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♣ DINÂMIA'CET – IUL and ISCTE – IUL - sergio.lagoa@iscte.pt, tel.:+351217903000, fax.:+351217964710.

DINÂMIA'CET – IUL, Centro de Estudos sobre a Mudança Socioeconómica e o Território
ISCTE-IUL – Av. das Forças Armadas, 1649-026 Lisboa, PORTUGAL
Tel. 217938638 Fax. 217940042 E-mail: dinamia@iscte.pt http://dinamiacet.iscte-iul.pt/

Inflation dynamics in open economies: empirical evidence for G7 countries on the role of import prices and the cost channel

Sérgio Lagoa (ISCTE- University Institute of Lisbon, Dep. of Political Economics) *

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Abstract

The supply side effects of nominal interest rate and import prices on inflation are very important for the design of monetary policy. However, the empirical identification of the cost channel has ignored import prices. We start by developing a model which shows that ignoring import prices in the estimation of the cost channel may lead to wrong results. Taking this into account, we study the empirical relevance of the cost channel and import prices using the New Keynesian Phillips Curve (NKPC) for the G7 countries. In order to introduce import prices in the NKPC, we test several ways in which imports can affect inflation. It is assessed if imports should be treated as inputs and/or consumption goods, and also if there is immediate or slow exchange rate pass-through. Finally, besides the traditional concept of cost channel, where wages are paid in advance, it is tested whether is relevant to extend the cost channel assuming that imports of final consumption goods are also paid in advance. Empirical results indicate that the cost channel is present in imported consumption good and open economy variables play an important role in explaining inflation dynamics.

Keywords: Inflation, open economy New Keynesian Phillips Curve, cost channel.

JEL classifications: C22, E31, E43.

* Av. das Forças Armadas, 1649-026 Lisboa, Portugal. sergio.lagoa@iscte.pt, tel.: +351217903000, fax.:+351217964710.

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1 Introduction

The main goal of this paper is to assess the empirical impact of import prices and the cost channel in inflation using a New Keynesian Phillips curve (NKPC). The cost channel, *i.e.*, the fact that firms borrow money to pay wages in advance, has emerged as one of the main explanations of the price puzzle associated with an increase in interest rate. However, Ravenna and Walsh (2006) and Chowdbury et al. (2006), using a Cobb-Douglas production function, did not emphasize the role of open economy variables when estimating the cost channel. In contrast, in the present paper, assuming a more general CES production function, a model is developed were import prices are considered simultaneously with the cost channel. In this model the marginal cost and supply side inflation depend simultaneously on the nominal interest rate and the terms of trade; and these variables are related with each other. Thus, only in some circumstances, the cost channel will be correctly identified when the terms of trade are ignored. This makes clear the relevance of assessing the supply side effect of interest rate on inflation considering also the impact of the terms of trade.

As we need to introduce open economy variables in the Phillips curve to properly estimate the cost channel, it is necessary to identify the correct way of doing so. Regarding this issue does not exist a theoretical consensus. On the one hand, some works on the open economy NKPC (e.g. Gali and Monacelli, 2005) assume imports as final consumption goods and ignore imported intermediate goods. On the other hand, McCallum and Nelson (2001) treat imports only as intermediate goods. For the UK, Kara and Nelson (2003) concluded that a model where imports are modelled only as intermediate goods provides a reasonable match with the data. The goal of this paper is to research whether or not that conclusion can be applied to other countries as well. Given its importance for the design of monetary policy (Clarida et al., 2001; Monacelli, 2005; and Corsetti, 2006), it will be also tested the aggregate relevance of slow exchange rate pass-through.

Finally, it is tested whether is empirically relevant to extend the cost channel assuming that imports of final consumption goods are also paid in advance. This would imply that the change in the nominal interest rate affects CPI inflation.

To our knowledge this is the first paper studying the empirical relevance of the cost channel considering explicitly open economy variables. The research into whether or not the data confirm that imports of consumption goods are paid in advance is also new in the context of works on the working capital channel. This paper also contributes to the literature testing for the G7 countries and in the context of the NKPC the empirical relevance of slow exchange rate pass-through. Lastly, the test for the G7 countries of whether imports should be considered as inputs and/or consumption goods also adds to the NKPC literature, because until now such a test has only been attempted for the UK.

In the estimation, we used the GMM since with rational expectations is possible to obtain ortogonality conditions to estimate the model. Our empirical results indicate that open economy variables play an important role in explaining inflation dynamics, both for domestic and CPI inflations. It is shown that slow exchange rate pass-through is relevant and that imports should not be considered only as inputs in production, but also consumption goods. Regarding the cost channel, there is weak evidence that the level of the nominal interest rate affects inflation, but there is strong evidence that the change in the nominal interest rate affects CPI inflation.

The remainder of the paper is organised as follows. Section 2 develops a model to study the role of import prices in the identification of the cost channel. Section 3 estimates the NKPC for domestic inflation. Section 4 analyses the best empirical way of describing CPI inflation using the NKPC. Section 5 concludes the study.

2 Identifying the cost channel in an open economy

This section develops a model for a small open economy similar to Gali and Monacelli (2005) in order to study the identification of the cost channel. This model has two novelties. Firstly, assuming a more general CES production function with labour and imports, import prices are considered simultaneously with the cost channel. Secondly, it is assumed that imports of consumption goods are also paid in advance. Section 2.1 describes households' behaviour. Section 2.2 explains how the price of imported goods is established by retailers. Section 2.3 discusses how the international risk sharing links the domestic and foreign outputs. Section 2.4 obtains an expression for aggregate demand. Section 2.5 discusses how the determination of domestic prices by firms leads to the Phillips curve. Section 2.6 presents the marginal cost and the flexible-price output. Finally, in Section 2.7 the Phillips curve is written in deviations from the flexible-price equilibrium.

2.1 Households

There are two countries: the home country (h) and the foreign country (f). Both countries have the same preferences and technologies. The home country uses foreign goods for both final consumption and production of domestic goods. For the sake of simplicity, it is assumed that the foreign country only uses domestic goods for consumption.

In both countries, households consume goods, supply labour, and hold money and a portfolio of assets. Using a CES function, consumption goods are composed of home goods, $\widehat{c}_t^h$, and foreign goods, $\widehat{c}_t^f$. The home country consumption, $\widehat{c}_t$, is [1]:

$$\widehat{c}_t = (1 - \gamma_c)\,\widehat{c}_t^h + \gamma_c \widehat{c}_t^f . \tag{1}$$

In both domestic and foreign markets there exists a set of differentiated goods produced by monopolistically competitive firms of measure 1. Thus, $\widehat{c}_t^h$ and $\widehat{c}_t^f$ are composed of several domestic and foreign goods, respectively. A household optimally allocates spending within each category of goods. Solving for the optimal allocation between aggregated domestic and

[1] The lowercase letters with a hat denote variables in percentage deviation around the steady-state.

imported goods, results in the demand for the foreign good i

$$\widehat{c}_t^f(i) = -\theta\left(\widehat{p}_t^f(i) - \widehat{p}_t^f\right) + \widehat{c}_t^f \tag{2}$$

There is a similar demand function for $\widehat{c}_t^h(i)$. Combining the two resulting demand curves, yields the relative demand of foreign goods:

$$\widehat{c}_t^f = \widehat{c}_t^h - a\widehat{\delta}_t, \tag{3}$$

, where $\widehat{\delta}_t = \widehat{p}_t^f - \widehat{p}_t^h$ is the gross terms of trade.

The consumer price index (CPI) is given by:

$$\widehat{p}_t^c = (1-\gamma_c)\,\widehat{p}_t^h + \gamma_c\widehat{p}_t^f. \tag{4}$$

Households maximise expected present discounted utility subject to the CIA constraint, leading to the usual first order conditions (FOC):

$$\beta\frac{P_t^c}{P_{t+1}^c}\frac{\xi_{t+1}C_{t+1}^{-\sigma}}{\xi_t C_t^{-\sigma}} = \Omega_{t,t+1} \tag{5}$$

$$\frac{\chi N_t^\eta}{\xi_t C_t^{-\sigma}} = \frac{W_t}{P_t^c}. \tag{6}$$

, where β denotes the discount factor, ξ_t a random taste shock, $\Omega_{t,t+1}$ is the stochastic discount factor for one-period ahead nominal payoffs relevant to the domestic household, N_t is hours of work, χ determines the disutility of labour, and W_t is the hourly *nominal* wage.

2.2 Import prices and some important identities

In this section, we explain the pricing of imports and define some important identities that are used latter. In the home country there exists a large number of retailers that import differentiated goods from the foreign country. In this monopolistically competitive market, a retailer facing demand for good i defined by equation (2), can set the price of that good in domestic currency, $P_t^f(i)$. The local retailer only supports two costs: the price paid for the foreign good in the international market and the financial cost of paying for that good in advance. As a result, the marginal cost, in local currency, of the retailer that imports good i is

$$MC_t(i) = I_t \ddot{E}_t P_t^{f*}(i) \tag{7}$$

, with $P_t^{f*}(i)$ as the price of foreign good i in foreign currency and $\ddot{E}_t$ as the nominal exchange rate (price of foreign currency in terms of domestic currency).

In order to simplify the analysis, we assume a complete and immediate exchange rate pass-through of nominal exchange rate to import prices. [2] Retailers' decision simplifies then to maximise profit subject to the demand for product i, equation (2). The FOC for this problem is: $P_t^f(i) = \frac{\theta}{\theta-1} MC_t(i)$, corresponding to the typical solution in monopolistic competition.

Aggregating the last expression for all imported goods and using (7), we obtain:

$$\widehat{p}_t^f = \widehat{i}_t + \widehat{e}_t + \widehat{p}_t^{f*} \tag{8}$$

, with $\widehat{p}_t^f$ as the aggregated price index in domestic currency of imported goods. We assume that imported goods are used both for consumption and production. Importers follow precisely the same steps to establish the price of imported *inputs*. With an individual price elasticity for imported inputs of θ, aggregate price of imported inputs in domestic currency is also given by (8).

We can isolate the *direct* effect of the nominal interest rate on the terms of trade, by writing: $\widehat{\delta}_t = \widehat{i}_t + \widehat{\delta}_t^{'}$, where: $\widehat{\delta}_t^{'} = \widehat{e}_t + \widehat{p}_t^{f*} - \widehat{p}_t^h$. We call $\widehat{\delta}_t^{'}$ the terms of trade. Next, we use the terms of trade to define some identities that will be useful later. Using the gross terms of

[2] This can be seen as an extreme case of a situation where retailers have a smaller price rigidity than domestic firms.

trade, equation (4) and the definitions of π_t^h and π_t^c, we obtain:

$$\pi_t^c = \pi_t^h + \gamma_c \left(\widehat{\delta}_t' - \widehat{\delta}_{t-1}'\right) + \gamma_c \left(\widehat{i}_t - \widehat{i}_{t-1}\right). \tag{9}$$

Therefore, an increase in the nominal interest rate increases *directly* CPI inflation because it increases the gross terms of trade.

Replacing $\widehat{p}_t^c$ and the terms of trade in the optimal leisure-consumption choice (equation (6)), we have:

$$\widehat{w}_t - \widehat{p}_t^h = \eta \widehat{n}_t + \sigma \widehat{c}_t - \widehat{\xi}_t + \gamma_c \left(\widehat{\delta}_t' + \widehat{i}_t\right) \tag{10}$$

The real exchange rate is the ratio of two countries' CPIs expressed in a common currency. Assuming that the foreign country is large in relation to the home country, the real exchange rate is:

$$\widehat{q}_t' = (1 - \gamma_c)\, \widehat{\delta}_t' - \gamma_c \widehat{i}_t. \tag{11}$$

This expression is associated with the fact that an increase in the nominal interest rate increases the price of imported goods, causing an increase in domestic CPI, which leads to an appreciation of the real exchange rate.

2.3 Foreign country and international risk sharing

Since the foreign country is large relative to the home country, exports' share in demand is very small for the foreign country, implying that consumption ($\widehat{c}_t^{f*}$) is equal to output ($\widehat{y}^f$).

To simplify, we assume that the foreign country only uses imported goods for final consumption. The demand that foreign consumers make of domestic goods ($\widehat{c}_t^{h*}$) depends positively on output and the terms of trade:

$$\widehat{c}_t^{h*} = \widehat{y}_t^f + a \widehat{\delta}_t'. \tag{12}$$

Turning now to the international risk sharing, above it was shown the FOC for domestic household's consumption (equation (5)). Under the assumption of complete securities markets, a similar expression will hold for the foreign representative household. Following the reasoning of Gali and Monaceli (2005) and Monacelli (2003), we obtain $\widehat{c}_t = \widehat{c}_t^{f*} + \frac{1}{\sigma}\widehat{q}_t' + \frac{1}{\sigma}\widehat{\xi}_t$. Using the relation between the real exchange rate and the terms of trade (equation (11)) and the equality $\widehat{c}_t^{f*} = \widehat{y}_t^f$, we get:

$$\widehat{c}_t = \widehat{y}_t^f + \frac{1-\gamma_c}{\sigma}\widehat{\delta}_t' - \frac{\gamma_c}{\sigma}\widehat{i}_t + \frac{1}{\sigma}\widehat{\xi}_t. \tag{13}$$

This means that with efficient risk sharing, domestic consumption should be high when the price of domestic consumption is low relative to foreign consumption, *i.e.*, when $\widehat{\delta}_t'$ is high.

2.4 Aggregate demand

Using the terms of trade and equations (1) and (3), we get:

$$\widehat{c}_t^h = \widehat{c}_t + \gamma_c a\left(\widehat{\delta}_t' + \widehat{i}_t\right). \tag{14}$$

In equilibrium, the demand for domestic output has to be equal to output ($\widehat{y}_t$):

$$\widehat{y}_t = (1-\gamma)\,\widehat{c}_t^h + \gamma\widehat{c}_t^{h*}. \tag{15}$$

Now, substitute (12) and (14) into (15) to obtain:

$$\widehat{y}_t = (1-\gamma)\,\widehat{c}_t + [(1-\gamma)\,\gamma_c a + \gamma a]\,\widehat{\delta}_t' + (1-\gamma)\,\gamma_c a\widehat{i}_t + \gamma\widehat{y}_t^f. \tag{16}$$

It is possible to observe that the nominal interest rate affects domestic demand. With total consumption and the terms of trade constant, if interest rate increases, consumption of imported goods decreases in favour of domestic goods's consumption.

2.5 Domestic firms

As usual in models with sticky prices, a Calvo (1983) setup will be used to describe how domestic firms set prices. In each period, only a fraction $1-\omega$ of randomly selected firms is able to adjust prices optimally.

A key element determining prices' adjustment is the marginal cost, which is related to the production function. All firms use identical technology, with aggregate CES production function given by:

$$Y_t = \left[\alpha_N (Z_t N_t)^{1-\frac{1}{\varepsilon}} + \alpha_M (M_t)^{1-\frac{1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{17}$$

, where $\alpha_N \,\epsilon\, (0,1]$, $\alpha_M = 1-\alpha_N$, ε is the elasticity of substitution between inputs with $\left(1-\frac{1}{\varepsilon}\right) \epsilon\, (-\infty, 1)$, Y_t is domestic output, Z_t is the *aggregate* technological shock, and M_t is the amount of imported inputs defined as an index of foreign goods: $M_t = \left(\int_0^1 m_t(i)^{\frac{\theta-1}{\theta}} di\right)^{\frac{\theta}{\theta-1}}$.

All firms have to borrow from intermediaries, at the *gross* nominal interest rate I_t, to pay wages and imports in advance. As a result, the unitary *nominal* cost of labour is $I_t W_t$ and the marginal cost of imports is given by (7).

Firms minimise the real cost of production, $I_t \frac{W_t}{P_t^h} N_t + \delta_t M_t$, subject to the production function. One of the FOC yields the marginal cost:

$$MC_t = \frac{I_t \frac{W_t}{P_t^h} \frac{N_t}{Y_t}}{\frac{\partial F}{\partial N_t} \frac{N_t}{Y_t}} = \frac{I_t S_t}{\gamma_t} \tag{18}$$

, where γ_t is the elasticity of output with respect to labour: $\gamma_t = \frac{\partial F}{\partial N_t} / \frac{Y_t}{N_t}$, and S_t is the labour income share $N_t W_t / P_t^h Y_t$.

With flexible prices, the real marginal cost is always equal to its steady-state value,$1/\Phi = \theta - 1/\theta$. However, with sticky prices, real marginal cost deviates from its steady-state value.

In this case, we have the standard NKPC for domestic inflation: [3]

$$\pi_t^h = \beta E_t \pi_{t+1}^h + k\widehat{mc}_t \tag{19}$$

, with $k = (1-\omega)(1-\omega\beta)/\omega$.

2.6 Marginal cost and the flexible-price output

In this section, we characterise the small open economy's marginal cost and the flexible-price output. This output allow us to write the model in terms of output gap. The elasticity of output with respect to labour is:

$$\widehat{\gamma}_t = \left(1 - \frac{1}{\varepsilon}\right)(\widehat{z}_t - \widehat{y}_t + \widehat{n}_t). \tag{20}$$

Substituting equations (10), the labour income share, and (20) into the marginal cost, we obtain

$$\widehat{mc}_t = \widehat{i}_t + \left(\eta + \frac{1}{\varepsilon}\right)\widehat{n}_t + \sigma\widehat{c}_t + \gamma_c\left(\widehat{\delta}'_t + \widehat{i}_t\right) - \frac{1}{\varepsilon}\widehat{y}_t - \left(1 - \frac{1}{\varepsilon}\right)\widehat{z}_t - \widehat{\xi}_t. \tag{21}$$

Meanwhile, it is possible to obtain an expression for the amount of labour used in production, $\widehat{n}_t$, as a function of output. Firstly, the production function can be expressed in deviations from the steady-state as:

$$\widehat{y}_t = \left(1 - \gamma'_i\right)(\widehat{z}_t + \widehat{n}_t) + \gamma'_i \widehat{m}_t, \tag{22}$$

where $\gamma'_i = \Phi\gamma_i/(1+\gamma_i)$ and γ_i is the share of imported inputs on the value added. In order to guarantee zero net exports in the steady-state, it is necessary that $\gamma_c = \gamma - \gamma_i(1-\gamma)$.

After solving equation (22) for $\widehat{n}_t$, we still have to derive the demand for imported inputs.

[3] The percentage deviation of inflation from its steady state is simply the inflation rate, because the steady-state value of inflation is zero.

The latter function can be obtained from the production function as:

$$\widehat{m}_t = -\varepsilon\left(\widehat{\delta}'_t + \widehat{i}_t\right) + \varepsilon\widehat{mc}_t + \widehat{y}_t. \tag{23}$$

Then, plugging (23) into (22), the demand for labour can be expressed as: $\widehat{n}_t = \widehat{y}_t + \frac{\gamma'_i\varepsilon}{1-\gamma'_i}\left(\widehat{\delta}'_t + \widehat{i}_t - \widehat{mc}_t\right) - \widehat{z}_t$. Plugging last expression into (21), and solving (16) for $\widehat{c}_t$ and plugging the result into (21), we get:

$$\widehat{mc}_t = \frac{1-\gamma'_i}{1+\gamma'_i\eta\varepsilon}\left[v\widehat{i}_t + \left(\eta + \frac{\sigma}{1-\gamma}\right)\widehat{y}_t + h\widehat{\delta}'_t - \frac{\sigma\gamma}{1-\gamma}\widehat{y}^f_t - (\eta+1)\widehat{z}_t - \widehat{\xi}_t\right], \tag{24}$$

with: $v = 1-\gamma_c\,(\sigma a - 1) + \frac{\gamma'_i(1+\eta\varepsilon)}{1-\gamma'_i}$ and $h = \frac{\gamma'_i(1+\eta\varepsilon)}{1-\gamma'_i} - \frac{\gamma+w}{1-\gamma}$. An expression for the flexible-price equilibrium output can be obtained taking into account that the marginal cost is constant in the flexible-price equilibrium ($\widehat{mc}^o_t = 0$). In general, $\widehat{x}^o_t$ is the value of a general variable x_t in the flexible-price equilibrium.

Above, we obtained the risk sharing condition involving consumption. Now, to obtain the relation between output and the terms of trade, first incorporate equation (13) into equation (14), getting $\widehat{c}^h_t = \widehat{y}^f_t + \frac{1+\gamma_c(\sigma a-1)}{\sigma}\widehat{\delta}'_t + \frac{\gamma_c(\sigma a-1)}{\sigma}\widehat{i}_t + \frac{1}{\sigma}\widehat{\xi}_t$. Second, replacing the last equation and (12) into (15), it follows after some manipulations that:

$$\widehat{y}_t = \widehat{y}^f_t + \frac{w+1}{\sigma}\widehat{\delta}'_t + \frac{(1-\gamma)\gamma_c\,(\sigma a - 1)}{\sigma}\widehat{i}_t + \frac{1-\gamma}{\sigma}\widehat{\xi}_t, \tag{25}$$

, with $w = (\sigma a - 1)\left[(1-\gamma)\,\gamma_c + \gamma\right]$. Apart from the taste shock, this equation makes clear that a movement in countries' relative output is associated with a change in the terms of trade or nominal interest rate.

Now, equation (25) in the flexible-price equilibrium, allows to obtain an expression for $\widehat{\delta}'^o_t$. Using this expression and $\widehat{y}^o_t$ (from (24)), we obtain a reduced form for the flexible-price equilibrium output:

$$\widehat{y}_t^o = \frac{1}{\eta + \frac{\sigma}{1-\gamma} + \frac{h\sigma}{w+1}} \left[\begin{array}{c} \sigma \left(\frac{h}{w+1} + \frac{\gamma}{1-\gamma} \right) \widehat{y}_t^f + \left[\frac{h(1-\gamma)\gamma_c(\sigma a-1)}{w+1} - v \right] \widehat{i}_t^o \\ + \left(\frac{h(1-\gamma)}{w+1} + 1 \right) \widehat{\xi}_t + (\eta+1)\, \widehat{z}_t \end{array} \right]. \tag{26}$$

2.7 Deviations from the flexible-price equilibrium

In this section, we write the Phillips Curve in deviations from the flexible-price equilibrium. To start with, equation (24) can be expressed as:

$$\widehat{mc}_t = \frac{(1-\gamma_i')\, v}{1+\gamma_i'\eta\varepsilon} \left(\widehat{i}_t - \widehat{i}_t^o \right) + \frac{(1-\gamma_i')\, h}{1+\gamma_i'\eta\varepsilon} \left(\widehat{\delta}_t' - \widehat{\delta}_t'^o \right) + \frac{1-\gamma_i'}{1+\gamma_i'\eta\varepsilon} \left(\eta + \frac{\sigma}{1-\gamma} \right) (\widehat{y}_t - \widehat{y}_t^o). \tag{27}$$

where $\widehat{y}_t - \widehat{y}_t^o$ is the output gap. From (25) it is possible to obtain the expression for the terms of trade in deviation from its flexible-price level:

$$\widehat{\delta}_t' - \widehat{\delta}_t'^o = \frac{\sigma}{w+1} (\widehat{y}_t - \widehat{y}_t^o) - \frac{(1-\gamma)\gamma_c\,(\sigma a - 1)}{w+1} \left(\widehat{i}_t - \widehat{i}_t^o \right). \tag{28}$$

With the last equation, we can eliminate the terms of trade from the expression of the marginal cost, getting:

$$\widehat{mc}_t = \frac{(1-\gamma_i')}{1+\gamma_i'\eta\varepsilon} \left(\frac{\sigma h}{1+w} + \eta + \frac{\sigma}{1-\gamma} \right) (\widehat{y}_t - \widehat{y}_t^o) + \frac{1-\gamma_i'}{1+\gamma_i'\eta\varepsilon} \left(v - \frac{h(1-\gamma)\gamma_c\,(\sigma a-1)}{w+1} \right) \left(\widehat{i}_t - \widehat{i}_t^o \right). \tag{29}$$

Finally, using the last expression to replace $\widehat{mc}_t$ in (19), we obtain Phillips curve as:

$$\begin{aligned} \pi_t^h \;&=\; \beta E_t \pi_{t+1}^h + \frac{(1-\gamma_i')}{1+\gamma_i'\eta\varepsilon} \left(\frac{\sigma h}{1+w} + \eta + \frac{\sigma}{1-\gamma} \right) k\, (\widehat{y}_t - \widehat{y}_t^o) \\ &\quad + \frac{(1-\gamma_i')}{1+\gamma_i'\eta\varepsilon} \left(v - \frac{h(1-\gamma)\gamma_c\,(\sigma a-1)}{w+1} \right) k \left(\widehat{i}_t - \widehat{i}_t^o \right). \end{aligned} \tag{30}$$

This equation is in reduced form and results from eliminating the terms of trade using the relation between them and output gap and interest rate. This means that our result is similar to the typical Phillips curve for a closed economy, with the only difference in the coefficients of the nominal interest rate and output gap. In particular, the nominal interest rate has a direct effect on domestic inflation due to the presence of the cost channel.

The Phillips curve obtained nests other standard cases. If the economy is closed ($\gamma_i = \gamma = 0$), then we have the standard Phillips curve with a cost channel, described by Ravenna and Walsh (2006). Moreover, if we ignore both imported inputs ($\gamma_i = 0$) and the cost channel, we get the standard Phillips curve for a small open economy described by Walsh (2003).

Now, regarding the empirical identification of the cost channel, equation (27) indicates that the marginal cost is affected by the interest rate, the terms of trade and output gap. When it is assumed that imports of consumption goods are paid in advance, terms of trade are directly affected by the interest rate - see equation (28). In this case, the marginal cost's reduced form is given by expression (29). Then, we can observe in equation (30) that the coefficient of the interest rate does not translate the cost channel only, but it also captures the effect of the interest rate on the terms of trade. In the reduced form marginal cost, the interest rate coefficient equals the true effect of the cost channel subtracted by $A = h(1-\gamma)\gamma_c\,(\sigma a - 1)\,/\,(w+1)$. Notice that the sign of A is not well defined due to h.

Therefore, in order to assess the sign of A, we have to calibrate this expression using parameters that are standard in the literature for a small open economy. Parameter θ is assumed equal to 11, which generates $\Phi = 1.1$. Following Walsh (2003), we assume $\sigma = 1.5$ and $\eta = 1$. Parameter ε is equal to $1/3$, following McCallum and Nelson (1999); a is equal to 1, as in Gali and Monacelli (2005); γ is set to 0.4, as suggested by Gali and Monacelli (2005); and γ_i is equal to 0.1, as suggested by Adolfson (2001).

With our calibration, it turns out that A is negative. Moreover, if we assume (one at a time) different values for the parameters, expression A is always negative or zero (Figure 1). As a result, when estimating the Phillips curve while ignoring the terms of trade, the coefficient of the interest rate is larger than when the terms of trade are specifically taken into account. This means that the identification of the cost channel is distorted when ignoring

Table 1: Sensitivity analysis of expression A's value

	epsilon						**gamma i**			
	0	1/3	1	1.5	2		0	0.1	0.4	2/3
A	-0.0829	-0.0800	-0.7420	-0.0699	-0.0655	*A*	-0.1090	-0.0800	-0.01803	0.0000
	gamma						**sigma**			
	0	0.2	0.4	0.6			1	1.5	2	
A	-0.0104	-0.0120	-0.0800	-0.1889		*A*	0.0000	-0.0800	-0.1939	
	eta						**a**			
	0	1	2				0.1	1	2	
A	-0.0829	-0.0800	-0.0771			*A*	-0.1201	-0.0800	-0.4678	

the terms of trade. This is the reason why, below, we identify the cost channel taking into account open economy variables.

3 NKPC for domestic inflation

3.1 Data

The current research uses quarterly data to estimate the Phillips curve for the G7 countries. [4] For countries not belonging to the euro area, we analysed the period 1980-2006, and for euro area countries we restricted the study to the period 1980-98, in order to avoid any structural break arising from the introduction of the euro.

Regarding variables' measurement, some comments are necessary. Firstly, two alternative measures of inflation will be used, GDP deflator and CPI, both from International Financial Statistics (IFS) of IMF. GDP deflator, which captures inflation on domestically produced goods, is used by most papers on the NKPC. In this paper, as in Kara and Nelson (2003), we also use CPI, which allows to study the impact of imported final goods on CPI inflation. Additionally, following some important works in the literature (see for instance, Gali and Gertler, 1999; Batini et al., 2005; Jondeau and Bihan, 2005), the current research will use the

[4] We have chosen the G7 economies because they are a set of open economies for which it exist quarterly data for a long period of time. This set of countries also allow an easy comparison with other papers on the NKPC and the cost channel. The study of a set of countries aims to test if models can be seen as general or country-specific.

quarterly inflation rate (seasonally adjusted). [5]

Another central issue is the measurement of the marginal cost. This can be measured using labour income share (s_t), which is given by the ratio of total labour costs to nominal GDP (Gali and Gertler, 1999). To obtain this ratio, also called real unit labour cost, we used data from OECD National Accounts, as is common in the literature (see for example Leith and Malley, 2007; Chowdhury et al., 2003; and Jondeau and Bihan, 2005).

Seasonally adjusted wages in manufacturing (w_t) are from OECD Main Economic Indicators. Real wages (ω_t) refer to wages in manufacturing deflated by CPI. Data on real GDP seasonally adjusted is from IFS. Note also that to measure short-run nominal interest rate (i_t) the Treasury Bill Rate from IFS was used.

Import prices inflation was obtained with the seasonally adjusted import prices deflator, $P_{m,t}$, from OECD National Accounts. Real effective exchange rate based on the CPI (q_t) is from IFS.

Finally, we constructed an index similar to the IMF index (that was not available for the all sample), expressed in national currencies, using data on prices of both fuel (weight 47.8%) and non-fuel primary commodities (weight 52.2%). The real commodity price index is simply the commodity price index divided by the GDP deflator.

3.2 Estimating the baseline NKPC

In this section, the NKPC is used to describe domestic inflation, as measured by the change in the GDP deflator. To begin with, we estimate the interest rate augmented NKPC, where import prices are ignored:

$$\pi_t^h = \gamma_f E_t \pi_{t+1}^h + \gamma_b \pi_{t-1}^h + \gamma_s \widehat{s}_t + \gamma_i \widehat{i}_t \tag{31}$$

[5] $\pi_t = \log(P_t) - \log(P_{t-1})$, with P_t as the relevant price index seasonally adjusted.

, where π_t^h is the inflation rate of goods produced and sold domestically, and the parameters γ are constants. Our modelisation strategy consist in first estimate the NKPC without import prices, and after introduce these variables. In this way, we are able to analyse the impact of introducing import prices on the cost channel.

The last equation and others below are estimated using GMM. With rational expectations, we can replace expectations by observed values, implying that the error term will have an expectation error. Since the latter error is not correlated with information available in t or earlier, it is possible to write orthogonality conditions to estimate the model by GMM. For that, instruments dated from $t-1$ or earlier are used (Gali et al., 2001).

GMM estimation involves some important choices. Firstly, it is necessary to define the set of instruments. Here, we follow the common practice in the literature of using as instruments at least four lags of the regressors. [6] In addition, four lags of output gap were also used due to its relevance in explaining inflation. [7] We choosed a relatively small set of instruments to avoid the increase in estimation bias (Ravenna and Walsh, 2006) and the reduction in the J-test's power (Mavroeidis, 2005) arising from introducing too many instruments.

We use the GMM Continuously Updated Estimator (CUE) of Hansen et al. (1996), where the weighting matrix and the coefficients' vector are estimated simultaneously. This estimator has better finite-sample properties than the two-step GMM, and has better performance in the presence of weak instruments (Hahn et al., 2004).

Estimations were made robust to heteroskedasticity and autocorrelation of unknown form. Controlling for autocorrelation allows us to take into account the presence of measurement errors in real marginal cost (Gali et al., 2001). The estimation of the covariance matrix of the sample moments conditions was done following Newey and West (1987) and using the Barlett Kernel.

[6] Notice that we do not use exactly the same instruments for all countries because inflation dynamics have country-specific aspects.

[7] Our measure of output gap is the difference between the log of output and the H-P filtered log of output with smoothing parameter of 1600.

As shown in equation (31), the labour income share is expressed in deviations from the steady-state. We removed the trend from the variables in levels using the HP filter (with $\lambda = 1600$). [8] Canova (2007) suggests precisely that in a GMM application when data is non-stationary, it is possible to detrend data using the HP filter. Moreover, the use of this filter allows the variables' steady-state to change over time. This is useful because during the sample period inflation has decreased considerably in some countries.

We are now in conditions to analyse estimations (Table 2).[9] In accordance with the J-statistic, we do not reject the validity of instruments. Moreover, the estimated curves are sensible for several reasons. Labour income share has a positive effect on inflation for all countries, but it is statistically significant only for Germany and the UK. Even though the backward component of inflation is significant, the forward component dominates inflation dynamics. [10] Only for France does the backward behaviour of inflation prevails. Moreover, in general the sum of both components is near 1. Overall, these results are close to Bardsen et al. (2004) and Jondeau and Bihan (2005).

Regarding the cost channel, the nominal interest rate has a positive effect on inflation for all countries, except Germany, and its effect is statistically significant for Canada and Japan. [11] This indicates that the cost channel is not particularly strong in the majority of the analysed countries. These results are more negative for the cost channel as a general phenomenon than those of Chowdhury et al. (2006).

In order to check the robustness of results, some sensitivity analysis was carried out. Firstly, the more usual way of obtaining deviations from the steady-state was used: log deviations from the average, $\widehat{z}_t = \log(z_t) - \log(\overline{z}_t)$, where z_t is any of the variables used in

[8] The HP filter is used in the labour share, interest rate, relative prices of imports and commodities. When possible, the filter is applied for the sample starting in 1975Q1. The inflation rate is not used in deviations from the steady state because the Phillips curve has one lag and one lead of this variable.

[9] We do not estimate the structural parameters, because to do so we would need to calibrate some parameters, and we wish to avoid uniform calibration across countries.

[10] For Japan the backward component of inflation is negative and insignificant. Thus, we restrict that coefficient to zero for Japan. Moreover, in Japan the forward inflation coefficient came out larger than 1, but is not significantly different from 1.

[11] It is also significant at 15% for Italy.

Table 2: Estimates of the NKPC for domestic inflation augmented with the interest rate

	π_{t+1}	π_{t-1}	$\hat{s}_t$	$\hat{\imath}_t$	J-stat.
Canada	0.6181***	0.3720***	0.0070	0.0016*	0.0909
	(0.0632)	(0.0598)	(0.0195)	(0.0008)	[0.4643]
France	0.4009***	0.6092***	0.0200	0.0006	0.1814
	(0.0671)	(0.0602)	(0.0264)	(0.0014)	[0.3890]
Germany	0.8225***	0.1944***	0.0426*	-0.0007	0.1145
	(0.0558)	(0.0588)	(0.0240)	(0.0014)	[0.7950]
Italy	0.6554***	0.3766***	0.0077	0.0040	0.1732
	(0.0425)	(0.0356)	(0.0246)	(0.0024)	[0.4347]
Japan	1.0210***	-	0.0607	0.0003**	0.0830
	(0.0752)		(0.0547)	(0.0001)	[0.8496]
UK	0.8226***	0.1919**	0.0532**	0.0001	0.0639
	(0.0881)	(0.0878)	(0.0249)	(0.0017)	[0.9098]
USA	0.6822***	0.3035***	0.0077	0.0001	0.1196
	(0.0559)	(0.0542)	(0.0121)	(0.0002)	[0.4540]

Notes: Instruments: four lags of inflation, labour income share, interest rate and output gap. Due to lack of significance in the first-stage regression, for Canada the lags $t-2$ to $t-4$ of output gap were not used. (...) contain standard errors. [...] contains p-values. *** means significance at 1%, ** at 5%, and * at 10%.

estimations. In this case, evidence in favour of the cost channel becomes even weaker. [12] After that, the output gap was used instead of the labour income share, but that variable has a negative coefficient for five countries. The bad performance of the output gap confirms the evidence of previous works, which show that labour income share is a better driver of inflation than output gap (Gali and Gertler, 1999; and Gali et al., 2001).

3.3 Estimating the NKPC with open economy variables

In this section we estimate the NKPC incorporating open economy variables. With a Cobb-Douglas production function, the price of imported inputs does not affect the marginal cost (Gali and Lopez-Salido, 2001). However, if we depart from the unitary elasticity of substitution between inputs and assume a CES production function, the marginal cost and inflation are affected by imports price (Gali and Lopez-Salido, 2001). For Canada, USA and Eurozone, Gagno and Khan (2005) show that the use of a CES rather than a Cobb-Douglas technology leads to an improvement in the fit of the NKPC. In line with this, we assume a CES production function with labour and imported materials (eq. (17)), in the spirit Gali and Lopez-Salido (2001). In addition, firms have to borrow to pay in advance both imported inputs and wages, leading to the marginal cost given by eq. (18). With these assumptions, from cost minimisation, we have:

$$\frac{N_t}{M_t} = \left(\frac{\alpha_N P_{m,t} I_t}{\alpha_M W_t I_t}\right)^{\varepsilon} = \left(\frac{\alpha_N P_{m,t}}{\alpha_M W_t}\right)^{\varepsilon}, \tag{32}$$

Notice that both $P_{m,t}$ and W_t are expressed in nominal terms. It is also possible to show that $\gamma_t = 1 - \alpha_M \left(Y_t/M_t\right)^{\frac{1}{\varepsilon}-1}$. Substituting (32) into the last expression and log-linearising, we get: $\widehat{\gamma}_t = -\phi\left(\widehat{p}_{m,t} - \widehat{w}_t\right)$, where $\phi = \left(\frac{1-\Phi s}{\Phi s}\right)(\varepsilon - 1)$, and s is the steady-state labour income share. Therefore, from equation (18) we obtain the NKPC:

[12] The robustness results are vailable upon request from the author.

$$\pi_t^h = \gamma_f E_t \pi_{t+1}^h + \gamma_b \pi_{t-1}^h + \gamma_s \widehat{s}_t + \gamma_i \widehat{i}_t + \gamma_{pw} \left(\widehat{p}_{m,t} - \widehat{w}_t\right) \tag{33}$$

, with $\gamma_{pw} = k\phi$. The impact of imports price on the marginal cost depends on ε. [13] If $\varepsilon > 1$, a decrease in the relative price of imports decreases the marginal cost, because firms substitute labour by imported inputs. This curve nests the standard NKPC (with $\gamma_i = 0$ and $\gamma_{pw} = 0$). Notice that equation (33) is a different way of writing the Phillips curve of Section 2. [14]

Equation (33) is valid either there is slow or immediate exchange rate pass-through of exchange rate to imports price. Though if we are willing to accept immediate exchange rate pass-through, it is possible to write equation (33) using the real exchange rate. Indeed, notice that is possible to write: $\frac{P_{m,t}}{W_t} = \frac{\left(\ddot{E}_t P_{mt}^*/P_t^c\right)}{(W_t/P_t^c)} = \frac{q_t'}{\omega_t}$, where $\ddot{E}_t$ is the nominal exchange rate, P_{mt}^* is the price of imports in the world market, P_t^c is the domestic's CPI, q_t' is the real exchange rate (RER), and ω_t is the real wage. [15] Combining the latter expression and equation (33), we obtain:

$$\pi_t^h = \gamma_f E_t \pi_{t+1}^h + \gamma_b \pi_{t-1}^h + \gamma_s \widehat{s}_t + \gamma_i \widehat{i}_t + \gamma_{qw} \left(\widehat{q}_t' - \widehat{\omega}_t\right). \tag{34}$$

This means that we can use the last equation to test if the exchange rate pass-through is slow or immediate. On the one hand, if pass-through is immediate, using in the NKPC the real exchange rate or import prices would produce basically similar results. On the other hand, if the exchange rate pass-through is slow, then equation (33) will be a better description of reality than equation (34). This question is rather important for optimal monetary policy design, being determinant to decide if the central bank should target domestic inflation or CPI inflation, and what weight should it give to exchange rate movements (Clarida et al.,

[13] As seen above, if the production function is a Cobb-Douglas, *i.e.*, $\varepsilon \to 1$, then the relative price of imports does not affect the marginal cost.

[14] From equation (18) we obtain an expression where the marginal cost depends on $\widehat{i}_t$, $\widehat{s}_t$ and $\widehat{\delta}_t'$: $\widehat{mc}_t = \frac{1}{1-\left(1-\frac{1}{\varepsilon}\right)\frac{\gamma_i'\varepsilon}{1-\gamma_i'}} \left[\left(1-\left(1-\frac{1}{\varepsilon}\right)\frac{\gamma_i'\varepsilon}{1-\gamma_i'}\right)\widehat{i}_t + \widehat{s}_t - \left(1-\frac{1}{\varepsilon}\right)\frac{\gamma_i'\varepsilon}{1-\gamma_i'}\widehat{\delta}_t'\right]$.

[15] An increase in q_t' corresponds to a *depreciation* of the *domestic* currency.

Table 3: Estimates of the open economy NKPC for domestic inflation with the relative real exchange rate

	π_{t+1}	π_{t-1}	$\hat{s}_t$	$\hat{\imath}_t$	$\widehat{rer}_t - \widehat{\omega}_t$	J-stat.
Canada	0.5346***	0.4313***	0.0384*	0.0020**	0.0128**	0.1105
	(0.0629)	(0.0589)	(0.0226)	(0.0009)	(0.0055)	[0.5416]
France	0.3829***	0.6143***	-0.0203	0.0017	-0.0130	0.1652
	(0.0513)	(0.0460)	(0.0201)	(0.0012)	(0.0081)	[0.7507]
Germany	0.7784***	0.2526***	0.0309***	0.0006	-0.0082	0.1382
	(0.0471)	(0.0464)	(0.0112)	(0.0014)	(0.0060)	[0.8390]
Italy	0.6553***	0.4624***	0.4186***	0.0033	0.0594***	0.1912
	(0.0725)	(0.0639)	(0.0759)	(0.0052)	(0.0173)	[0.6156]
Japan	0.9832***	-	-0.0162	0.0004*	0.0038	0.0859
	(0.1108)		(0.0633)	(0.0002)	(0.0048)	[0.9422]
UK	0.8910***	0.1285	0.0397	-0.0023	-0.0111	0.0718
	(0.0772)	(0.0777)	(0.0305)	(0.0021)	(0.0128)	[0.9577]
USA	0.7005***	0.2816***	0.0241	-0.00005	0.0043	0.1170
	(0.0626)	(0.0565)	(0.0159)	(0.00029)	(0.0033)	[0.7323]

Notes: Instruments: four lags of inflation, labour income share, interest rate, relative RER and output gap. For Canada the lags $t-2$ to $t-4$ of output gap were not used. See notes to Table 2

2001; Monacelli, 2003; and Corsetti, 2006).

Estimation's results show that for Canada, Italy, Japan and the USA the coefficient of the relative RER is positive, being significant for Canada and Italy (Table 3). In turn, for France, Germany and the UK that coefficient is negative. [16]

Now, let us see if slow exchange rate pass-through has a better empirical fit (equation (33)). As can be seen from Table 4, the relative price of imports has a positive coefficient for all countries; and it is statistically significant for Canada, Germany, Italy and Japan. [17] The fact that the coefficient of import prices is statistically significant for a larger number of countries than the real exchange rate, indicates that the Phillips curve with import prices has a better empirical performance than with real exchange rate. As a result, it can be inferred that slow exchange rate pass-through describes better reality than immediate pass-through.

[16] This is possible if $\varepsilon < 1$.

[17] For the USA it is also significant at 15%. It is worth mentioning that for the UK we use the commodity price index instead of imports price deflator, because it was a better predictor of inflation. In the estimations below the same procedure is followed.

Table 4: Estimates of the open economy NKPC for domestic inflation with the relative price of imports

	π_{t+1}	π_{t-1}	$\hat{s}_t$	$\hat{\imath}_t$	$\hat{p}_{m,t} - \widehat{\omega}_t$	J-stat.
Canada	0.5136***	0.4422***	0.0380*	0.0009	0.0251**	0.1098
	(0.0713)	(0.0640)	(0.0220)	(0.0012)	(0.0103)	[0.5477]
France	0.5222***	0.4914***	0.0162	-0.0005	0.0052	0.1589
	(0.0643)	(0.0580)	(0.0298)	(0.0022)	(0.0054)	[0.6730]
Germany	0.5594***	0.4281***	0.0344**	-0.0015	0.0212**	0.1239
	(0.0278)	(0.0259)	(0.0158)	(0.0013)	(0.0098)	[0.8952]
Italy	0.6172***	0.4812***	0.2108***	-0.0048	0.0309***	0.1741
	(0.0683)	(0.0604)	(0.0329)	(0.0045)	(0.0093)	[0.6553]
Japan	0.9830***	-	0.0072	0.0003*	0.0141**	0.0801
	(0.0986)		(0.0737)	(0.0002)	(0.0057)	[0.9353]
UK	0.8622***	0.1363*	0.0305	-0.0032*	0.0011	0.1015
	(0.0784)	(0.0789)	(0.0291)	(0.0017)	(0.0028)	[0.8475]
USA	0.6671***	0.3134***	0.0055	-0.0002	0.0058	0.1287
	(0.0430)	(0.0411)	(0.0126)	(0.0003)	(0.0036)	[0.6058]

Notes: For the UK the commodity price index was used instead of imports deflator. Instruments: four lags of inflation, labour income share, interest rate, relative price of imports and output gap. The exceptions are: for Canada the lags $t-2$ to $t-4$ of output gap were not used, for France the lag $t-4$ of the relative price of imports was not used, and for Japan the lag $t-4$ of the labour income share was not used. See notes to Table 2

With the calibrated model of Section 2, it was predicted that the coefficient of the interest rate would decrease once the relative price of imports was explicitly considered in the Phillips curve. From the above results, we observe exactly that: after including the relative price of imports, interest rate is no longer statistically significant for Canada and its coefficient becomes negative for France, Italy, the UK and the USA (Table 4). But among the countries where the interest rate's coefficient is negative, it is only significant for the UK at 10% significance level.

4 NKPC for CPI inflation

This section aims to explain CPI inflation using the NKPC and test the empirical importance of the cost channel when import prices are considered. As above, it is also tested if the exchange rate pass-through is slow or immediate. Additionally, it is analysed if imports should be treated as final consumption goods and/or inputs in production. The latter question is very important for optimal monetary policy. McCallum and Nelson (2001) and Kara and Nelson (2003) suggest that when imports are treated only as inputs, then all prices are sticky and therefore the policy maker should target CPI inflation. Kara and Nelson's (2003) empirical result for the UK show that imports should in fact be treated as inputs.

In order to answer the above questions, we begin by estimating the interest rate augmented NKPC for CPI inflation - equation (31) with π^c instead of π^h (see Table 5). Results obtained are sensible, with labour income share's coefficient being positive for all countries and statistically significant for Canada and the UK. [18] Comparing the Phillips curve for CPI inflation with the Phillips curve for domestic inflation, we observe that in the former case the average backward coefficient of inflation is larger, with the exception of Canada and France. Finally, we can observe that, with the exception of Italy, the interest rate always has a positive

[18] Firstly, for the USA the labour income share is also statistically significant at a 15% level of significance. Secondly, since for Italy the labour income share has a negative coefficient, we used the output gap instead. For the same reasons, the output gap will also be used for Italy in the Phillips curves with import prices.

Table 5: Estimates of the NKPC for CPI inflation augmented with the interest rate

	π_{t+1}	π_{t-1}	$\hat{s}_t$	$\hat{\imath}_t$	J-stat.
Canada	0.6513***	0.3395***	0.0346**	0.0011	0.1369
	(0.0400)	(0.0362)	(0.0149)	(0.0008)	[0.3209]
France	0.5477***	0.4542***	0.0012	0.0013	0.1417
	(0.0482)	(0.0441)	(0.0218)	(0.0011)	[0.4623]
Germany	0.7346***	0.2687***	0.0068	0.00009	0.1324
	(0.0469)	(0.0356)	(0.0157)	(0.00082)	[0.6887]
Italy	0.5820***	0.4244***	0.0178	-0.0011	0.1554
	(0.0697)	(0.0657)	(0.0125)	(0.0013)	[0.5427]
Japan	0.8338***	0.1719***	0.0055	0.0003***	0.1288
	(0.0758)	(0.0612)	(0.0270)	(0.0001)	[0.3320]
UK	0.7931***	0.2227**	0.0267**	0.0005	0.0826
	(0.0576)	(0.0540)	(0.0122)	(0.0007)	[0.7843]
USA	0.5900***	0.4465***	0.0510	0.0008	0.1012
	(0.0476)	(0.0425)	(0.0289)	(0.0008)	[0.6244]

Notes: For Italy the output gap is used instead of the labour income share. Instruments: four lags of inflation, labour income share, interest rate and output gap. For France the lags $t-3$ and $t-4$ of the interest rate are not used, and for Japan the lag $t-4$ of the labour income share is not used.

coefficient, but it is statistically insignificant for all countries except for Japan.

4.1 NKPC assuming imports as final consumption goods

In this section import prices are introduced in the Phillips curve for CPI inflation. We start by assuming imports as final consumption goods and immediate exchange rate pass-through. The Phillips curve proposed by Kara and Nelson (2003) is extended to include a cost channel and a backward component of inflation. Firstly, CPI inflation is $\pi_t^c = (1-\gamma_c)\pi_t^h + \gamma_c \pi_t^m$, where γ_c is the share of imported goods in CPI basket, and π_t^m is inflation rate of imported *consumer* goods. This equation can be written as:

$$\pi_t^c = \pi_t^h + \gamma_c \left(\pi_t^m - \pi_t^h \right). \tag{35}$$

Admitting immediate pass-through, we have $\pi_t^m = \pi_t^{f*} + \Delta e_t$, where π_t^{f*} is the world price of imported consumer goods and Δe_t is the change in nominal exchange rate. This allows us to get $\pi_t^m - \pi_t^h = \pi_t^{f*} + \Delta e_t - \pi_t^h = \Delta q_t'$, where $\Delta q_t'$ is the change in the real exchange rate. Using this result together with equation (35), we obtain: $\pi_t^h = \pi_t^c - \gamma_c \Delta q_t'$. Assuming $\widehat{mc}_t = \widehat{i}_t + \widehat{s}_t$, the last identity can be used in equation (19), to get:

$$\pi_t^c = \gamma_f E_t \pi_{t+1}^c + \gamma_b \pi_{t-1}^c + \gamma_s \widehat{s}_t + \gamma_i \widehat{i}_t + \gamma_{\Delta q} \left(\Delta q_t - \gamma_f E_t \Delta q_{t+1} - \gamma_b \Delta q_{t-1} \right). \qquad (36)$$

, where $\Delta q_t = -\Delta q_t'$. [19] It is expected that an increase in Δq_t (real *appreciation)* decreases inflation ($\gamma_{\Delta q} = -\gamma_c < 0$), because a real appreciation makes imports less expensive in domestic currency. Notice that the impact of $E_t \Delta q_{t+1}$ and Δq_{t-1} on π_t^c is positive and contrary to the effect of Δq_t.

From Table 6, we can see that for France, Germany and the UK this model does not make sense, because the coefficient of real exchange rate's change is positive, and significant for the first two countries. [20] For the other countries, that coefficient is negative as expected, but statistically insignificant.

The weak empirical performance of the model with imports as final consumption goods may be related to the assumption of immediate pass-through underlying equation (36). Instead, it may be better to use the price of imports, allowing for the possibility of slow exchange rate pass-through (Kara and Nelson, 2003). [21] To obtain the NKPC with imported goods' inflation, notice first that domestic inflation can be written as: $\pi_t^h = \frac{1}{1-\gamma_c} \left(\pi_t^c - \gamma_c \pi_t^m \right)$. Plugging the last equation in (19) and after some manipulations we obtain: [22]

$$\pi_t^c = \gamma_f E_t \pi_{t+1}^c + \gamma_b \pi_{t-1}^c + \gamma_s \widehat{s}_t + \gamma_i \widehat{i}_t + \gamma_c \left(\pi_t^m - \gamma_f E \pi_{t+1}^m - \gamma_b \pi_{t-1}^m \right), \gamma_m > 0. \qquad (37)$$

[19] $\Delta q_t = \log(q_t) - \log(q_{t-1})$

[20] For the UK it is significant at a 15% level of significance.

[21] Kara and Nelson (2002) have used the following formulation of the PC: $\pi_t^c = \beta E_t \pi_{t+1}^c + \alpha mc_t + \phi \left(\pi_t^m - \pi_t^c \right)$.

[22] Regarding the coefficients of the labour income share and the nominal interest rate, we obtain $\gamma (1 - \gamma_m) \left(\widehat{s}_t + \widehat{i}_t \right)$, which we simplify to a unrestricted version: $\gamma_s \widehat{s}_t + \gamma_i \widehat{i}_t$, allowing for $\gamma_s \neq \gamma_i$.

Table 6: Estimates of the NKPC for CPI inflation with imports as consumption goods, using the change in the RER

	π_{t+1}	π_{t-1}	$\hat{s}_t$	$\hat{\imath}_t$	Δq_t	J-stat.
Canada	0.6352***	0.3495***	0.0336**	0.0017**	-0.0049	0.1464
	(0.0376)	(0.0345)	(0.0135)	(0.0007)	(0.0244)	[0.4662]
France	0.4661***	0.5294***	0.0335	-0.00008	0.1450***	0.1384
	(0.0803)	(0.0712)	(0.0214)	(0.00104)	(0.0302)	[0.8754]
Germany	0.7615***	0.2363***	0.0192	0.0003	0.0405**	0.1430
	(0.0558)	(0.0435)	(0.0140)	(0.0008)	(0.0163)	[0.8174]
Italy	0.5278***	0.4486***	0.0184	-0.0030***	-0.0113	0.1992
	(0.0620)	(0.0605)	(0.0132)	(0.0009)	(0.0095)	[0.5879]
Japan	0.9307***	0.0989	0.0622*	0.0003***	-0.0116	0.1392
	(0.0901)	(0.0659)	(0.0339)	(0.0001)	(0.0082)	[0.5729]
UK	0.6321***	0.3776***	0.0162*	-0.0005	0.0239	0.0999
	(0.0481)	(0.0458)	(0.0092)	(0.0007)	(0.0152)	[0.8282]
USA	0.6545***	0.3544***	0.0148	0.0007	-0.0142	0.1169
	(0.0440)	(0.0393)	(0.0227)	(0.0008)	(0.0247)	[0.7488]

Notes: The coefficient of Δq is $\gamma_{\Delta q}$. Instruments: four lags of inflation, labour income share, interest rate, change in the RER and output gap. See notes to Table 2.

Estimating equation (37) shows that for all countries imported goods inflation has a positive and significant effect on CPI inflation (Table 7).[23] This means that the NKPC with slow exchange rate pass-through has a better empirical adherence than the Phillips curve with immediate pass-through. In addition, our results go in the direction of Mihailov et al. (2009), in the sense that the variable translating the impact of imports on inflation has a larger statistical significance than the variable capturing the influence of the business cycle.

The above results also indicate that when imported consumption goods are considered, the *average* backward component of inflation becomes more important for Germany, Italy, Japan and the UK, but it remained basically the same for Canada and France, and for the US it decreased. In general, this shows that imports have an effect on the estimated degree of firms that are backward-looking. Probably, in some cases the omission of import prices, which are related to a volatile and forward-looking variable like the exchange rate, forces the forward component of inflation to be larger.

Furthermore, with the introduction of imported goods' inflation in the Phillips curve, the coefficient of the interest rate becomes significant and changes to negative for France, Germany and the UK. In conclusion, it seems that the introduction of imports inflation reduces the empirical relevance of the cost channel.

Some explanations can be advanced for the existence of a negative interest rate coefficient for some countries. The reasons that we will point out indicate that the nominal interest rate has a direct effect on inflation opposite to the traditional view of the cost channel, and therefore also help to understand why that channel is not statistically significant for some countries. Firstly, interest rate may have a negative supply-side effect on inflation due to its negative effect on the equilibrium mark-up. An increase in interest rate makes collusion more difficult (Tirole, 1988), reducing markups and prices.

[23] Notice that for Italy only the lag of imported goods inflation is significant, with a positive sign, as expected. In opposition to equation (37), in this case lagged imported inflation should have a positive coefficient, because this empirical formulation does not assume that the impact of imported goods inflation on CPI inflation is given by equation (35).

Table 7: Estimates of the NKPC for CPI inflation with imports as consumption goods, assuming slow exchange rate pass-through

	π_{t+1}	π_{t-1}	$\hat{s}_t$	$\hat{\imath}_t$	π_m	J-stat.
Canada	0.6726***	0.3240***	0.0389***	0.0004	0.1482***	0.1146
	(0.0414)	(0.0350)	(0.0130)	(0.0007)	(0.0319)	[0.7250]
France	0.6052***	0.4399***	0.0212	-0.0026**	0.0518**	0.1995
	(0.0364)	(0.0303)	(0.0173)	(0.0010)	(0.0259)	[0.5123]
Germany	0.6513***	0.3686***	0.0428**	-0.0054***	0.1940***	0.1407
	(0.0523)	(0.0429)	(0.0180)	(0.0015)	(0.0183)	[0.8279]
Italy	0.4057***	0.5878***	0.0441***	-0.0022	0.0132***	0.1616
	(0.0686)	(0.0640)	(0.0129)	(0.0018)	(0.0046)	[0.7240]
Japan	0.5788***	0.3153***	0.0061	0.0005***	0.1097***	0.1539
	(0.0532)	(0.0519)	(0.0303)	(0.0001)	(0.0229)	[0.7253]
UK	0.5190***	0.4873***	0.0235***	-0.0011**	0.0531***	0.1183
	(0.0257)	(0.0231)	(0.0077)	(0.0005)	(0.0115)	[0.9136]
USA	0.6277***	0.3918***	0.0321	0.0003	0.1101***	0.0993
	(0.0440)	(0.0417)	(0.0231)	(0.0006)	(0.0340)	[0.8316]

Notes: The coefficient of π^m is γ_c. For Italy the output gap is used instead of the labour income share, and the coefficient of imported goods' inflation corresponds only to π^m_{t-1}. Instruments: four lags of inflation, labour income share, interest rate, imports price inflation and output gap. For Japan and the UK four lags of the relative price of commodities (nominal commodity price / nominal wage) were also used, because they have proved to be good instruments. See notes to Table 2.

Secondly, credit growth can increase inflation even after controlling for its effect on aggregate demand. An increase in credit means a redirection of demand towards non-tradable goods, creating inflation even if it does not affect output gap. As a result, because an increase in the interest rate reduces credit growth, it may have a negative effect on inflation, even after taking into consideration its effect on the business cycle.

Finally, an increase in interest rate is usually associated with a decrease in expected inflation. If for any reason expected inflation is not properly accounted for in the Phillips curve (Jondeau and Bihan, 2005), the interest rate's coefficient captures part of the effect of inflation's expectations on current inflation.

4.2 NKPC assuming imports as both final consumption goods and inputs

Besides final consumption goods, imports are also inputs in production. Therefore, we tested a NKPC for CPI inflation where imports can have those two roles. When imports are inputs, the marginal cost depends on the price of imports, as shown in equation (33). In that case, the NKPC with a slow exchange rate pass-through is:

$$\pi_t^c = \gamma_f E_t \pi_{t+1}^c + \gamma_b \pi_{t-1}^c + \gamma_s \widehat{s}_t + \gamma_i \widehat{i}_t + \gamma_{pw} \left(\widehat{p}_{m,t} - \widehat{w}_t\right) + \gamma_c \left(\pi_t^m - \gamma_f E \pi_{t+1}^m - \gamma_b \pi_{t-1}^m\right), \gamma_m > 0 \tag{38}$$

Equation (38) allows testing different versions of the NKPC. On one hand, if as suggested by McCallum and Nelson (2001), imports should be treated only as inputs in production, then γ_c is statistically non-significant and the coefficient γ_{pw} is statistically significant. On the other hand, if the correct treatment of imports is both as final goods and inputs, then γ_c and γ_{pw} are both statistically significant and γ_c is positive.

Table 8 shows that the relative price of imports has a positive effect on CPI inflation for all countries and is significant for France, Italy, and Japan. This result indicate that for some countries imports should be treated simultaneously as inputs and final consumption goods. [24]

4.3 NKPC assuming imports of consumer goods paid in advance

This section tests whether or not consumer goods' imports are also paid in advance. If that is the case, CPI inflation takes the form of equation (9). Naturally domestic inflation is: $\pi_t^h = \pi_t^c - \gamma_c \Delta \widehat{\delta}_t' - \gamma_c \Delta \widehat{i}_t$. Using the last expression to replace π_t^h on the Phillips curve for

[24] It is worth making two comments. For Japan, in equation (38) imposing $\gamma_c \left(\pi_t^m - \gamma_f E \pi_{t+1}^m - \gamma_b \pi_{t-1}^m\right)$ has proved to be too restrictive. Therefore, the model was estimated allowing free parameters in the following form: $\gamma_{c,c} \pi_t^m + \gamma_{c,f} E \pi_{t+1}^m + \gamma_{c,b} \pi_{t-1}^m$. For Germany, the best way of translating the impact of relative price of imported inputs on inflation was using the lag of this variable.

Table 8: Estimates of the NKPC for CPI inflation with imports both as consumption goods and inputs, assuming slow exchange rate pass-through

	π_{t+1}	π_{t-1}	$\hat{s}_t$	$\hat{\imath}_t$	π^m	π^m_{t+1}	π^m_t	π^m_{t-1}	$\hat{p}_{m,t} - \widehat{\omega}_t$	J-stat.
Canada	0.6590***	0.3263***	0.0497***	0.0019***	0.0883***	-	-	-	0.0043	0.1421
	(0.0406)	(0.0326)	(0.0125)	(0.0006)	(0.0207)				(0.0066)	[0.7094]
France	0.8426***	0.2266***	0.0582***	-0.0043***	0.0199**	-	-	-	0.0163***	0.2059
	(0.0495)	(0.0408)	(0.0166)	(0.0009)	(0.0122)				(0.0034)	[0.6805]
Germany	0.5665***	0.4511***	0.0547***	-0.0071***	0.1967***	-	-	-	0.0058	0.1496
	(0.0552)	(0.0423)	(0.0197)	(0.0020)	(0.0200)				(0.0106)	[0.9107]
Italy	0.6211***	0.3721***	0.0078	-0.0019**	-	-	-	0.0006	0.0017*	0.1653
	(0.0365)	(0.0328)	(0.0099)	(0.0008)				(0.0039)	(0.0009)	[0.8963]
Japan	0.5185***	0.3247***	0.0193	0.00006	0.0518***	-0.0250**	0.0075***	-0.0389***	0.0075***	0.1595
	(0.0615)	(0.0799)	(0.0348)	(0.0001)	(0.0175)	(0.0119)	(0.0024)	(0.0083)	(0.0024)	[0.4232]
UK	0.5181***	0.4915***	0.0260***	-0.0013**	0.0552***	-	-	-	0.0005	0.1135
	(0.0305)	(0.0284)	(0.0080)	(0.0006)	(0.0116)				(0.0008)	[0.9027]
USA	0.5869***	0.4279***	0.0203	0.00001	0.1510***	-	-	-	0.0019	0.1380
	(0.0405)	(0.0368)	(0.0185)	(0.0007)	(0.0280)				(0.0026)	[0.7786]

Notes: π^m refer to coeficient γ_c in eq. (37). For Japan it is assumed that γ_c may vary for different lags of π^m : $\gamma_{c,c}\pi^m_t + \gamma_{c,f}E\pi^m_{t+1} + \gamma_{c,b}\pi^m_{t-1}$. For Italy the reasonable model assumes only the coefficient of π^m_{t-1} is different from zero, since the coefficients π^m_t and π^m_{t+1} were non-significant and with the wrong sign. For Italy, Japan and the UK pw_t is the relative price of commodities. For Germany we used pw_{t-1}. Instruments: four lags of inflation, labour income share, interest rate, imports inflation, relative price of imports (or commodities) and output gap. See notes to Table 2.

domestic inflation, equation (31), we get after some manipulations:

$$\begin{aligned}\pi_t^c &= \gamma_f E_t \pi_{t+1}^c + \gamma_b \pi_{t-1}^c + \gamma_c \left(\Delta\widehat{\delta}_t' - \gamma_b \Delta\widehat{\delta}_{t-1}' - \gamma_f E_t \Delta\widehat{\delta}_{t+1}'\right) \\ &\quad + \gamma_c \left(\Delta\widehat{i}_t - \gamma_b \Delta\widehat{i}_{t-1} - \gamma_f E_t \Delta\widehat{i}_{t+1}\right) + \gamma_s \widehat{s}_t + \gamma_r \widehat{i}_t\end{aligned} \tag{39}$$

To estimate the previous equation, we use the change in import prices instead of the change in the terms of trade, because the former has proved above to be empirically successful. According to Table 9, the change in the nominal interest rate has the expected coefficient for all countries and is always significant. [25]

It can be argued that the last result is driven by the fact that we are replacing $\Delta\widehat{\delta}_t'$ by π_t^m and so ignoring π_t^h. To test this argument, we re-estimated the model using $\Delta\left(p_{m,t}/p_t^h\right)$, but results remained almost the same. Additionally, we have shown that for France, Italy and Japan the *level* of relative import prices is statistically significant. When we add that variable to equation (39), the change in interest rate continues with positive and significant coefficients. [26]

5 Conclusion

We start by developing an open economy New Keynesian model to evaluate how the inclusion of open economy variables affects the identification of the cost channel. It is concluded that ignoring the terms of trade in the estimation of the NKPC leads to an overestimation of the size of the cost channel.

Using an open economy Phillips curve, we test two complementary versions of the cost channel. The first assumes that inputs (wages and imported intermediate goods) are paid in advance. The second version considers that trade companies pay imports of consumption

[25] For estimations proposes we assumed that γ_c associated to $\Delta\widehat{\delta}'$ does not need to be equal to the coefficient γ_c associated to $\Delta\widehat{i}$. The latter coefficient is re-named $\gamma_{\Delta i}$.

[26] These robustness results are available upon request from the authors.

Table 9: Estimates of the NKPC for CPI inflation with imports of consumption goods paid in advance

	Canada	France	Germany	Italy	Japan	UK	USA
π_{t+1}	0.6911***	0.6730***	0.8601***	0.3922***	0.5185***	0.6168***	0.4839***
	(0.0373)	(0.0451)	(0.0325)	(0.0390)	(0.0615)	(0.0368)	(0.0566)
π_{t-1}	0.3080***	0.3357***	0.1619***	0.5899***	0.3247***	0.4052***	0.5216***
	(0.0326)	(0.0407)	(0.0318)	(0.0364)	(0.0799)	(0.0314)	(0.0514)
$\hat{s}_t$	0.0452***	0.0020	0.0010	0.0121	0.0193	0.0496***	0.0481**
	(0.0126)	(0.0187)	(0.0167)	(0.0083)	(0.0348)	(0.0114)	(0.0233)
$\hat{i}_t$	-0.0003	0.0007	-0.0062***	0.0003	0.00006	-0.0027***	0.0004
	(0.0008)	(0.0009)	(0.0012)	(0.0011)	(0.00013)	(0.0009)	(0.0006)
π^m	0.0999***	0.0629**	0.1236***	-		0.0535***	0.0943***
	(0.0355)	(0.0250)	(0.0212)			(0.0121)	(0.0275)
π^m_{t+1}	-	-	-	-	-0.0092	-	-
					(0.0093)		
π^m_t	-	-	-	-	0.0501***	-	-
					(0.0171)		
π^m_{t-1}	-	-	-	0.0050	-0.0547***	-	-
				(0.0036)	(0.0123)		
Δi	0.0011***	0.0011***	0.0025***	0.0007**	-	-	-
	(0.0003)	(0.0003)	(0.0005)	(0.0003)			
Δi_{t+1}	-	-	-	-	-	-	-0.0020***
							(0.0003)
Δi_t	-	-	-	-	0.0064***	-	0.0016***
					(0.0017)		(0.0004)
Δi_{t-1}	-	-	-	-	-0.0005	0.0008***	-
					(0.0008)	(0.0002)	
J-stat.	0.0878	0.1722	0.1677	0.1657	0.1692	0.1262	0.1153
	[0.9662]	[0.6659]	[0.8511]	[0.8587]	[0.6245]	[0.9546]	[0.8289]

Notes: Δi refers to the coefficient $\gamma_{\Delta i}$. For the UK the coeficients of $\Delta\widehat{i}_{t+1}$ and $\Delta\widehat{i}_t$ were not statistically different from zero. For Japan and the USA, imposing $\gamma_{\Delta i}\left(\Delta\widehat{i}_t - \gamma_b\Delta\widehat{i}_{t-1} - \gamma_f E_t\Delta\widehat{i}_{t+1}\right)$ is too restrictive. Therefore, for those countries we estimate the model with free parameters: $\gamma_{\Delta i,c}\Delta\widehat{i}_t + \gamma_{\Delta i,b}\Delta\widehat{i}_{t-1} + \gamma_{\Delta i,f}E_t\Delta\widehat{i}_{t+1}$. Additionally, for Japan and the USA the lead and the lag of the change in the interest rate were not statistically significant, respectively. For the interpretation of the coefficients π_m please see note to Table (8). Instruments: four lags of inflation, labour income share, interest rate, imports inflation, change in the interest rate and output gap. Exceptions: for France lags $t-2$ to $t-4$ of the interest rate's change are not used, and for Japan and UK four lags of the relative price of commodities are additionally used. See notes to Table 2.

goods in advance. In our sample, without considering import prices, there is some evidence in favour of the first concept of cost channel in both domestic and CPI inflation. That evidence becomes weaker when import prices are added to the Phillips curve. However, there is strong evidence that the cost channel is present in imported consumption goods.

Estimations also indicate that open economy variables play an important role in explaining inflation dynamics, both for domestic and CPI inflations. For some countries those variables are significant, while labour income share is not. In addition, introducing the price of imports leads to two interesting conclusions. Firstly, the empirical success of the NKPC with slow exchange rate pass-through is larger than with immediate pass-through. Secondly, the model of McCallum and Nelson (2001), where imports are solely considered as inputs in production, is rejected by the data in favour of a model with imports as both consumption goods and inputs.

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