter estimates obtained from matching DSGE and VAR impulse response functions; standard errors are reported in parentheses.

addition, we pin down values for the parameters measuring investment adjustment costs, χ, habits, b, as well as values for those parameters which specify the interest rate feedback rule: ϕ_π, ϕ_y and ρ. Two additional parameters, which are of particular importance for the international monetary transmission mechanism are η which is directly related to the degree of strategic price-setting complementarities and ξ_R which governs the extent of price stickiness in the retail sector and thus the pass-through of exchange rate changes into consumer price inflation.

3.4 Results

Table 1 reports results. We find plausible point estimates and fairly narrow confidence bounds implied by the standard errors reported in parentheses. The estimated trade price elasticity is below the values often used or found in the literature. Yet several recent studies suggest that a low trade price elasticity may help to account for a larger set of macroeconometric observations, see Lubik and Schorfheide (2006), Kollmann (2006) and de Walque, Smets, and Wouters (2005). We perform sensitivity analysis regarding the role of this parameter for the international transmission mechanism below. Also χ, the parameter capturing investment adjustment costs is somewhat below the value reported in Christiano et al. (2005). This is likely to be the result of the imperfect substitutability of domestically produced and imported goods, see the discussion in Backus et al. (1994).

Regarding monetary policy we find parameter values which imply a fairly loose monetary stance. Note, however, that our solution procedure rules out equilibrium indeterminacy. The degree of interest rate smoothing is in line with previous findings in the literature, see, for instance, Clarida et al. (2000) for the US. We find a considerable amount of habits in consumption, somewhat above the values

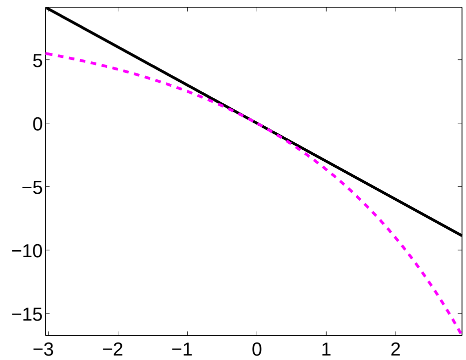

Figure 2: Demand function for intermediate goods. Notes: vertical axes: relative demand in percent; horizontal axes: relative price in percent; solid line: CES case ($\eta = 0$); dashed-dotted line: NCES case, as implied by estimate.

reported in Smets and Wouters (2005) both for the euro area and the US. Finally, the estimate for the parameter η provides a measure for the curvature of our demand functions. Our estimate is somewhat higher than the values assumed by Gust et al. (2006) and Guerrieri et al. (2008), but close to the value assumed by Smets and Wouters (2007) in a closed economy context.

In order to assess the implication of our estimate for η, we display in figure 2 the percentage change in demand for a generic good (vertical axis) resulting from a percentage change in its relative price (horizontal axis). The dashed line shows the implied demand function for our estimate of η, while the solid line displays the results for $\eta = 0$ implying a constant elasticity of substitution (CES). Relative to the CES case, our estimate implies strongly curved demand functions. As a result, if the relative price increases, demand falls more than proportionally, while, if the relative price falls, demand increases less than proportionally. This induces strategic complementarities in price-setting, which, ceteris paribus, provides firms with an incentive to limit deviations from the domestic currency price charged by domestic and foreign competitors.

Given the estimated parameter values, we compute the impulse responses of the model and compare them to those obtained from the VAR model. The dashed-dotted lines in the panels of figure 1 show that the model responses track the empirical responses quite closely. All the responses are within the confidence bounds of the VAR responses, except for the interest rate where the response of the model exceeds the empirical impulse response for a number of quarters. Also the theoretical response of investment is somewhat less pronounced than its empirical counterpart. The response of the consumption differential, as well as those of inflation and net exports are matched particularly closely. Overall, we conclude that the DSGE model—if evaluated at the point estimates—provides a quantitatively satisfactory account of the monetary transmission mechanism as apparent for the estimated VAR model.

4 The role of openness in monetary policy transmission

In this section we take up the question which motivates our investigation: does trade integration play a quantitatively important role for the transmission of monetary policy? Given that the estimated DSGE model provides a structural account of the monetary transmission mechanism, we address this question by means of counterfactual experiments.

4.1 Trade integration

While several quantitative studies have demonstrated that it is possible to account for the evidence on the transmission mechanism while abstracting from foreign trade altogether, we have shown that our two-country model is able to match the impulse responses obtained from a VAR model estimated on data for the US relative to the EA. For this purpose we have assumed that imports account for 2 percent of GDP only, corresponding to the average share of US imports from the EA in US GDP. Clearly, the US is more open to trade and, importantly, the import share is likely to increase further. Yet long time series for all trading partners of the US are not available and/or subject to structural breaks. In order to explore the role of trade openness for the monetary transmission mechanism we therefore rely on model simulations. Specifically, we compare impulse responses to a monetary policy shock obtained for the estimated model (baseline scenario) to those obtained while assuming that imports account for 15 and 30 percent of GDP on average.

Figure 3 displays impulse responses to a domestic monetary policy shock, i.e. an exogenous increase in the nominal interest rate by 100 basis points. We focus on the response of the variables in the home country, rather than on relative variables as in figure 1. Horizonal axes measure quarters, while vertical axes measure responses in percentage deviation from steady state, percent (inflation and interest rate) or percent of output (net exports). The responses are computed using the estimated DSGE model where all parameters, except for ω (which is adjusted to target a particular steady-state import share), are held fixed at the values of the baseline scenario. The solid lines show responses for the baseline scenario, where imports account for 2 percent of GDP on average, while the dashed and dashed-dotted lines show results for an average import share of 15 and 30 percent, respectively.

The response of consumption, displayed in the upper-left panel, shows a hump-shaped decline reflecting habit formation. For more open economies we find the responses much more muted. In order to understand this result, note that a contractionary monetary policy shock raises long-term real interest rates in the domestic economy and appreciates the exchange rate and the terms of trade (not shown). In fact, the terms of trade provide a measure for the long-term real interest rate in the home country relative to its foreign counterpart.[19] Under complete financial markets, the terms of trade, in turn, are

[19] This follows from solving an approximation of the uncovered interest rate parity condition forward, see Galí and Monacelli (2005) for details.

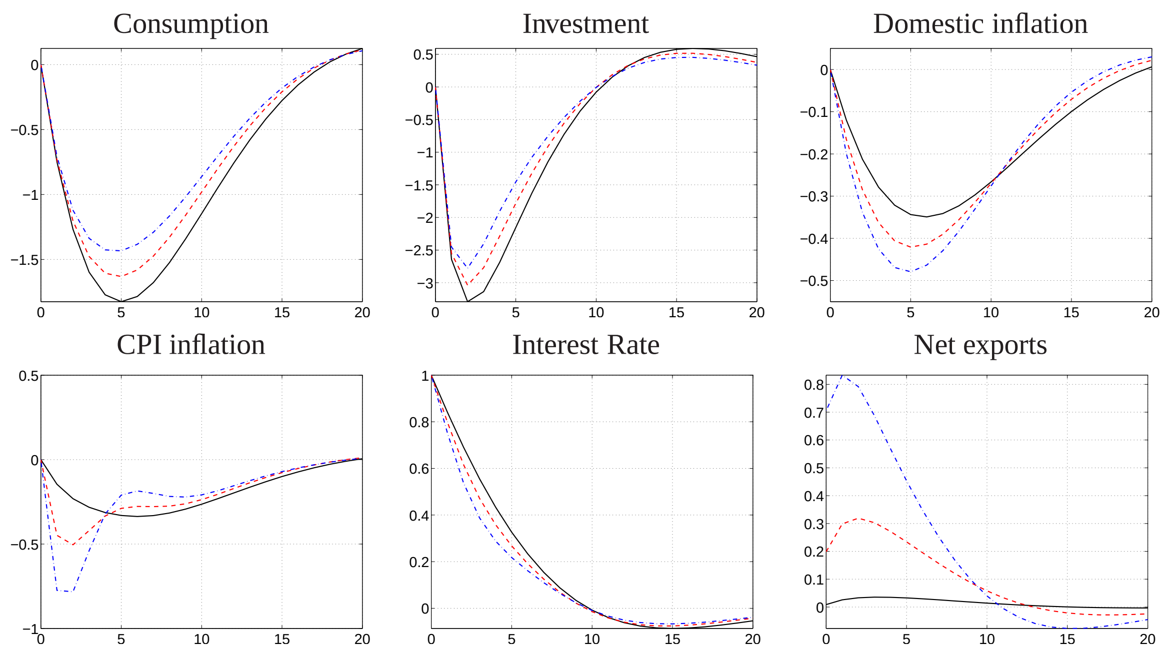

Figure 3: Effects of a monetary policy shock. Notes: the shock is an exogenous increase in domestic nominal interest rate by 100 basis points; lines show response of domestic variables. Vertical axes: percentage deviation from trend (consumption and investment), quarterly percentage points (inflation and interest rate) and percent of output (net exports). Horizontal axes: quarters. Solid line: responses for 2 percent import share (baseline); dashed line: 15 percent import share; dashed-dotted line: 30 percent; for all parameters except for ω we assume the values of the (estimated) baseline scenario.

tightly linked to (relative) consumption via the risk-sharing condition. Specifically, as emphasized by Erceg et al. (2010), domestic consumption (relative to foreign consumption) is less sensitive to the terms of trade, the more open an economy. In response to a given increase in relative long-term real interest rates consumption thus declines less in more open economies.[20]

Similarly, investment decisions are linked to the terms of trade, as they alter the marginal return on domestic capital, see Corsetti and Müller (2006). Intuitively, an appreciation of the terms of trade raises, all else equal, the value of domestically produced goods in terms of final goods. For a given appreciation of the terms of trade, this effect is stronger, the more open an economy, because imported goods, whose relative value depreciates, make up for a larger fraction of capital goods. As the monetary policy shock appreciates the terms of trade, we therefore observe, in the second panel of figure 3, a muted response of investment in more open economies. The responses are hump-shaped because of investment adjustment costs.

Turning to the response of domestic inflation, displayed in the upper right panel, we find that it responds more strongly to monetary policy shocks in more open economies. In fact, domestic inflation falls by about 48 basis points under a scenario where imports account for 30 percent, rather than by about 33 basis points under a scenario where imports account for 2 percent only. The strength of the response thus increases by some 45 percent. That openness increases the effect of monetary policy shocks on *domestic* inflation, i.e. inflation of domestically produced goods, is largely due to the new dimension of the exchange rate channel emerging under strategic complementarities in price setting, which according to our estimate for η are quite sizeable. Intuitively, as discussed in section 2.8 above, to the extent that monetary policy appreciates the exchange rate, the price of imported goods falls and induces domestic intermediate good firms to lower their prices as well. This effect is stronger, the larger the average weight of foreign goods in the production of wholesale goods.

The first panel in the second row of figure 3 shows the response of CPI inflation. Under the baseline scenario the dynamics of CPI inflation mimic those of domestic inflation—in line with the VAR evidence. While monetary policy appreciates the exchange rate and thus reduces the price of imported goods, the effect on the overall price for final goods is fairly small, because imported goods account for a very small fraction of overall inputs in wholesale production. Conversely, CPI inflation responds much more sharply in more open economies. This reflects a considerable amount of exchange rate pass-through into consumer prices. Yet pass-through of wholesale price changes and hence exchange-rate changes into consumer prices remains limited. In fact, it is zero on impact, as retail prices are predetermined by assumption and remains further limited as retailers adjust prices infrequently. Our estimates suggest that retail prices are adjusted on average approximately every second quarter.

[20]Intuitively, the smaller the degree of home bias (i.e. the more open the economy), the less will domestic consumption drop in response to an appreciation of the terms of trade (i.e. a rise in the relative long-term real interest rate) as a result of full risk-sharing under complete financial markets.

Interest rates respond endogenously to stabilize CPI inflation. The stronger fall in CPI inflation in more open economies also provides a rationale for why policy rates decline more quickly in this case (shown in the middle panel of the second row of figure 3). The lower right panel displays the response of net exports (relative to GDP). While for the baseline scenario the response is muted, the value net exports relative to GDP rises by almost one percent if imports (and exports) account for 30 percent. The response reflects a value and a substitution effect triggered by the appreciated exchange rate: wholesale producers substitute towards foreign goods and net exports in real terms decline; at the same time, the value of exports increases relative to the value of imports. Overall, we find that net exports increase relative to GDP, as the second effect dominates due to a low estimate of the trade-price elasticity.

4.2 Output and inflation dynamics

We now turn to results from additional experiments meant to shed light on the transmission mechanism implied by our estimated DSGE model. Specifically, we highlight the role of the trade price elasticity and strategic complementarities in price setting. To simplify the discussion, we focus on domestic absorption (the sum of consumption and investment, as government spending is constant), (domestic) inflation, output and CPI inflation for which the responses are displayed in figure 4. Here we consider again the responses of domestic variables to a contractionary monetary policy shock by 100 basis points. Results displayed in the left column are obtained for the baseline parameterization and three openness scenarios (with an import share of 2, 15 and 30 percent as above). Domestic absorption (top panel) declines less in more open economies, in line with our earlier discussion. The responses of inflation have been discussed above and are reproduced here to allow for a comparison with the results obtained under alternative assumptions.

The third panel shows the response of output which is somewhat more pronounced in more open economies. As analyzed in Erceg et al. (2010), the interest-sensitivity of output increases in openness if the trade price elasticity is high relative to the intertemporal elasticity of substitution.[21] Our estimates imply a relatively low value for the trade price elasticity. Nevertheless, the value for the effective intertemporal elasticity of substitution is even lower, because habits and investment adjustment costs attenuate the initial response of domestic absorption to changes in interest rates. Openness thus raises the interest rate sensitivity of output, as the relative importance of the interest-sensitivity of real net exports increases.

To investigate this issue further, we compute impulse responses assuming a higher value for the trade

[21] Specifically, they show that a weighted average of the intertemporal elasticity of substitution and the trade-price elasticity determines the interest-sensitivity of output. It increases in openness if the trade price elasticity exceeds the intertemporal elasticity of substitution and vice versa.

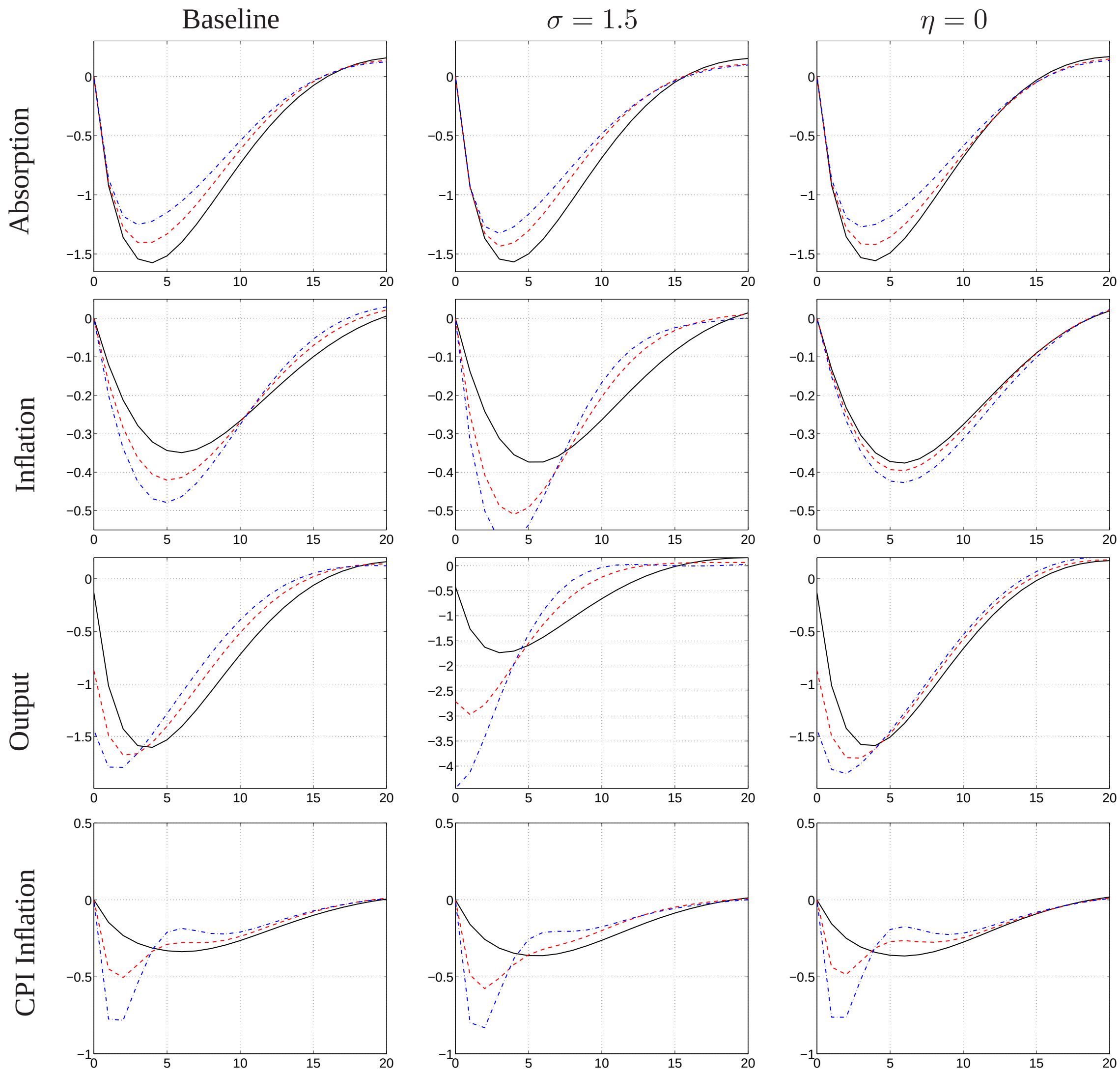

Figure 4: Effects of a monetary policy shock. Notes: see figure 3; left column shows results for estimated model (solid lines) and two alternative openness scenarios (15 and 30 percent import share displayed by dashed and dashed-dotted lines, respectively); middle column shows results for higher trade price elasticity; right column shows results for CES case while assuming an unchanged coefficient on marginal costs in the Phillips curve relative to the estimated model.

price elasticity.[22] We set $\sigma = 1.5$, as, for instance, in Backus et al. (1994). Results are shown in the middle column of figure 4. In this case, the role of openness for the output response is considerably magnified. Output declines strongly, because net exports (in real terms) fall strongly. Note that assuming a higher value for the trade price elasticity also changes how openness alters the response of domestic inflation. In fact, as discussed in section 2.8 above, the larger the trade price elasticity, the more strongly will changes in the price of imported goods impact on the pricing decisions of domestic producers. As the monetary policy shock lowers, via an exchange rate appreciation, the price of imported goods, its deflationary effect, is more strongly felt if the trade-price elasticity is high.

In the right column of figure 4 we show impulse responses which are computed while assuming that there are no strategic complementarities in price setting ($\eta = 0$). All other parameter values are unchanged relative to the baseline scenario with the exception of ξ_I which governs the degree of price stickiness in the intermediate goods sector and hence the slope of the new Keynesian Phillips curve. We adjust it so as to keep the latter unchanged relative to the estimated version.[23] Absent strategic complementarities we find the responses of domestic inflation to a monetary policy shock hardly altered by openness.[24] While openness still magnifies the response of CPI inflation due the direct effect of lower import prices on the price of final goods, the indirect effect through a stronger response of domestic inflation is reduced. Hence, strategic complementarities add an important dimension to the exchange rate channel of monetary policy transmission.

4.3 Exchange rate pass-through

So far we have assumed that the law of one price holds for intermediate goods such that exchange rate pass-through at the border is complete. As intermediate good firms set prices in their own currency (producer currency pricing, or PCP, for short) and adjust them infrequently, exchange rate changes alter the price paid by wholesale firms. Consequently, there is considerable amount of expenditure switching in response to exchange rate changes. We now analyze how our results on openness differ under the alternative assumption of local-currency pricing (LCP, for short). Here producers are

[22] As discussed above, our estimate for the trade price elasticity conforms well with results of recent macroeconometric studies, but is lower than the values suggested by estimates on the basis of disaggregated data. Imbs and Mejean (2009) argue that macroeconometric estimates can be biased as a result of considerable cross-sectoral heterogeneity which characterize disaggregated data.

[23] As equation (24) illustrates, the parameter η not only determines how strongly the domestic currency price of foreign competitors matters for domestic inflation, but also how strongly changes in marginal costs are passed-through into domestic inflation. Assuming that strategic complementarities are absent—both with respect to domestic and foreign competitors of intermediate goods producers—thus raises, all else equal, the slope of the new Keynesian Phillips curve. Intuitively, those firms which are able to adjust prices will do so by larger amounts in this case. In order to isolate the role of strategic complementarities for the exchange rate channel of monetary policy transmission, we increase the value of ξ_I so that the coefficient on marginal costs is unchanged relative to the estimated model whenever we set $\eta = 0$.

[24] Openness still induces some change in the response of domestic inflation, because output and, hence, marginal costs fall more strongly in more open economies in response to the monetary policy contraction.

assumed to be able to discriminate and set different prices across markets. As prices are sticky in both currencies, exchange rate changes are not immediately reflected in buyers' prices, but partially absorbed by time-varying markups.[25]

We modify our model assuming that intermediate good firms which engage in LCP set two distinct prices for the domestic and for the foreign market whenever they have the opportunity to adjust prices.[26] Specifically, we consider two alternatives relative to the PCP scenario. First, we assume that all intermediate firms engage in LCP. Second, we consider the possibility that while domestic firms engage in PCP, foreign firms engage in LCP. As the home country is meant to represent the US economy, these assumptions capture in a stylized manner the observation that international prices are largely set in US dollars.[27]

Results are shown in figure 5: the left column reproduces results for the baseline scenario (PCP) to facilitate comparison with results for full LCP (middle column) and for LCP in the foreign country (right column). As usual, we distinguish three degrees of openness for each case. Regarding LCP, Obstfeld and Rogoff (2000) have stressed that the terms of trade and the real exchange rate co-move negatively under this assumption. Consumption and investment decisions are thus not tied to the terms of trade in the same way as under PCP. We find accordingly that openness hardly alters the response of absorption to the monetary policy shock.

While a monetary policy contraction appreciates the real exchange rate, it weakens the terms of trade. As a result, output falls less in more open economies reflecting an increase in net exports (in real terms). Regarding the responses of inflation, we observe that domestic inflation falls slightly less in more open economies under LCP. This reflects the smaller decline in marginal costs, in line with the muted output response. Similarly, the response of CPI inflation is virtually unaffected by openness: as there is no exchange rate pass-through at the border under LCP, the effect of exchange rate changes is not felt at the level of final good prices either.

Results displayed in the third column show that different assumptions on the price setting behavior of domestic (PCP) and foreign (LCP) intermediate good firms does not fundamentally alter the transmission of a monetary policy shock originating in the home country relative to the baseline (PCP) scenario. While the openness effect is somewhat reduced, the key results are basically unchanged: domestic absorption falls less in more open economies, inflation falls more strongly, as do CPI infla-

[25]We treat trade openness and exchange pass-through as two distinct aspects of the international transmission mechanism. They may be interrelated, however. Dornbusch (1987), for instance, argues that the extent of exchange rate pass-through and goods market integration are jointly determined. Gust et al. (2006) also link trade integration and exchange rate pass-through in a framework with strategic complementarities. However, they abstract from nominal rigidities.

[26]See Bergin (2006) for a similar formulation, Betts and Devereux (1996, 2000) for early contributions and Obstfeld and Rogoff (2000) for a critical discussion. In the appendix we provide a formal outline of the model modifications.

[27]According to evidence surveyed by Obstfeld and Rogoff (2000) the US, where 92% of exports and 80% of imports are invoiced in dollars, differ considerably from other countries where imports are not denominated in the destination country's currency to such a large extent.

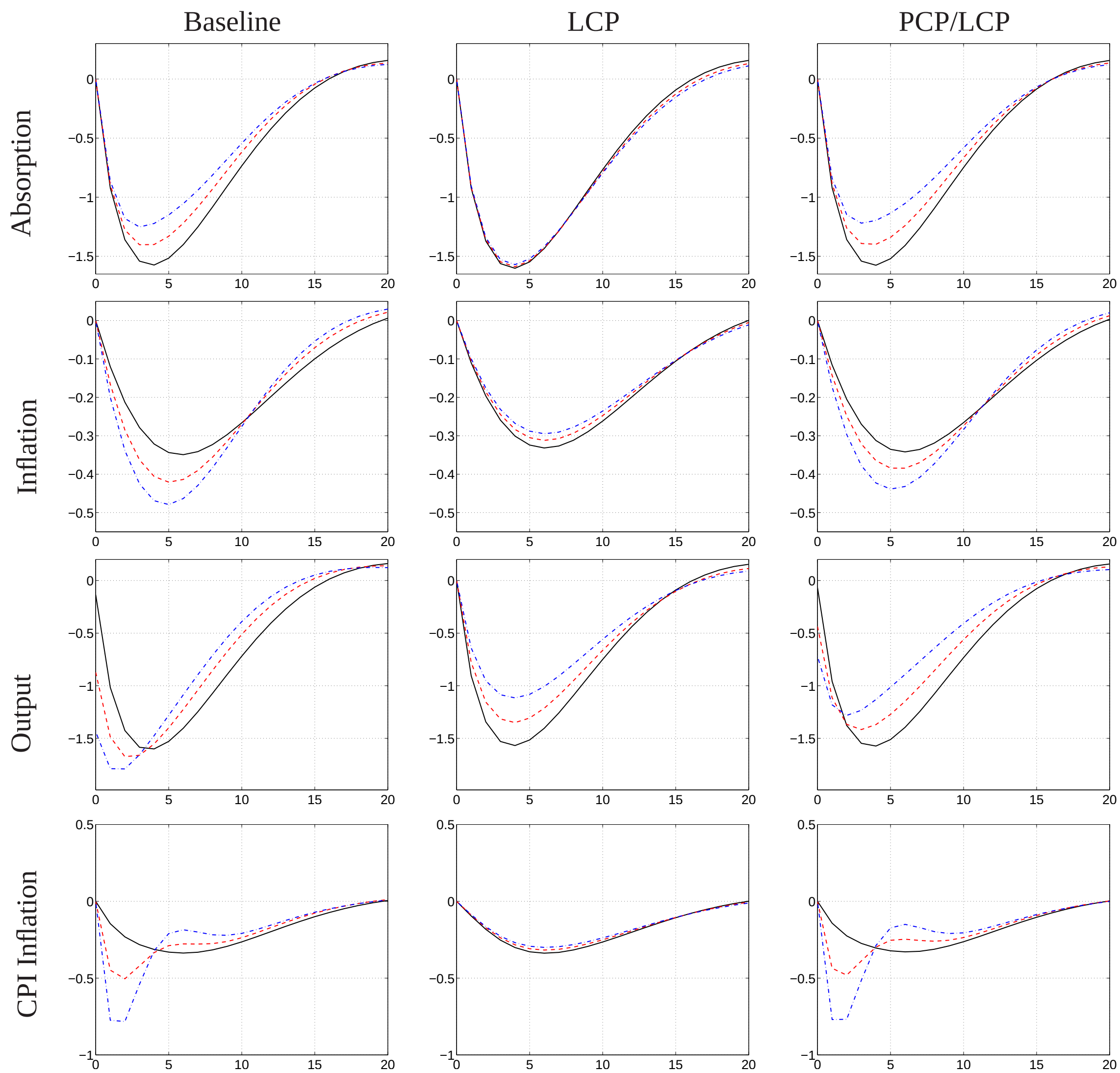

Figure 5: Effects of a monetary policy shock. Notes: see figure 3; LCP: all intermediate goods producers engage in local currency pricing; PCP/LCP: only foreign intermediate goods producers engage in local currency pricing.

Table 2: Monetary policy trade-offs and openness

	Baseline	$\sigma = 1.5$	LCP	PCP/LCP	$\eta = 0$
2% Imports	5.9	6.3	6.4	5.8	5.4
15% Imports	4.2	6.4	5.9	3.6	4.5
30% Imports	3.4	6.4	5.1	2.4	3.6

Notes: Left column indicates steady-state import share; other entries: cumulative reduction in output relative to CPI inflation for the first year after monetary policy shock.

tion and output on impact.

4.4 Implications for monetary policy

We find that openness has a sizeable impact on the monetary policy transmission. In order to fully explore the implications for monetary policy one would need to account for business cycle fluctuations and the shocks which initiate them, because they determine the trade-offs which systematic policy making has to confront. Yet, while our analysis does not provide a full-fledged account of business cycle fluctuations, we may nevertheless make a first pass on how openness alters the trade-offs faced by monetary policy. Specifically, we ask by how much output has to be reduced in order to engineer a certain reduction in CPI inflation.[28]

The entries in columns 2 to 5 of table 2 report the cumulative output response relative to the cumulative response of CPI inflation for the first four quarters after the monetary policy shock for different scenarios. The first row displays results obtained under the assumption that imports account for 2 percent of GDP, the second and third row refer to a scenario where imports account for 15 and 30 percent of GDP, respectively. The first column shows results for the baseline scenario. Here parameter values are set according to the estimates reported in table 1 above and prices are assumed to be set in producer currency (PCP). As discussed above, both CPI inflation and output respond more strongly to a monetary policy shock in this case. It turns out, however, that the relative reduction of output is much smaller in more open economies, i.e., the output loss which is necessary to bring about a reduction in inflation is smaller. We thus find monetary policy's control over inflation increased in more open economies.

Strategic complementarities in price setting play some role for this result—as the right column of table 2 illustrates. Here we repeat the previous experiment while assuming $\eta = 0$ (and adjusting ξ_I so as to keep the slope of the Phillips curve unchanged) and find the relative output loss somewhat less reduced in openness. As discussed above, strategic complementarities provide monetary policy with a *direct*

[28]Our measure is thus related to the sacrifice ratio, except that we do not consider a permanent reduction in inflation.

leverage on domestic inflation, which operates on top of the effects of a contraction in demand and more strongly so, the more open an economy. Yet while changes in domestic inflation are eventually passed-through into CPI inflation, openness exerts a larger impact on CPI inflation via the direct effect of exchange rate changes. This traditional channel gives monetary policy a better leverage over CPI inflation in more open economies even in the absence of strategic complementarities in price setting.[29]

The middle columns of table 2 show results for the alternative assumptions considered above. Assuming a higher trade price elasticity ($\sigma = 1.5$) induces a stronger output response in more open economies, because real net exports fall more strongly in response to a monetary contraction. As a consequence, increasing openness does not reduce the output loss which is necessary to bring about a reduction in CPI inflation. Assuming local currency pricing in both countries, in turn, implies a smaller relative reduction of output in more open economies, but the openness effect is smaller than in the PCP case. The openness effect under LCP is due to the smaller output decline in more open economies, because inflation is hardly effected by openness in this case.[30] Finally, assuming PCP in the home country and LCP in the foreign country gives rise to a rather strong openness effect. This is in line with the results displayed in figure 5 which show a weaker output response, but a stronger inflation response in more open economies relative to the baseline scenario.

5 Conclusion

In this paper we explore the role of trade integration for monetary policy transmission. First, we develop a two-country DSGE model featuring several frictions which recent business cycle research has found to be important in accounting for several macroeconometric observations. In addition, following Gust et al. (2006), Sbordone (2007) and Guerrieri et al. (2008), we assume a fairly general aggregation technology which allows to combine domestically produced and imported goods. It induces strategic complementarities in price-setting with respect to domestic and foreign competitors such that domestic firms will find it optimal to adjust their prices in response to exchange rate changes which alter the domestic currency price of imports—a new dimension of the exchange rate channel by which monetary policy gains direct leverage over domestic inflation.

In order to quantify the effects of openness on monetary transmission, we estimate, in a first step, a VAR on time series for the US relative to the EA. We identify monetary policy shocks by imposing an identification scheme which is consistent with our theoretical model and trace out the transmission mechanism through impulse response functions. In a second step, we find parameter values of the

[29] The output loss necessary to bring about a reduction in *domestic* inflation, instead, depends critically on the extent of strategic complementarities.

[30] Our results are in line with findings reported by Erceg et al. (2010). On the basis of the SIGMA model of the FED they compute sacrifice ratios for different degrees of openness and find no important role for the latter while assuming LCP.

DSGE model by matching its impulse responses to those obtained from the VAR. We find that the estimated model is generally able to mimic the empirical response functions quite closely. We also find evidence for strategic complementarities in price setting.

In a third step, we compare the effects of a monetary policy shock in the baseline scenario (with an import-to-GDP ratio of 2 percent) with alternative scenarios assuming a higher degree of openness. We find that a contractionary monetary policy shock has stronger output effects in more open economies, as real net exports decline more strongly. At the same time CPI inflation and domestic inflation also decline more strongly in more open economies, which, in the latter case, is the result of complementarities in price setting.

We also perform a sensitivity analysis. First, considering a higher than estimated value for the trade price elasticity, we find that the effects of a monetary policy shock on output and domestic inflation increase in openness. Second, assuming that exchange rate pass-through at the border is limited because of LCP, we find the role of openness in monetary policy transmission more limited. Third, assuming asymmetric price setting behavior where domestic firms set export prices in their own currency, but foreign exporters in the currency of the destination country, we find the effects of domestic monetary policy shocks comparable to those obtained under the baseline scenario.

Finally, turning to the implications for monetary policy, we compute the output loss which is necessary to bring about a temporary reduction in inflation. For the baseline scenario it turns out that the reduction in output relative to inflation is smaller in more open economies. In this sense monetary policy's control over domestic and CPI inflation tends to increase in more open economies.

A The model with LCP-firms

In the following we outline the changes to the model that follow from allowing for the possibility that a fraction of intermediate good firms (α) engages in LCP.

First, in specifying price indices for domestically produced intermediate and imported goods (i.e. the equivalent to equation (12)), we distinguish between prices set by LCP-firms, $P_t^{A,LCP}(j)$, and PCP-firms, $P_t^{A,PCP}(j)$:

$$P_t^A = \left(\int_0^\alpha P_t^{A,LCP}(j)^{\frac{\upsilon}{\upsilon-1}} dj + \int_\alpha^1 P_t^{A,PCP}(j)^{\frac{\upsilon}{\upsilon-1}} dj \right)^{\frac{\upsilon-1}{\upsilon}}, \tag{28}$$

$$P_t^B = \left(\int_0^\alpha P_t^{B,LCP}(j)^{\frac{\upsilon}{\upsilon-1}} dj + \int_\alpha^1 P_t^{B,PCP}(j)^{\frac{\upsilon}{\upsilon-1}} dj \right)^{\frac{\upsilon-1}{\upsilon}}. \tag{29}$$

In the general case, the price index for the wholesale good is given by

$$\begin{aligned} P_t^W &= \frac{1}{1+\eta}\Gamma_t + \frac{\eta}{1+\eta}\omega \left(\int_0^\alpha P_t^{A,LCP}(j)dj + \int_\alpha^1 P_t^{A,PCP}(j)dj \right) \qquad (30) \\ &+ \frac{\eta}{1+\eta}(1-\omega) \left(\int_0^\alpha P_t^{B,LCP}(j)dj + \int_\alpha^1 P_t^{B,PCP}(j)dj \right). \end{aligned}$$

Note that in this case the law of one price holds for PCP-firms only:

$$P_t^{B,PCP}(j) = S_t P_t^{B,PCP*}(j); \quad P_t^{A,PCP}(j) = S_t P_t^{A,PCP*}(j). \tag{31}$$

Second, we have to distinguish the pricing problems of PCP- and LCP-firms. The problem of a generic PCP-firm is given by

$$\max \sum_{k=0}^{\infty} \xi_I^k E_{t-1} \left(\frac{Q_{t,t+k} Y_{t+k}(j)}{P_{t+k}} \left[\widetilde{P}_t^{A,PCP}(j) \prod_{s=1}^{k} \left(\Pi_{t+s-1}^A \right) - MC_{t+k} \right] \right). \tag{32}$$

A generic LCP-firm sets two distinct prices for the domestic and foreign market. The domestic price $P_t^{A,LCP}(j)$ is set to solve

$$\max \sum_{k=0}^{\infty} \xi_I^k E_{t-1} \frac{Q_{t,t+k} A_{t+k}(j)}{P_{t+k}} \left[\widetilde{P}_t^{A,LCP}(j) \prod_{s=1}^{k} \left(\Pi_{t+s-1}^A \right) - MC_{t+k} \right]. \tag{33}$$

Instead, the price charged on the foreign market is set foreign currency $P_t^{A,LCP*}(j)$ in order to solve

$$\max \sum_{k=0}^{\infty} \xi_I^k E_{t-1} \frac{Q_{t,t+k} A_{t+k}^*(j)}{P_{t+k}} \left[S_{t+k} \widetilde{P}_t^{A,LCP*}(j) \prod_{s=1}^{k} \left(\Pi_{t+s-1}^B \right) - MC_{t+k} \right]. \tag{34}$$

B The New Keynesian Phillips curve

We derive the New Keynesian Phillips curve for the general case where we parameterize the fraction of LCP firms (α). For $\alpha = 0$ the New Keynesian Phillips curve simplifies to equation (24) where we abstract from indexation. We proceed in three steps. First, we solve the pricing problem of a generic intermediate good LCP-firm in the domestic market (eq. 33). Next, we solve the pricing problem of a generic intermediate good PCP-firm in the domestic market (eq. 32). Finally, we combine results using a first order approximation to the definition of the producer price index.

B.1 Pricing problem of a LCP-firm

Defining $I_{t+k} = \prod_{s=1}^{k}(\Pi^A_{t+s-1})$ and maximizing equation (33) subject to the demand function (10), we derive the following first order condition

$$E_{t-1}\sum_{k=0}^{\infty}\xi_I^k Q_{t,t+k}\left(P_{t+k}\right)^{-1} I_{t+k}\left[1-\left(1-\frac{MC_{t+k}}{I_{t+k}P_t^{A,LCP}(j)}\right)\epsilon_{t+k}(j)\right]A_{t+k}(j)=0, \qquad (35)$$

where the elasticity of demand for good j in the domestic market is

$$\epsilon_{t+k}(j)=\frac{1}{1-\upsilon}\left[1+\eta\left(\frac{P_t^{A,LCP}(j)I_{t+k}}{P^A_{t+k}}\right)^{\frac{1}{1-\upsilon}}\left(\frac{P^A_{t+k}}{\Gamma_{t+k}}\right)^{\frac{-\sigma}{\sigma(\upsilon-1)-\upsilon}}\right]^{-1}. \qquad (36)$$

Rewriting equation (35) using the definition of real marginal cost $MC_t^R = \frac{MC_t}{P_t^A}$, defining the contract price as $P_t^{AQ,LCP}(j) = \frac{P_t^{A,LCP}(j)}{P_t^A}$ and linearizing gives

$$E_{t-1}\left[\widehat{P}_t^{AQ,LCP}(j)\right]=\sum_{k=1}^{\infty}\left(\beta\xi_I\right)^k E_{t-1}\left[\widehat{\Pi}^A_{t+s}-\widehat{\Pi}^A_{t+s-1}\right]$$
$$+\left(1-\beta\xi_I\right)\sum_{k=0}^{\infty}\left(\beta\xi_I\right)^k E_{t-1}\left[\widehat{MC}^R_{t+k}-\frac{1}{\epsilon-1}\widehat{\epsilon}_{t+k}(j)\right].$$

In the above equation all variables are expressed in log-deviations from steady-state. Log-linearizing the elasticity of demand for good j equation (36), with $\Gamma_t^Q = \frac{\Gamma_t}{P_t^A}$, we get

$$\widehat{\epsilon}_{t+k}(j)=-\eta\epsilon\left(\widehat{P}_t^{AQ,LCP}(j)-\sum_{k=1}^{\infty}\left(\widehat{\Pi}^A_{t+s}-\widehat{\Pi}^A_{t+s-1}\right)\right)+\eta\tilde{\sigma}\widehat{\Gamma}^Q_{t+k}. \qquad (37)$$

Substituting this expression for the demand elasticity in the first order condition, we have

$$E_{t-1}\left[\widehat{P}_t^{AQ,LCP}(j)\right]=\sum_{k=1}^{\infty}\left(\beta\xi_I\right)^k E_{t-1}\left[\widehat{\Pi}^A_{t+s}-\widehat{\Pi}^A_{t+s-1}\right]$$
$$+\left(\frac{1-\beta\xi_I}{1-\frac{\eta\epsilon}{\epsilon-1}}\right)\sum_{k=0}^{\infty}\left(\beta\xi_I\right)^k E_{t-1}\left[\widehat{MC}^R_{t+k}-\frac{\eta\epsilon}{\epsilon-1}\frac{\tilde{\sigma}}{\epsilon}\widehat{\Gamma}^Q_{t+k}\right].$$

Using the definition of the steady state markup $\mu = \frac{\epsilon}{\epsilon-1}$ and the definition of $\Psi = \frac{-\eta\mu}{1-\eta\mu}$, this expression after quasi-differencing can be written as

$$E_{t-1}\left[\widehat{P}_t^{AQ,LCP}(j) - \beta\xi_I \widehat{P}_{t+1}^{AQ,LCP}(j)\right] = \beta\xi_I E_{t-1}\left(\widehat{\Pi}_{t+1}^A - \widehat{\Pi}_t^A\right)$$
$$+(1-\beta\xi_I)E_{t-1}\left[(1-\Psi)\widehat{MC}_t^R + \Psi\frac{\tilde{\sigma}}{\epsilon}\widehat{\Gamma}_t^Q\right].$$

The log-linearized version of the competitive price index equation (13) in the domestic country implies that

$$\widehat{\Gamma}_t^Q = (1-\omega)\widehat{q}_t, \tag{38}$$

where $q_t = \frac{P_t^B}{P_t^A}$ is the relative import price in domestic currency. Using this to substitute for the relative competitive price index above we get

$$E_{t-1}\left[\widehat{P}_t^{AQ,LCP}(j) - \beta\xi_I \widehat{P}_{t+1}^{AQ,LCP}(j)\right] = \beta\xi_I E_{t-1}\left(\widehat{\Pi}_{t+1}^A - \widehat{\Pi}_t^A\right)$$
$$+(1-\beta\xi_I)E_{t-1}\left[(1-\Psi)\widehat{MC}_t^R + \Psi\frac{\tilde{\sigma}}{\epsilon}(1-\omega)\widehat{q}_t\right].$$

B.2 Pricing problem of a PCP-firm

We can derive a similar expression for the PCP-firms. Maximizing equation (32) subject to the demand function (16), we derive the following first order condition:

$$E_{t-1}\sum_{k=0}^{\infty}\xi_I^k Q_{t,t+k}\left(P_{t+k}\right)^{-1} I_{t+k}\left[Y_{t+k} - \left(1 - \frac{MC_{t+k}}{I_{t+k}P_t^{A,PCP}(j)}\right)\left(\epsilon_{t+k}^H(j)A_{t+k}(j) + \epsilon_{t+k}^F(j)A_{t+k}^*(j)\right)\right] = 0,$$

where the elasticity of demand for good j in the domestic market is similar to the LCP-firms problem

$$\epsilon_{t+k}^H(j) = \frac{1}{1-\upsilon}\left[1 + \eta\left(\frac{P_t^{A,PCP}(j)I_{t+k}}{P_{t+k}^A}\right)^{\frac{1}{1-\upsilon}}\left(\frac{P_{t+k}^A}{\Gamma_{t+k}}\right)^{\frac{-\sigma}{\sigma(\upsilon-1)-\upsilon}}\right]^{-1}, \tag{39}$$

and the elasticity of demand for good j in the foreign market is given by

$$\epsilon_{t+k}^F(j) = \frac{1}{1-\upsilon}\left[1 + \eta\left(\frac{P_t^{A,PCP}(j)I_{t+k}}{S_{t+k}P_{t+k}^{A*}}\right)^{\frac{1}{1-\upsilon}}\left(\frac{P_{t+k}^{A*}}{\Gamma_{t+k}^*}\right)^{\frac{-\sigma}{\sigma(\upsilon-1)-\upsilon}}\right]^{-1}. \tag{40}$$

Linearizing the first order condition of the firms problem using $P_t^{AQ,PCP}(j) = \frac{P_t^{A,PCP}(j)}{P_t^A}$ gives

$$E_{t-1}\left[\widehat{P}_t^{AQ,PCP}(j)\right] = \sum_{k=1}^{\infty}\left(\beta\xi_I\right)^k E_{t-1}\left[\widehat{\Pi}_{t+s}^A - \widehat{\Pi}_{t+s-1}^A\right]$$
$$+\left(1-\beta\xi_I\right)\sum_{k=0}^{\infty}\left(\beta\xi_I\right)^k E_{t-1}\left[\widehat{MC}_{t+k}^R - \frac{1}{\epsilon-1}\omega\widehat{\epsilon}_{t+k}^H(j) - \frac{1}{\epsilon-1}(1-\omega)\widehat{\epsilon}_{t+k}^F(j)\right].$$

Linearizing both demand elasticities defining $\Gamma_t^{Q*} = \frac{\Gamma_t^*}{P_t^{A*}}$ and the law-of-one-price gap as $q_t^{A*} = \frac{S_t P_t^{A*}}{P_t^A}$ gives

$$\widehat{\epsilon}_{t+k}^H(j) = -\eta\epsilon\left(\widehat{P}_t^{AQ,PCP}(j) - \sum_{k=1}^{\infty}\left(\widehat{\Pi}_{t+s}^A - \widehat{\Pi}_{t+s-1}^A\right)\right) + \eta\tilde{\sigma}\widehat{\Gamma}_{t+k}^Q,$$
$$\widehat{\epsilon}_{t+k}^F(j) = -\eta\epsilon\left(\widehat{P}_t^{AQ,PCP}(j) - \sum_{k=1}^{\infty}\left(\widehat{\Pi}_{t+s}^A - \widehat{\Pi}_{t+s-1}^A\right) - \widehat{q}_{t+k}^{A*}\right) + \eta\tilde{\sigma}\widehat{\Gamma}_{t+k}^{Q*}.$$

Substituting the demand elasticities into the first order condition and simplifying yields

$$E_{t-1}\left[\widehat{P}_t^{AQ,PCP}(j)\right] = \sum_{k=1}^{\infty}(\beta\xi_I)^k E_{t-1}\left[\widehat{\Pi}_{t+s}^A - \widehat{\Pi}_{t+s-1}^A\right]$$
$$+ (1-\beta\xi_I)\sum_{k=0}^{\infty}(\beta\xi_I)^k E_{t-1}\left[(1-\Psi)\widehat{MC}_{t+k}^R + \Psi\omega\frac{\tilde{\sigma}}{\epsilon}\widehat{\Gamma}_{t+k}^Q + \Psi(1-\omega)\frac{\tilde{\sigma}}{\epsilon}\widehat{\Gamma}_{t+k}^{Q*} + \Psi(1-\omega)\widehat{q}_{t+k}^{A*}\right].$$

After quasi-differencing, the expression can be rewritten as

$$E_{t-1}\left[\widehat{P}_t^{AQ,PCP}(j) - \beta\xi_I\widehat{P}_{t+1}^{AQ,PCP}(j)\right] = \beta\xi_I E_{t-1}\left(\widehat{\Pi}_{t+1}^A - \widehat{\Pi}_t^A\right)$$
$$+(1-\beta\xi_I)E_{t-1}\left[(1-\Psi)\widehat{MC}_t^R + \Psi\omega\frac{\tilde{\sigma}}{\epsilon}\widehat{\Gamma}_t^Q + \Psi(1-\omega)\frac{\tilde{\sigma}}{\epsilon}\widehat{\Gamma}_t^{Q*} + \Psi(1-\omega)\widehat{q}_t^{A*}\right].$$

One can linearize the competitive price index in the foreign country analogously to the one in the home country defining the relative export price in foreign currency as $q_t^{B*} = \frac{P_t^{A*}}{P_t^{B*}}$:

$$\widehat{\Gamma}_t^{Q*} = -\omega\widehat{q}_t^{B*} \tag{41}$$

Using this expression and equation (38) to substitute for the relative competitive price indices above we get

$$E_{t-1}\left[\widehat{P}_t^{AQ,PCP}(j) - \beta\xi_I\widehat{P}_{t+1}^{AQ,PCP}(j)\right] = \beta\xi_I E_{t-1}\left(\widehat{\Pi}_{t+1}^A - \widehat{\Pi}_t^A\right)$$
$$+(1-\beta\xi_I)E_{t-1}\left[(1-\Psi)\widehat{MC}_t^R + \Psi(1-\omega)\omega\frac{\tilde{\sigma}}{\epsilon}\widehat{q}_t^B - \Psi(1-\omega)\omega\frac{\tilde{\sigma}}{\epsilon}\widehat{q}_t^{B*} + \Psi(1-\omega)\widehat{q}_t^{A*}\right].$$

B.3 New Keynesian Phillips Curve

The log-linearized version of the producer price index, equation (28), reads as

$$\alpha\widehat{P}_t^{AQ,LCP}(j) + (1-\alpha)\widehat{P}_t^{AQ,PCP}(j) = \frac{\xi_I}{1-\xi_I}\left(\widehat{\Pi}_t^A - \widehat{\Pi}_{t-1}^A\right). \tag{42}$$

Using the final equations in the two subsections above to substitute for the contract prices of LCP- and PCP-firms one finally obtains a general formulation for the new Keynesian Phillips curve:

$$E_{t-1}\left(\widehat{\Pi}_t^A - \widehat{\Pi}_{t-1}^A\right) = \beta E_{t-1}\left(\widehat{\Pi}_{t+1}^A - \widehat{\Pi}_t^A\right)$$
$$+\lambda E_{t-1}\left[(1-\Psi)\widehat{MC}_t^R + \Psi\left((1-\omega)(\alpha+(1-\alpha)\omega)\frac{\tilde{\sigma}}{\epsilon}\widehat{q}_t^B - (1-\omega)\omega(1-\alpha)\frac{\tilde{\sigma}}{\epsilon}\widehat{q}_t^{B*} + (1-\omega)(1-\alpha)\widehat{q}_t^{A*}\right)\right]$$

with $\lambda = (1 - \beta\xi_I)(1 - \xi_I)\xi_I^{-1}$.

The special case (baseline) for PCP ($\alpha = 0$) is discussed in section 2.8. In case $0 < \alpha < 1$, two terms (in addition to $\widehat{q}_t^B$ and marginal costs) enter the Philips curve: $\widehat{q}_t^{B*}$ and $\widehat{q}_t^{A*}$. Intuitively, a contractionary monetary policy shock which appreciates the exchange rate reduces the relative price of imports and induces domestic firms (LCP and PCP firms) to reduce their prices (because of strategic complementarities). As PCP-firms set only one price (in domestic currency) for both markets, price changes in foreign markets also enter the pricing decision and eventually matter for domestic inflation.

C Data

Our data are obtained from the OECD Economic Outlook database, see OECD (2007). We use data for private consumption (volume), private fixed investment (excl. stockbuilding, nominal), and the deflator for private consumption and the deflator for GDP. The deflator for private consumption is used to construct the CPI-inflation series and to deflate nominal investment in a manner consistent with the definition of real investment in the model. The GDP deflator is used to compute domestic inflation. Measures for the US short term interest rates are also obtained from the Economic Outlook database (interest rate, short-term). For the euro area we draw on data from the Area-Wide Model database of the ECB, see Fagan, Henry, and Mestre (2001), STN series. Time series for net exports of the U.S. vis-á-vis the euro area are obtained from the IMF Direction of Trade database for the period from 1980 onwards. We approximate earlier data drawing on the observations reported by BEA for the period 1970–1979 for US versus Europe (US International Transactions Accounts Data). We backtrack our original series on the basis of growth rates. Net exports are scaled by nominal GDP obtained from the OECD Economic Outlook database.

References

M. Adolfson, S. Laséen, J. Lindé, and M. Villani. Bayesian estimation of an open economy DSGE model with incomplete pass-through. *Journal of International Economics*, 72(2):481–511, 2007.

J. D. Amato and T. Laubach. Estimation and control of an optimization-based model with sticky prices and wages. *Journal of Economic Dynamics and Control*, 27(7):1181–1215, 2003.

D. Backus, P. Kehoe, and F. Kydland. Dynamics of the trade balance and the terms of trade: the J-curve? *American Economic Review*, 84(1):84–103, March 1994.

P. R. Bergin. How well can the new open economy macroeconomics explain the exchange rate and current account? *Journal of International Money and Finance*, 25(5):675–701, 2006.

B. S. Bernanke. Globalization and monetary policy. Speech at the Fourth Economic Summit, Stanford Institute for Economic Policy Research, 2007.

C. Betts and M. B. Devereux. The exchange rate in a model of pricing-to-market. *European Economic Review*, 40(3-5):1007–1021, 1996.

C. Betts and M. B. Devereux. Exchange rate dynamics in a model of pricing-to-market. *Journal of International Economics*, 50(1):215–244, 2000.

J. Bovin and M. Giannoni. Has monetary policy become more effective? *The Review of Economics and Statistics*, 88(3):445–462, 2006.

V. V. Chari, P. J. Kehoe, and E. R. McGrattan. Can sticky price models generate volatile and persistent real exchange rates? *Review of Economics Studies*, 69(3):533–563, 2002.

N. Chen, J. Imbs, and A. Scott. The dynamics of trade and competition. *Journal of International Economics*, 77:50–62, 2009.

L. J. Christiano, M. Eichenbaum, and C. L. Evans. Monetary policy shocks: What have we learned and to what end? In J. B. Taylor, editor, *Handbook of Macroeconomics*, pages 319–347. Elsevier B.V., 1999.

L. J. Christiano, M. Eichenbaum, and C. L. Evans. Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy*, 113(1):1–45, 2005.

R. Clarida and J. Gali. Sources of real exchange-rate fluctuations: How important are nominal shocks? *Carnegie-Rochester Conference Series on Public Policy*, 41:1–56, 1994.

R. Clarida, J. Galí, and M. Gertler. Monetary policy rules and macroeconomic stability: Evidence and some theory. *Quarterly Journal of Economics*, 115(1):147–180, February 2000.

R. Clarida, J. Galí, and M. Gertler. Optimal monetary policy in open versus closed economies: an integrated approach. *American Economic Review*, 91(2):248–252, 2001.

G. Corsetti and L. Dedola. A macroeconomic model of international price discrimination. *Journal of International Economics*, 67(1):129–155, 2005.

G. Corsetti and G. J. Müller. Twin deficits: Squaring theory, evidence and common sense. *Economic Policy*, pages 599–638, 2006.

G. Corsetti and P. Pesenti. International dimensions of optimal monetary policy. *Journal of Monetary Economics*, 52(2):281–305, 2005.

D. O. Cushman and T. Zha. Identifying monetary policy in a small open economy under flexible exchange rates. *Journal of Monetary Economics*, 39(3):433–448, 1997.

B. De Paoli. Monetary policy and welfare in a small open economy. *Journal of International Economics*, 77:11–22, 2009.

G. de Walque, F. Smets, and R. Wouters. An estimated two-country DSGE model for the Euro area and the US economy. mimeo, 2005.

M. B. Devereux and C. Engel. Exchange rate pass-through, exchange rate volatility, and exchange rate disconnect. *Journal of Monetary Economics*, 49:913–940, 2002.

R. Dornbusch. Exchange rates and prices. *American Economic Review*, 77(1):93–106, 1987.

M. Dotsey and R. G. King. Implications of state-dependent pricing for dynamic macroeconomic models. *Journal of Monetary Economics*, 52(1):213–242, 2005.

M. Eichenbaum and C. L. Evans. Some empirical evidence on the effects of shocks to monetary policy on exchange rates. *The Quarterly Journal of Economics*, 110(4):975–1009, 1995.

C. Erceg, C. Gust, and D. López-Salido. The transmission of domestic shocks in open economies. In J. Gali and M. J. Gertler, editors, *International Dimensions of Monetary Policy*. University of Chicago Press, 2010.

G. Fagan, J. Henry, and R. Mestre. An area-wide model (AWM) for the euro area. ECB Working Paper 42, 2001.

J. Faust and J. H. Rogers. Monetary policy's role in exchange rate behavior. *Journal of Monetary Economics*, 50(7):1403–1424, 2003.

J. Galí and T. Monacelli. Monetary policy and exchange rate volatility in a small open economy. *Review of Economic Studies*, 72(3):707–734, 2005.

L. S. Goldberg and J. M. Campa. The sensitivity of the cpi to exchange rates: Distribution margins, imported inputs, and trade exposure. *Review of Economics and Statistics*, 92(2):392–407, 2010.

L. Guerrieri, C. Gust, and D. López-Salido. International competition and inflation: A new keynesian perspective. International Finance Discussion Papers, 918, 2008.

C. Gust, S. Leduc, and R. J. Vigfusson. Trade integration, competition, and the decline in exchange-rate pass-through. International Finance Discussion Papers, Number 864, Board of Governors of the Federal Reserve System, 2006.

J. Imbs and I. Mejean. Elasticity optimism. CEPR Discussion paper 7177, 2009.

S. Kim. International transmission of U.S. monetary policy shocks: Evidence from VAR's. *Journal of Monetary Economics*, 48(2):339–372, 2001.

S. Kim and N. Roubini. Exchange rate anomalies in the industrial countries: A solution with a structural VAR approach. *Journal of Monetary Economics*, 45(3):561–586, 2000.

M. Kimball. The quantitative analytics of the basic monetarist model. *Journal of Money, Credit and Banking*, 27(4):1241–1277, 1995.

R. Kollmann. Monetary policy rules in the open economy: Effects on welfare and business cycles. *Journal of Monetary Economics*, 49(5):989–1015, 2002.

R. Kollmann. International portfolio equilibrium and the current account. CEPR Discussion Paper 5512, 2006.

T. Lubik and F. Schorfheide. A bayesian look at new open economy macroeconomics. In M. Gertler and K. Rogoff, editors, *NBER Macroeconomics Annual 2005, Volume 20*, pages 313–366. MIT Press, Cambridge MA, 2006.

A. Meier and G. J. Müller. Fleshing out the monetary transmission mechanism: Output composition and the role of financial frictions. *Journal of Money, Credit and Banking*, 38:2099–2134, 2006.

M. Melitz and G. Ottaviano. Market size, trade, and productivity. *Review of Economic Studies*, 75: 295–316, 2008.

F. S. Mishkin. Globalization, macroeconomic performance, and monetary policy (speech). *BIS Review*, 108, 2007.

E. Nakamura and J. Steinsson. Five facts about prices: A reevaluation of menu cost models. mimeo

Columbia University, 2008.

M. Obstfeld and K. Rogoff. New directions for stochastic open economy models. *Journal of International Economics*, 50(1):117–153, 2000.

OECD. SourceOECD. http://www.sourceoecd.org/, 2007.

J. H. Rogers. Monetary shocks and real exchange rates. *Journal of International Economics*, 49(2): 269–288, 1999.

J. R. Rotemberg and M. Woodford. An optimization-based econometric framework for the evaluation of monetary policy. In J. B. Taylor, editor, *NBER Macroeconomics Annual*, pages 297–346. Cambridge, MA.: MIT Press, 1997.

A. M. Sbordone. Globalization and inflation dynamics: the impact of increased competition. NBER Working Paper 13556, 2007.

A. Scholl and H. Uhlig. New evidence from the puzzles: Results from agnostic identification on monetary policy and exchange rates. *Journal of International Economics*, forthcoming, 2008.

F. Smets and R. Wouters. Comparing shocks and frictions in US and euro area business cycles: a Bayesian DSGE approach. *Journal of Applied Econometrics*, 20(2):161–183, 2005.

F. Smets and R. Wouters. Shocks and frictions in US business cycles: A bayesian DSGE approach. *American Economic Review*, 97:586–606, 2007.

L. E. Svensson. Open-economy inflation targeting. *Journal of International Economics*, 50(1):155–183, 2000.

J. L. Yellen. Monetary policy in a global environment. Speech at The Euro and the Dollar in a Globalized Economy Conference, U.C. Santa Cruz, Stanta Cruz, CA, 2006.