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Globalisation, import prices and inflation dynamics
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Abstract

In this paper we model the role of open-economy effects within a New Keynesian Phillips Curve (NKPC) via the inclusion of intermediate imports in firms' production technology. Using this framework we provide evidence on two questions: first, does the inclusion of import prices help explain post-war inflation dynamics in the United Kingdom, United States and Japan; and second, has the influence of import prices in firms' costs become greater over the more recent period since the mid-1980s. Overall, our results suggest that import prices do help explain movements in inflation; in particular, NKPC models that allow for import prices to enter into firms' costs outperform closed-economy models in sample. However, our results suggest that the influence of import prices has generally remained constant across our sample period, with perhaps only the United Kingdom providing some evidence that import prices have become more important in firms' marginal costs.

Key words: Globalisation, inflation dynamics, import prices, New Keynesian Phillips Curves.

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Summary

The past two decades saw a marked fall in inflation across the globe, also associated with a rise in stability more generally. This stability is currently less obvious, as the major economies are experiencing a set of shocks that may mean that this benign period will eventually be judged to be one of only temporary respite from a more normal level of macroeconomic volatility. Whether this is the case or not, there may be important lessons to be learned from recent experience, and this paper examines the role that globalisation, and in particular rising imports and competition from low-cost countries, may have played in exerting downward pressure on global prices over that period of stability (specifically, we examine the periods from 1965 and 1985 until early 2007).

While theory tells us that the level of inflation is ultimately determined by monetary policy and its effectiveness in anchoring long-term inflation expectations, globalisation has certainly engendered a marked decline in the relative price of imported to domestically produced goods. In the short run, this may also have had an impact on inflation by lowering production costs, if firms were able to substitute between domestic and imported inputs to production. Stronger competitive pressures may also have had an impact on dampening inflation by making it harder for firms to raise their prices in the face of increased cost pressures. Explaining the dynamics of inflation in the light of increased global integration is thus high up on the agenda of policymakers.

Several recent papers have sought directly to analyse the impact of an increase in import openness or competitive pressures on inflation in an empirical framework by employing a 'reduced-form' approach, which conflates separate, fundamental, relationships into a single empirical vehicle. This approach has two main drawbacks. First, it is difficult to link back the finding of lower relative prices in more-open sectors to aggregate inflation. Second, the estimates cannot tell us which underlying economic mechanisms are driving the relationship between globalisation and inflation. Consequently, in this paper a structural model of inflation dynamics – a New Keynesian Phillips Curve (NKPC) – is employed which allows us better to examine the impact of globalisation on inflation. The role of globalisation is modelled via the inclusion of intermediate imports in firms' production functions, and the results compared to those from a simpler closed-economy version of the model. This framework provides evidence on two questions. First, does the inclusion of import prices in firms' marginal costs (the cost of

producing an extra unit of output) provide a relatively better in-sample fit of post-war inflation dynamics in the United Kingdom, United States and Japan than a model where marginal costs reflect labour costs alone? Second, is the weight on import prices in marginal costs now larger than it was prior to the most recent period of globalisation that has been evident since the mid-1980s?

Overall, the results suggest that import prices do help explain movements in inflation. In particular, NKPC models that allow for import prices to enter into firms' costs outperform closed-economy models in sample. However, they also suggest that the influence of import prices has generally remained constant across the whole sample period, with perhaps only the United Kingdom providing some evidence that import prices have become more important in firms' marginal costs.

1 Introduction

Prior to the recent rises in energy and commodity prices, the past two decades saw a marked fall in inflation across the globe. In advanced economies, inflation, on average, declined from almost 13% in 1981 to 6% in 1990 and further to below 2% on an annualised basis between 1996 and 2007. One explanation for these benign developments is that monetary policy frameworks have been improved in many countries. But in recent years, the debate turned to the role that globalisation, and in particular rising imports and competition from low-cost countries played in exerting downward pressure on global prices. For instance, *The Economist* argued that 'Several structural factors, such as the IT revolution, deregulation and competition from cheaper Chinese goods, have helped to hold down traditional inflation [. . .] in rich economies', (3 February 2005).

While theory tells us that the steady-state level of inflation is ultimately determined by monetary policy and its effectiveness in anchoring long-term inflation expectations, globalisation has certainly engendered a marked decline in the relative price of imported to domestically produced goods. In the short run, this may also have had an impact on inflation by lowering production cost, if firms were able to substitute between domestic and imported inputs to production. Stronger competitive pressures may also have had an impact on dampening inflation by making it harder for firms to raise their prices in the face of increased cost pressures. Explaining the dynamics of inflation in the light of increased global integration is thus high up on the agenda of policymakers.

Several recent papers have sought to directly analyse the impact of an increase in import openness or competitive pressures on inflation in an empirical framework, by employing reduced-form equations and/or industry-level data (Gamber and Hung (2001); Kamin *et al* (2004); Pain *et al* (2006); and Chen *et al* (2007)). These approaches have two main drawbacks. First, it is difficult to link back the finding of lower relative prices in more-open sectors to aggregate inflation (eg Ball (2006) sharply criticises this approach). Second, a shortcoming of using reduced-form equations to estimate the impact of globalisation on domestic inflation is that the estimated coefficients do not inform about the economic channels that are driving the relationships.

Other authors have studied the role of open-economy aspects on inflation dynamics within the structural framework of a New Keynesian Phillips Curve (NKPC) model. For instance, the

model by Balakrishnan and López-Salido (2002) allows firms to substitute between imported inputs and labour in their production processes. The authors find that, for the United Kingdom, developments in inflation can be significantly better explained by movements in real marginal cost which include the impact of intermediate imports. This is because the relative price of imported inputs to wages fell during the disinflationary period since the mid-1970s and the labour share alone cannot account for the fall in inflation. Batini *et al* (2005) also model open-economy aspects for the United Kingdom by taking into account the cost of imported materials in their marginal cost function. In addition, they allow equilibrium mark-ups to vary in response to changes in the external competitive environment. Their findings confirm those of Balakrishnan and López-Salido (2002) in that including open-economy aspects in the pricing decisions of firms improves the fit of NKPC models. They also find some evidence that foreign competitive pressures (measured by the ratio of M6 − that is the G7 excluding the United Kingdom − export prices to the gross value added deflator) affect equilibrium mark-ups of domestic firms and thus inflation.

Leith and Malley (2007) start out from a more complicated two-country open-economy model. In addition to intermediate goods' trade considered by the two papers above, their model allows for trade in final goods. They show that the resulting marginal cost function contains an additional terms of trade term. In contrast to the earlier papers, however, the authors' results suggest that the estimated price-setting behaviour is not significantly affected by changes in terms of trade effects in the G7 economies. An explanation raised for these findings is that firms price to market, implying that firms' profit margins may absorb changes in open-economy variables. Their results do suggest, however, that the elasticity of substitution between imported goods and labour in production is neither unity (the Cobb Douglas case) nor zero (the Leontief case), suggesting that it may be beneficial to assume a constant elasticity of substitution production function.

Two other important aspects of globalisation have been stressed by the theoretical literature. First, Razin and Binyamini (2007) argue that an increase in both immigration and outsourcing will act to increase productivity and, therefore, reduce real marginal cost. Moreover, both higher migration and outsourcing are likely to dampen the response of real marginal cost to increases in domestic demand since workers will be less willing to bid for higher wages given the greater risk that their jobs might be replaced by lower-wage foreign workers at home or abroad. Second, Sbordone (2007) suggests that globalisation might lead to an increase in the variety of goods

traded which, in turn, can affect the degree of real rigidity. More specifically, it increases the sensitivity of demand for a firm's output to movements in its relative price, it reduces the sensitivity of a firm's desired price to marginal cost, and it reduces the sensitivity of a firm's marginal cost to movements in its output. Sbordone notes that the net effect of these channels on the slope of the NKPC is theoretically ambiguous.

Our aim in this paper is to add to the debate about the role of global factors on inflation dynamics within a structural NKPC framework, thus building on the aforementioned papers, but comparing our results for the relatively open economy of the United Kingdom to the relatively closed economies of the United States and Japan. We model the role of open-economy aspects via the inclusion of intermediate imports in firms' production functions and compare the results to a simpler, closed-economy version of the model. In essence, we aim to answer two interlinked questions. First, does the inclusion of import prices in firms' marginal costs provide a relatively better in-sample fit of post-war inflation dynamics in the United Kingdom, United States and Japan than a model where marginal costs reflect labour costs alone; and second, is the weight on import prices in marginal costs now larger than it was prior to the most recent period of globalisation that has been evident since the mid-1980s?

The paper is structured as follows. In the next section we set out our small open-economy NKPC model and explain the mechanisms through which globalisation might impact on inflation dynamics. Next, we discuss our econometric methodology which follows the recent paper by Kurmann (2007). This methodology can be viewed as an improvement to the usual technique of general method of moments used in much of the extant literature. After briefly covering the data we use, we then report and discuss our results. In short, our estimates suggest that import prices do help explain movements in inflation; in particular, NKPC models that allow for import prices to enter into firms' costs outperform closed-economy models in sample. However, our results suggest that the influence of import prices has generally remained constant across our sample period, with perhaps only the United Kingdom providing some evidence that import prices have become more important in firms' marginal costs. The final section concludes and offers some suggestions for future work.

2 A small open-economy NKPC model

An increasing literature models inflation dynamics within a NKPC framework (see, for example, Galí and Gertler (1999); Balakrishnan and López-Salido (2002); and Kurmann (2007)). The advantages of such a structural framework are its micro-foundations, arising from the derivation of aggregate inflation via the individual optimisation by firms, thereby avoiding the Lucas critique. In this framework, real marginal cost can have an influence on the dynamics of inflation due to the assumption of price stickiness, leading to a slow adjustment in nominal variables to real shocks.

In the NKPC model, firms are monopolistic competitors who set their prices in order to maximise profits, based on the expected path of future marginal costs. Price stickiness is often introduced using Calvo (1983)'s model of staggered price setting, where only a fraction $(1 - \theta)$ of all firms are allowed to adjust their price level in any given period, while the remaining θ firms keep their price fixed at p_{t-1}. (Alternatively, sluggish price adjustment can be modelled under the assumption that firms face menu costs to changing their price as in Rotemberg (1982).)

The individual optimisation problem of firms can be aggregated to lead to a short-run relationship between inflation and real marginal cost. This yields the following formulation of the NKPC, where both inflation π and real marginal cost rmc are expressed in terms of log deviations from steady-state values

$$\pi_t = \beta E_t \pi_{t+1} + \lambda rmc_t + u_t \qquad (1)$$

where the slope of the NKPC $\lambda = (1 - \beta\theta)(1 - \theta)/\theta$ depends on the frequency of price adjustment θ and on the subjective discount factor β. Hence, inflation is a function of current real marginal cost as well as the discounted value of expected future inflation.

In the general NKPC model given by **(1)**, the exact expression of real marginal costs is not defined; it depends on the choice of the production function. Most commonly the literature assumes a closed-economy production function where value added Y is produced using domestic inputs of capital K (assumed to be fixed in the short run) and labour L. Assuming a Cobb-Douglas production function of the form

$$V_t = K_t^{1-\alpha} L_t^{\alpha} \qquad (2)$$

where α is the elasticity of substitution between capital and labour, we obtain the following expression for real marginal cost (in log deviations from steady-state value)

$$rmc_t = \frac{w}{p}\frac{L}{Y} \equiv s_t \tag{3}$$

which corresponds to the labour share (real unit labour costs).

How can globalisation or open-economy aspects affect inflation in the NKPC framework? The first channel arises by assuming that imported intermediate goods enter the assumed production function as done by Balakrishnan and López-Salido (2002). Increased trade openness of an economy is reflected in increased substitutability between imported production inputs and labour and also in a larger share of intermediate imports in firms' costs.

We thus employ an open-economy production function where each firm k is assumed to be able to use labour, $L_{t,k}$ and intermediate production from abroad, $M_{t,k}$, to produce gross output, $Y_{t,k}$.

$$Y_{t,k} = \left(L_{t,k}^{\frac{\sigma-1}{\sigma}} + M_{t,k}^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \tag{4}$$

where σ is the elasticity of substitution between domestic and foreign goods.

The profit maximisation problem of each firm is as follows

$$\text{Maximise} \sum_{t=0}^{\infty} \beta^t \left(P_{t,k}Y_{t,k} - W_t L_{t,k} - P_{m,t}M_{t,k}\right) \tag{5}$$

$$\text{subject to } Y_{t,k} = \left(L_{t,k}^{\frac{\sigma-1}{\sigma}} + M_{t,k}^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \tag{6}$$

$$\text{and } Y_{t,k} = \left(\frac{P_{t,k}}{P_t}\right)^{-\varepsilon} Y_t \tag{7}$$

Equation (6) implies that

$$\left(\frac{P_{m,t}\mu}{P_t}\right)^{\sigma} = \frac{Y_t}{M_t} \tag{8}$$

where μ is the steady-state mark-up, $\mu = \frac{\varepsilon}{\varepsilon-1}$.

For given prices and wages, real marginal cost is

$$RMC = \frac{\frac{W_t}{P_t}}{\frac{\partial Y_t}{\partial L_t}} = \frac{S_t}{\frac{L_t}{Y_t}\frac{\partial Y_t}{\partial L_t}} \tag{9}$$

where $S_t = \frac{W_t L_t}{P_t Y_t}$ is the labour share.

The denominator can be derived from the production function

$$\frac{L_t}{Y_t}\frac{\partial Y_t}{\partial L_t} = \frac{L_t}{Y_t}\left(\frac{Y_t}{L_t}\right)^{\frac{1}{\sigma}} = \left[1 - \left(\frac{Y_t}{M_t}\right)^{\frac{1-\sigma}{\sigma}}\right] \tag{10}$$

using $L_t = (Y_t^{\frac{\sigma-1}{\sigma}} - M_t^{\frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}}$. Using equation (8), this gives

$$\frac{L_t}{Y_t}\frac{\partial Y_t}{\partial L_t} = \left[1 - (\frac{P_{m,t}}{P_t}\mu)^{(1-\sigma)}\right] \tag{11}$$

and thus

$$RMC = \frac{S_t}{\frac{L_t}{Y_t}\frac{\partial Y_t}{\partial L_t}} = \frac{S_t}{\left[1 - (\frac{P_{m,t}}{P_t}\mu)^{1-\sigma}\right]} \tag{12}$$

This equation can be linearised, yielding a linear approximation of real marginal costs

$$\widehat{rmc} = \hat{s} + \eta\left(\widehat{\frac{P_m}{P}}\right) \tag{13}$$

where

$$\eta = \frac{(\sigma - 1)\left(\left(\frac{P_m}{P}\right)^* \mu\right)^{(1-\sigma)}}{\left[1 - \left(\left(\frac{P_m}{P}\right)^* \mu\right)^{(1-\sigma)}\right]} = \frac{(\sigma - 1)\left(\left(\frac{M}{Y}\right)^* \left(\frac{P_m}{P}\right)^* \mu\right)}{\left[1 - \left(\frac{M}{Y}\right)^* \left(\frac{P_m}{P}\right)^* \mu\right]} = \frac{(\sigma - 1)\mu s_m}{1 - \mu s_m} = \frac{(\sigma - 1)(1 - \mu s)}{\mu s} \tag{14}$$

using $(S_m + S)\mu = 1$, where S_m is the share of imports in revenue. Here $*$ denotes steady-state variables and $\hat{}$ denotes percentage differences from steady states.

In the model derived above, globalisation can only affect the slope of the NKPC through the frequency of price adjustment θ. So how can globalisation affect the level of price stickiness? One channel through which globalisation can have an impact on the level of price stickiness is

through changes in competition. For instance, in a widely cited paper, Rogoff (2003) argues that globalisation enhances competition which, in turn, makes prices more flexible. However, Khan (2004) shows that the theoretical predictions regarding the impact of competition on price stickiness are ambiguous and depend on the nature of the price-setting assumptions. Under the assumption of Rotemberg price-setting behaviour, tougher competition may make wages and prices more flexible as firms adjust their prices more often. This would lead to a steepening in the slope of the NKPC, thus amplifying short-run inflationary pressures. On the other hand, under Calvo price-setting behaviour increased competition may make firms less willing to raise their price relative to that of competitors in the face of rising marginal costs, since this would lead to a loss in market share. The result is a flattening in the NKPC, thus dampening inflationary pressures in the face of short-run deviations of real marginal costs from their steady state. Khan (2004)'s result thus suggests that the impact of the competition channel of globalisation in affecting inflation is ultimately an empirical question.

3   Econometric methodology

To estimate our small open-economy NKPC we employ a vector autoregression based methodology that exploits the cross-equation restrictions that the theory imposes on the coefficients of the vector autoregression (VAR) under rational expectations. Following Sargent (1979), the conventional approach is to express the coefficients of the VAR equation for inflation as a function of the structural parameters β and λ and the coefficients of the VAR equation for real marginal cost (see, for example, Fuhrer and Moore (1995); and Jondeau and Le Bihan (2001)). Intuitively, these cross-equation restrictions arise because the VAR-based predictions of inflation and real marginal cost must be consistent with the dynamic relationship between the two variables as predicted by the NKPC. However, multiple rational expectations solutions for inflation satisfy these cross-equation restrictions, with the number of solutions rapidly increasing in the dimension of the VAR. To get round this problem the conventional approach restricts the estimation to yield a unique stable rational expectations equilibrium. However, this uniqueness condition can lead to severe misspecification bias when, as is likely, multiple stable rational expectations equilibria exist.

Kurmann (2007) proposes a simple fix to this problem. Instead of expressing the coefficients of the VAR equation for *inflation* as a function of the other parameters of the model, he shows that the mapping from the coefficients of the VAR equation for *real marginal cost* to the structural

parameters β and λ and the coefficients of the inflation equation is unique and therefore circumvents the multiplicity of solutions problem of the conventional approach. Following Kurmann (2007), the econometric methodology we employ is outlined below.

Consider the general NKPC equation

$$\pi_t = \beta E_t \pi_{t+1} + \lambda rmc_t + u_t$$

and suppose that the dynamics are described by the following VAR process

$$z_t = M_1 z_{t-1} + M_2 z_{t-2} + M_3 z_{t-3} + M_4 z_{t-4} + e_{z,t}$$

where z_t is a vector of information on inflation and real marginal cost available at date t.

This VAR process can be written in companion form as

$$\mathbf{z}_t = \mathbf{M} \mathbf{z}_{t-1} + \mathbf{e}_t$$

where $\mathbf{z}_t = [z_t, z_{t-1}, z_{t-2}, z_{t-3}, z_{t-4}]'$ is the (8×1) vector of information, $\mathbf{e}_t = [e_{z,t}, 0, 0, 0, 0]'$ is the (8×1) vector of rational expectations errors with $E[e_t | \mathbf{z}_{t-1}] = 0$, and $\mathbf{M}$ is the (8×8) companion matrix given by

$$\mathbf{M} = \begin{bmatrix} M_1 & M_2 & M_3 & M_4 \\ I_2 & 0_2 & 0_2 & 0_2 \\ 0_2 & I_2 & 0_2 & 0_2 \\ 0_2 & 0_2 & I_2 & 0_2 \end{bmatrix}$$

The (2×2) blocks $M_i, i = 1, ..., 4$ contain the projection coefficients of z_{t-i} on z_t while I_2 and 0_2 are (2×2) identity and null matrices respectively. Hence $\mathbf{M}$ contains 16 non-trivial coefficients that we can stack in a column vector $m = [m_1, m_2]' = vec([M_1 M_2 M_3 M_4]')$ where $m_j, j = 1, 2$ holds the 8 coefficients of the VAR equation for inflation or real marginal cost.

Under the assumption that the econometrician's information set is a subset of the agents' full information set such that $\mathbf{z}_t \subseteq \mathbf{Z}_t$, and under the assumption that $E[u_t | \mathbf{z}_{t-1}] = 0$, the rational expectations cross-equation restrictions are

$$h_\pi [\mathbf{M} - \beta \mathbf{M}^2] = \lambda h_{rmc} \mathbf{M}$$

(see Kurmann (2007), equation (20)), where h_π and h_{rmc} are (1×8) selection vectors such that $h_\pi = [1 \, 0 \, 0 \dots 0]$ and $h_{rmc} = [0 \, 1 \, 0 \, 0 \dots 0]$.

Writing these eight restrictions equation by equation we obtain

$$m_{rmc,rmc,1} = (\beta m_{\pi,rmc,1} + \lambda)^{-1} \cdot (m_{\pi,rmc,1} \cdot (1 - \beta m_{\pi\pi,1}) - \beta m_{\pi,rmc,2})$$

$$m_{rmc,\pi,1} = (\beta m_{\pi,rmc,1} + \lambda)^{-1} \cdot (m_{\pi\pi,1} \cdot (1 - \beta m_{\pi\pi,1}) - \beta m_{\pi\pi,2})$$

$$m_{rmc,rmc,2} = (\beta m_{\pi,rmc,1} + \lambda)^{-1} \cdot (m_{\pi,rmc,2} \cdot (1 - \beta m_{\pi\pi,1}) - \beta m_{\pi,rmc,3})$$

$$m_{rmc,\pi,2} = (\beta m_{\pi,rmc,1} + \lambda)^{-1} \cdot (m_{\pi\pi,2} \cdot (1 - \beta m_{\pi\pi,1}) - \beta m_{\pi\pi,3})$$

$$m_{rmc,rmc,3} = (\beta m_{\pi,rmc,1} + \lambda)^{-1} \cdot (m_{\pi,rmc,3} \cdot (1 - \beta m_{\pi\pi,1}) - \beta m_{\pi,rmc,4})$$

$$m_{rmc,\pi,3} = (\beta m_{\pi,rmc,1} + \lambda)^{-1} \cdot (m_{\pi\pi,3} \cdot (1 - \beta m_{\pi\pi,1}) - \beta m_{\pi\pi,4})$$

$$m_{rmc,rmc,4} = (\beta m_{\pi,rmc,1} + \lambda)^{-1} \cdot (m_{\pi,rmc,4} \cdot (1 - \beta m_{\pi\pi,1}))$$

$$m_{rmc,\pi,4} = (\beta m_{\pi,rmc,1} + \lambda)^{-1} \cdot (m_{\pi\pi,4} \cdot (1 - \beta m_{\pi\pi,1}))$$

To obtain the parameters of the NKPC, we use maximum likelihood estimation which corresponds to minimising the weighted sum of squared error terms from the VAR subject to the model-consistent cross-equations restrictions given above.

4 Empirical results

This section presents our results structured around our two key questions. First, does the inclusion of import prices in firms' marginal costs provide a relatively better in-sample fit of post-war inflation dynamics in the United Kingdom, United States and Japan than a model where marginal costs reflect labour costs alone; and second, is the weight on import prices in marginal costs now larger than it was prior to the most recent period of globalisation that has been evident since the mid-1980s? All the estimates presented in this section are obtained using maximum likelihood together with the simulated annealing algorithm by Goffe (1996).

4.1 Data

Data definitions and sources are as follows. Inflation is the annualised change in the gross output deflator (ie the deflator for gross domestic product plus imports of goods and services). This

measure is chosen as it is consistent with the price level derived from our theoretical model which is based on gross output. The labour share (real unit labour costs) is the ratio of total compensation to nominal gross output. Note that we do not attempt to adjust this measure to include the self-employed or exclude the public sector as in Batini *et al* (2005) as this data is unavailable for Japan. Finally, the relative price of imports is the ratio of the imports of goods and services deflator to the gross output deflator. All variables are quarterly, in natural logs, and to generate deviations from steady state all variables are linearly detrended (and demeaned). Our sample period is from 1965 Q2 to 2007 Q1. Data are downloaded from Thomson Datastream. The exact data definitions and series codes are given in the appendix.

4.2 Do import prices help explain movements in inflation?

We begin by examining whether over the full sample import prices can help explain movements in inflation. In essence, this is equivalent to comparing whether the in-sample fit on inflation is improved once we include import prices in firms' marginal costs while ensuring that (a) the structural parameters estimated in the open-economy model are consistent with theoretical priors; and (b) the data supports the model in the sense that the model-consistent cross-equation restrictions are not rejected statistically. Note that the difference between the two models under consideration relates to the weight on real import prices in real marginal costs. In the closed-economy model $\phi = 0$ and thus real marginal costs correspond to the labour share (real unit labour costs) only ie $rmc_t = s_t$. In the open-economy model we calibrate the weight on real import prices by assuming that $\sigma = 1.3$, $\mu = 1.2$ and $\bar{s}$ equals the sample average labour share (ie $\bar{s} = T^{-1}\Sigma_{i=1}^{T}s_i$). This is the benchmark model in Balakrishnan and López-Salido (2002).

Table A (overleaf) reports the maximum likelihood estimates for both the closed and open-economy NKPC model for the United Kingdom, United States and Japan together with a number of metrics of model fit. These are the correlation coefficient between actual and fitted inflation from the estimated NKPC, R^2; the log likelihood of the restricted VAR, $\log L$; and two likelihood ratio tests: the first, LR_1, is a test of the cross-equation restrictions imposed by the theory and thus is based upon the ratio of $\log L$ to the log likelihood of the unrestricted VAR; the second likelihood ratio test, LR_2, tests the null hypothesis that $\phi = 0$ and thus that the closed-economy model is a valid restriction on the general open-economy model. Standard errors are reported in round brackets under the estimate for θ and the slope of the NKPC λ. Note that the reported standard error for the slope is calculated directly from the estimated standard

Table A: NKPC estimates: 1965 Q2 - 2007 Q1

	Structural parameters			Slope	Model fit			
	β	θ	ϕ	λ	R^2	$\log L$	LR_1	LR_2
UK	0.990	0.683		0.150	0.774	308.8	13.372	
		(0.044)		(0.047)			[0.100]	
	0.990	0.713	0.138	0.119	0.800	317.7	9.678	16.461
		(0.043)		(0.037)			[0.288]	[0.000]
US	0.990	0.755		0.082	0.888	506.8	5.058	
		(0.052)		(0.034)			[0.751]	
	0.990	0.790	0.133	0.058	0.900	515.8	9.940	17.084
		(0.029)		(0.016)			[0.296]	[0.000]
Japan	0.990	0.836		0.034	0.779	341.4	7.960	
		(0.042)		(0.015)			[0.437]	
	0.990	0.834	0.184	0.035	0.785	343.3	7.189	3.555
		(0.033)		(0.013)			[0.516]	[0.060]

error around θ. Similarly, p-values for the likelihood ratio tests are reported in square brackets under LR_1 and LR_2. Finally, following convention we calibrate the discount factor β to 0.99 (this corresponds to a discount rate of around 4% per annum), and constrain the remaining structural parameter to be estimated (θ) to lie between zero and one in line with its theoretical bound. The calibration of the weight on real import prices ϕ is discussed above.

Starting with the closed-economy models (where $\phi = 0$), the likelihood ratio test suggests that our estimated NKPC models cannot be rejected at conventional significance levels with p-values of 10% or more. Moreover, in each country the slope of the NKPC is significantly different from zero and enters with the correct sign. Since we calibrate the discount factor β, our estimate of the slope of the NKPC λ stems from the estimated degree of price rigidity θ. Specifically, the frequency of price adjustment is estimated to be $(1 - \widehat{\theta}) = 0.317$ for the United Kingdom, 0.245 for the United States and 0.164 for Japan. This implies an average price duration of $(1 - \widehat{\theta})^{-1} = 3.15$ quarters for the United Kingdom, 4.07 quarters for the United States and 6.10 quarters for Japan. The results for the United Kingdom and United States lie within the range

reported by micro studies which find that firms change their prices on average every 2.5 to 4 quarters (see Taylor (1998); Wolman (2000); or Blis and Klenow (2004)). Moreover, the results for the United Kingdom and the United States are close to previous estimates in the empirical literature. For instance, Galì and Gertler (1999) estimate that the average price duration in the United States is around 5 quarters. And although the results for Japan look a little high, Sbordone (2002) and Woodford (2003) show that the same frequency of price adjustment can imply a significantly lower degree of average price adjustment under alternative production technologies.

Turning next to the open-economy models (where $\phi > 0$), we see that qualitatively the results are very similar to those for the closed-economy models. In other words, the models cannot be rejected statistically (*p*-values are around 30% or more), suggest statistically significant and positive NKPC slopes, and generate estimates of price stickiness that are in line with microeconomic evidence. More importantly for our purposes, however, is that in terms of model fit the open-economy models are found to perform relatively better than their closed-economy counterparts. For instance, the log likelihoods are estimated to be larger in the open-economy model, particularly in the United Kingdom and the United States. Moreover, the likelihood ratio test for the restriction $\phi = 0$ is rejected in all cases at conventional significance levels with *p*-values of less than 1% for the United Kingdom and the United States, and a *p*-value of 6% for Japan. Overall, our estimates suggests that import prices do help explain movements in inflation, and that, in-sample, NKPC models that allow for import prices to enter into firms' costs outperform closed-economy models.

4.3 Has the influence of import prices become greater recently?

We now turn to our second question of interest on whether the influence of import prices become greater more recently. In order to speak to this question we re-estimate our closed and open-economy NKPC models over the shorter sample period from 1985 Q1 to 2007 Q1. We have chosen this start date as it seems that this is when the pace of globalisation (as measured by the import share of gross output) began to accelerate.

Before we discuss the results it should be noted that since our estimate of the steady-state labour share $\bar{s}$ is given by the sample average, our calibrated weight on import prices in firms' marginal costs changes. Comparing the weight on import prices across the two sample periods we find

that there are cross-country differences in the direction and magnitude of the change in weight. Specifically, the weight on import prices increases in the United Kingdom, decreases in Japan, and broadly remains constant in the United States. Our model, therefore, suggests that other things equal, the influence of import prices in firms costs has only become greater in the United Kingdom. Of course, it may be that increased foreign competition has rendered the equilibrium mark-up lower, or that firms are more willing to substitute domestic value added for imported goods. If so, then the weight on import prices in firms' costs may well be higher.

The influence of import prices will also be greater if the relationship between inflation and real marginal costs is stronger; in other words, if the slope of the NKPC λ is steeper. In our model that is equivalent to finding that the frequency of price adjustment θ is lower. Table B (overleaf) reports the maximum likelihood estimates for both the closed and open-economy NKPC models over the shorter sample period. Comparing the estimates of the slope coefficients for the open-economy models with those for the corresponding models over the full sample we see that, overall, there appears to be little evidence that the slope of the structural NKPC has changed. For both the United Kingdom and the United States the subsample slope coefficients are within one standard error of their full-sample counterparts. Moreover, although at first blush it appears that the estimate NKPC slope in Japan has steepened markedly, it must be noted that the open-economy model is rejected at the 5% significance level both against the unrestricted VAR model (LR_1) and against the closed-economy alternative (LR_2). Overall, our results suggest that the influence of import prices has generally remained constant across our sample period, with perhaps only the United Kingdom providing some evidence that import prices have become more important in firms' marginal costs.

5 Conclusion

Our aim in this paper was to model the role of open-economy effects within a NKPC via the inclusion of intermediate imports in firms' production technology to answer two questions: first, does the inclusion of import prices help explain post-war inflation dynamics in the United Kingdom, United States and Japan; and second, has the influence of import prices in firms' costs become greater over the more recent period since the mid-1980s. Overall, our results suggest that import prices do help explain movements in inflation; in particular, NKPC models that allow for import prices to enter into firms' costs outperform closed-economy models in sample. However, our results suggest that the influence of import prices has generally remained constant

Table B: NKPC estimates: 1985 Q1 - 2007 Q1

	Structural parameters			Slope	Model fit			
	β	θ	ϕ	λ	R^2	$\log L$	LR_1	LR_2
UK	0.990	0.750 (0.044)		0.086 (0.030)	0.534	206.9	4.984 [0.759]	
	0.990	0.716 (0.052)	0.155	0.115 (0.043)	0.585	210.5	3.666 [0.886]	6.692 [0.010]
US	0.990	0.898 (0.140)		0.013 (0.012)	0.610	293.6	15.685 [0.047]	
	0.990	0.787 (0.064)	0.136	0.060 (0.032)	0.632	297.3	12.725 [0.122]	6.815 [0.009]
Japan	0.990	0.806 (0.094)		0.049 (0.037)	0.349	197.8	24.594 [0.002]	
	0.990	0.650 (0.063)	0.172	0.192 (0.072)	0.355	199.7	15.183 [0.056]	3.423 [0.064]

across our sample period, with perhaps only the United Kingdom providing some evidence that import prices have become more important in firms' marginal costs.

There are a number of potentially fruitful avenues for further work. First, it is possible, though computationally demanding, to estimate the optimal weight on import prices in firms' costs as suggested by the data. By doing this one could provide more evidence on whether import prices have become more important without resorting to calibration. Moreover, by estimating the weight on import prices that would also provide evidence on the extent to which the elasticity of substitution between domestic and foreign goods differs between countries given a particular assumption on the equilibrium mark-up. Second, it might also be interesting to see whether including the terms of trade as suggested in the recent two-country DSGE paper by Leith and Malley (2007) improves the fit of the NKPC.

Appendix

All data are downloaded from Thomson Datastream. The variables are defined as follows with the Datastream codes in sans serif.

United Kingdom

p_t $\qquad = \ln[(\mathsf{UKGDP...B + UKIMNGS.B})/(\mathsf{UKGDP...D + UKIMNGS.D})]_t$

π_t $\qquad = 4 \times (p_t - p_{t-1})$

s_t $\qquad = \ln[\mathsf{UKDTWM..B}/(\mathsf{UKGDP...B + UKIMNGS.B})]_t$

pm_t $\qquad = \ln(\mathsf{UKIMNGS.B/UKIMNGS.D})_t$

United States

p_t $\qquad = \ln[(\mathsf{USGDP...B + USIMNGS.B})/(\mathsf{USGDP...D + USIMNGS.D})]_t$

π_t $\qquad = 4 \times (p_t - p_{t-1})$

s_t $\qquad = \ln[\mathsf{USCOMPRCB..B}/(\mathsf{USGDP...B + USIMNGS.B})]_t$

pm_t $\qquad = \ln(\mathsf{USmIMNGS.B/USIMNGS.D})_t$

Japan

p_t $\qquad = \ln[(\mathsf{JPGDP...B + JPIMNGS.B})/(\mathsf{JPGDP...D + JPIMNGS.D})]_t$

π_t $\qquad = 4 \times (p_t - p_{t-1})$

s_t $\qquad = \ln[\mathsf{JPOCFCEPB}/(\mathsf{JPGDP...B + JPIMNGS.B})]_t$

pm_t $\qquad = \ln(\mathsf{JPIMNGS.B/JPIMNGS.D})_t$

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