The Impact of Trade Integration and Competition on Real and Nominal Price Rigidities: Insights from a New-Keynesian DSGE Model*

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Abstract

The paper examines the impact of trade integration and product market competition on firms' price setting behaviour and the degree of price stickiness. The analysis is based on a New-Keynesian open-economy DSGE model with variable desired mark-ups and Calvo price setting in which the frequency of price adjustment is endogenised. The study demonstrates that trade integration and the resulting changes in competition affect the degree of strategic complementarity in firms' price setting decisions and the frequency with which firms change their prices, which determine the degree of real and nominal price rigidities respectively. The micro-founded macroeconomic model constructed explains the positive relationship between competition and the frequency of price adjustment evident from empirical studies and surveys of firms' price setting behaviour. By accounting for the impact of competition on firms' pricing policies, the study also provides new insights into the effects of global economic integration on the Phillips Curve and inflation dynamics.

JEL classification: F41; E31; E32

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1 Introduction

The substantial increase in trade integration all over the world during the last few decades initiated a heated debate on the impact of globalisation on the sensitivity of inflation to changes in domestic economic activity.[1] As understanding this impact is of crucial importance for the optimal design and conduct of monetary policy, the topic has not only attracted significant academic interest but has also been widely discussed by policy makers (see speeches by Kohn, 2006; Bean, 2006; Bernanke, 2007; Fukui, 2007; Trichet, 2008). One of the key determinants of the short-run inflation-output trade-off is the degree of nominal price rigidities, which depends on the frequency with which firms change their prices. Previous studies analysing the effects of global economic integration on inflation with the use of structural macroeconomic models have assumed that the frequency of price adjustment is constant and have therefore ignored the fact that changes in the openness of the economy and the resulting changes in competition may affect firms' pricing policies. This is an important omission as surveys of firms' price setting behaviour as well as empirical studies based on disaggregated price data provide strong evidence of a positive relationship between the level of competition and the frequency of price changes.[2] This study fills this gap by examining, within a New-Keynesian open-economy model, the impact of trade integration and changes in product market competition on the degree of price stickiness and their implications for inflation dynamics.

The contribution of the paper is two-fold. Firstly, the analysis provides new insights into the determinants of real and nominal price rigidities and, in particular, it explains the positive relationship between competition and the frequency of price adjustment observed in the data. Secondly, by accounting for the impact of competition on firms' price setting behaviour, it sheds new light on the effects of global economic integration on the Phillips Curve and inflation.

For the purpose of the analysis, the study develops a two-country New-Keynesian DSGE model which builds on the open-economy framework with staggered price setting developed by Clarida, Galí, Gertler (2002) and Galí, Monacelli (2005). In order

[1] Empirical research examining this issue includes Roberts (2006), the IMF (2006), Ball (2006), Pain, Koske and Sollie (2006), Mishkin (2007), Borio and Filardo (2007) and Ihrig *et al.* (2007). Among theoretical studies are Woodford (2007), Razin and Binyamini (2007), Sbordone (2007), Zaniboni (2009), Guerrieri, Gust and López-Salido (2009), Davis (2009), Benigno and Faia (2010).

[2] Surveys of the literature on the link between competition and the frequency of price adjustment can be found in Carlton (1989), Asplund and Friberg (1998) and Álvarez *et al.* (2006).

to capture the effects of competition on firms' pricing policies, the suggested model departs from two standard assumptions used in New-Keynesian open-economy general equilibrium models. Firstly, in place of the usual Dixit-Stiglitz consumption aggregator implying constant elasticity of substitution between differentiated goods, the model introduces an extension of the consumption aggregator suggested by Kimball (1995) to an open-economy environment with a variable number of traded goods. The consumption aggregator is characterised by non-constant price elasticity of demand, which generates strategic complementarity in firms' price setting decisions in that a firm's optimal price depends positively on the prices charged by its competitors. It also accounts for the negative impact of trade integration on firms' steady-state mark-ups.[3] Secondly, the frequency of price adjustment is endogenised. Firms set their prices as in Calvo (1983); however, the probability of a price change in a given period is not exogenous, as is usually assumed, but is subject to firms' optimising decisions.[4]

In the framework developed, the level of competition is defined as the total number of varieties available to domestic consumers. Trade integration, associated with an increase in the number of imported varieties, leads to an increase in the level of competition faced by firms.[5] Changes in competition induce changes in the steady-state price elasticity of demand and desired mark-ups, which affect the degree of strategic complementarity in firms' price setting decisions and firms' incentives to adjust their prices.

In the first part of the analysis, the impact of trade integration and competition on the degree of real rigidities is examined. This relationship has previously been investigated by Sbordone (2007), Guerrieri, Gust and López-Salido (2009) and Benigno

[3] The negative effect of trade openness on mark-ups has been documented by Katics and Petersen (1994), Beccarello (1996), Konings and Vandenbussche (2005) and Chen, Imbs and Scott (2009). See also Tybout (2003) for a comprehensive survey.

[4] A similar approach has been used by Romer (1990) to study the impact of trend inflation, price adjustment costs and the variance of shocks on the optimal frequency of price adjustment as well as by Devereux and Yetman (2002) and Levin and Yun (2007) to examine the effects of steady-state inflation on price flexibility and the inflation-output trade-off.

[5] Empirical evidence suggests that an increase in the number of traded varieties has been an important feature of recent economic integration. Broda and Weinstein (2006) estimate that in the period 1990-2001 the number of imported varieties in the US increased by 42 per cent. According to Galstyan and Lane (2008), in only five years between 2000 and 2004 the number of imported varieties increased by about 9-15 per cent in the US, Germany and Switzerland and by 132 per cent in China. The increase in the number of varieties exported by these countries was of a similar order of magnitude.

and Faia (2010). However, there are a number of differences between these studies and this paper. In both Sbordone (2007) and Guerrieri, Gust and López-Salido (2009) real rigidities are due to households' preferences implying non-constant price elasticity of demand, as is the case in this paper. However, in contrast to this paper, Sbordone's analysis is based on a closed-economy, rather than an open-economy model. Guerrieri, Gust and López-Salido do not allow for the impact of trade integration on firms' steady-state mark-ups and market shares, which this paper takes into account. Benigno and Faia (2010) consider a different source of real rigidity. In their analysis, sluggish real price adjustment is, as in this paper, driven by non-constant price elasticity of demand. However, variable desired mark-ups and the related strategic complementarity in firms' price setting decisions arise not on the demand side of the economy but they result from strategic pricing associated with oligopolistic competition and the fact that when setting their prices, firms take into account the impact of their prices on the aggregate price index. Another distinguishing feature of this paper is that it uses a general equilibrium approach, whereas all of the above mentioned studies are based on a partial equilibrium analysis.

The second part of the paper analyses the impact of competition on the frequency of price adjustment. Despite the central role that nominal price rigidities play in macroeconomic theory, their determinants are not very well understood. Macroeconomic literature is predominantly concerned with the question of why prices are sticky and the implications of sluggish price adjustment for monetary policy and the transmission of shocks rather than with factors affecting the speed of price adjustment. Existing studies investigating the determinants of the frequency of price adjustment focus on the role of trend inflation, the size of the price adjustment costs and the variance of shocks (e.g. Romer, 1990; Dotsey, King and Wolman, 1999; Kiley, 2000; Devereux and Yetman, 2002; Levin and Yun, 2007). At the same time, there is substantial empirical evidence that the frequency with which firms change their prices depends on the degree of competition. Recent surveys of firms' pricing policies conducted in a number of countries indicate that companies operating in markets with higher competitive pressure adjust their prices more frequently (Druant *et al.,* 2009; Vermeulen *et al.,* 2007; Álvarez and Hernando, 2007; Hoeberichts and Stokman, 2006; Álvarez and Hernando, 2005; Fabiani *et al.*, 2005; Aucremanne and Druant, 2005). In a study conducted by the Bank of England, UK firms named an increase in competition as the most important factor behind the increase in the

frequency with which they changed their prices over the last decade (Greenslade and Parker, 2008). The positive link between the degree of competition and the frequency of price adjustment has also been confirmed by empirical studies based on disaggregated price data (Cornille and Dossche, 2006; Álvarez *et al.,* 2006; Lűnnemann and Matha, 2005, Geroski, 1992; Carlton, 1986). Álvarez, Burriel and Hernando (2005) find that the frequency of producer price changes increases with import penetration. Despite the considerable empirical evidence, the theoretical literature investigating the relationship between competition and the speed of price adjustment is scarce and the mechanism underlying it remains unclear.

There are a few industrial organisation studies which analyse the impact of competition on the degree of nominal price rigidities in an oligopolistic environment and provide conflicting results concerning the direction of this relationship.[6] The influence of competition on the frequency of price adjustment under the assumption of monopolistic competition, which prevails in macroeconomic models, has hardly been examined. Some insights into the effects of competition on nominal rigidities in a monopolistically competitive environment can be gained from analysing the link between the price elasticity of demand and the frequency of price adjustment. Martin (1993) conducts such an analysis within a simple static setting, while Dotsey, King and Wolman (1999) use a dynamic general equilibrium model with state-dependent pricing. However, while a change in the price elasticity of demand can be an important consequence of the entry of new firms into a market and the associated increase in competition, it is not its only implication. Changes in the number of traded varieties also affect firms' market shares, the degree of strategic complementarity in price setting decisions and the variability of desired prices, all of which influence firms' incentives to adjust their prices. In contrast to previous studies, this paper analyses the effects of competition on the frequency of price changes in a dynamic stochastic general equillibrium model with real rigidities and a variable number of traded varieties which takes these effects into account.

By accounting for the influence of competition on real and nominal price rigidities, the study not only furthers the understanding of the determinants of the speed of price adjustment but also provides new insights into the impact of trade integration on the slope of the Phillips Curve and inflation dynamics. The slope of the Phillips Curve, which is the elasticity of inflation with regard to changes in domestic economic

[6] See Ginsburgh and Michel (1988) for a brief review.

activity, depends on three factors: the degree of real and nominal price rigidities, which determine the sensitivity of inflation to changes in real marginal cost, and the elasticity of marginal cost with respect to the output gap. Previous studies analysing the effects of globalisation on inflation with the use of structural models focus either on the impact of globalisation on the sensitivity of marginal cost to the output gap (e.g. Zaniboni, 2009; Davis, 2009, Razin and Binyamini, 2007; Woodford, 2007) or on its effects on real price rigidities (Sbordone, 2007; Guerrieri, Gust and López-Salido, 2009; Benigno and Faia, 2010). This study is the first to explore the influence of trade integration and the resulting increase in competition on the frequency with which firms change their prices.

The analysis demonstrates that an increase in competition associated with changes in the number of varieties available in the domestic market leads to an increase in the degree of strategic complementarity in firms' price setting decisions and therefore an increase in the extent of real rigidities. Furthermore, greater competitive pressures raise the opportunity cost of not adjusting prices and lead to more frequent price adjustment and a reduction in the degree of nominal rigidities. The study shows that changes in firms' pricing policies resulting from changes in competition affect the short-run trade-off between output and inflation and the response of inflation to shocks.

The remainder of the paper is organised as follows. The second section sets out the baseline version of the model developed for the purpose of this analysis, in which the frequency of price adjustment is assumed to be exogenous. Section three discusses the calibration of the model parameters. Section four analyses the impact of competition on the degree of real rigidities and the Phillips Curve. In section five, the baseline model is extended by endogenising the frequency of price adjustment. The impact of competition and other structural features of the economy on the optimal frequency of price adjustment is then analysed and the overall effect of changes in competition on inflation is discussed. The final section concludes.

2 Model

The analysis is based on a symmetric two-country DSGE model. Each country is populated by utility-maximising households and profit-maximising firms, owned by households, which produce differentiated goods and sell them in monopolistically

competitive markets. There are two types of firms – exporters, which sell their goods in both the domestic and foreign economy and non-exporters, which operate only in the domestic market. Firms set their prices using pricing-to-market, as in Betts and Devereux (1996), and Calvo contracts, as in Calvo (1983). In the baseline version of the model it is assumed that the probability of price adjustment in a given period is exogenous. Households consume all varieties which are sold in the domestic market. Their consumption aggregator is characterised by non-constant price elasticity of demand, which gives rise to strategic complementarity in firms' price setting decisions – a firm's optimal relative price depends not only on its marginal cost but is also positively related to the prices charged by its competitors. Monetary policy is conducted by a central bank which sets the nominal interest rate following a Taylor rule. Business cycles are driven by productivity, preference and monetary policy shocks.

2.1 Firms

The world economy consists of two countries, Home and Foreign. In each country, there is a continuum of firms indexed by $i \in [0, 1]$. All firms operating in the Home economy produce differentiated final consumption goods and sell them in an environment of monopolistic competitition. They use a production technology with constant returns to scale in which domestic labour is the only factor of production:

$$Y_{i,t} = A_t L_{i,t} e^{a_t} \tag{1}$$

where $Y_{i,t}$ is the output produced by firm i at time t and $L_{i,t}$ is the labour input used in the production of that good. A_t denotes total factor productivity which is subject to shocks a_t following an autoregressive process with $a_t = \rho_a a_{t-1} + \xi_t^a$ and $\xi_t^a \sim N(0, \sigma_a^2)$.

In the Home and in the Foreign economy, a fraction of firms, equal to N and N^* respectively[7], sell their goods both in the domestic market and abroad, whereas the remaining firms sell their goods only in the domestic market. All firms set their prices in the currency of the country in which their goods are sold.

Non-exporting firms in the Home economy, located in the interval $[N, 1]$, set their prices to maximise their expected discounted profits subject to the demand function, the production technology and the Calvo contracts. When they receive a signal to

[7] In the description of the model, foreign variables are denoted by an asterisk.

update their prices at time t, they choose the price of their product in the domestic market, $P_{H,i,t}$, that maximises:

$$\sum_{k=0}^{\infty} E_t \left(\alpha^k Q_{t,t+k} C_{H,i,t+k} (P_{H,i,t} - MC_{i,t+k}) \right) \tag{2}$$

where $C_{H,i,t}$ is the Home demand for the good produced by firm i at time t, $MC_{i,t}$ denotes the firm's nominal marginal cost at time t, $Q_{t,t+1}$ is the stochastic discount factor and $\alpha \in (0,1)$ denotes the fraction of firms that do not adjust their prices in a given period.

Exporting firms in the Home economy, located in the interval $[0, N]$, also maximise their expected discounted profits subject to similar constraints. However, they set two different prices – one for the Home market, $P_{H,i,t}$, and one for the Foreign market, $P^*_{F,i,t}$, so that they maximise:

$$\sum_{k=0}^{\infty} E_t \left(\alpha^k Q_{t,t+k} \left[C_{H,i,t+k} (P_{H,i,t} - MC_{i,t+k}) + C^*_{F,i,t+k} (S_{t+k} P^*_{F,i,t} - MC_{i,t+k}) \right] \right) \tag{3}$$

where $C^*_{F,i,t}$ denotes the Foreign demand for the good produced by firm i at time t; S_t is the nominal exchange rate at time t, defined as the price of one unit of Foreign currency in terms of Home currency. The price $P_{H,i,t}$ is expressed in the Home currency, whereas $P^*_{F,i,t}$ is expressed in the currency of the Foreign economy.

The assumption that exporters are engaging in international price discrimination is consistent with the findings from substantial empirical literature on pricing-to-market which shows that the same goods are priced with different mark-ups across importing markets (see Goldberg and Knetter, 1997, for an extensive review).

2.2 Households

Each country is populated by a continuum of identical, infinitely-lived households located in the interval $[0, 1]$. A representative household has a utility function which is addively separable in consumption, C_t, and labour, L_t, and given by:

$$E_t \sum_{k=0}^{\infty} \beta^k \left[\frac{C_{t+k}^{1-\sigma}}{1-\sigma} e^{u_t} - \frac{L_{t+k}^{1+\varphi}}{1+\varphi} \right] \tag{4}$$

where $\beta \in (0,1)$ is the intertemporal discount factor, u_t denotes a shock to the

marginal utility of consumption such that $u_t = \rho_u u_{t-1} + \xi_t^u$ and $\xi_t^u \sim N(0, \sigma_u^2)$.

Households maximise their expected discounted lifetime utility subject to a sequence of budget constraints:

$$P_t C_t + E_t \left\{ Q_{t,t+1} D_{t+1} \right\} = W_t L_t + D_t + T_t \tag{5}$$

where D_{t+1} is the nominal payoff in period $t+1$ of the portfolio held at the end of period t, W_t denotes nominal wage and T_t is a lump sum of transfers and taxes. It is assumed that in both countries, households have unrestricted access to a complete set of contingent claims, traded internationally.

2.3 Demand aggregator

Households in the Home economy consume all domestically produced differentiated goods and all Foreign varieties available in the domestic market. Their consumption aggregator, C_t, is implicitly defined by the condition:

$$\int_0^1 f\left(\frac{C_{H,i,t}}{C_t}\right) di + \int_1^{(1+N^*)} f\left(\frac{C_{F,i,t}}{C_t}\right) di = 1 \tag{6}$$

where $f(\frac{C_{X,i,t}}{C_t})$ is an increasing, strictly concave function and $X = \{H, F\}$. The consumption aggregator adopted in the analysis extends the aggregators suggested by Kimball (1995) and Sbordone (2007) to an open-economy environment with a variable number of traded goods.

The parameter $N^* \in (0,1)$ is the fraction of Foreign goods which are exported to the Home economy and it determines the degree of trade integration. The total number of varieties available for sale in the Home market is equal to $(1+N^*)$ and it is a measure of the level of competition in the economy.

The functional form of $f(\frac{C_{X,i,t}}{C_t})$ used in the analysis is given by:

$$f\left(\frac{C_{X,i,t}}{C_t}\right) = \frac{1}{(1+\eta)\gamma}\left[(1+\eta)\frac{C_{X,i,t}}{C_t} - \eta\right]^{\gamma} - \frac{1}{1+N^*}\left[\frac{1}{(1+\eta)\gamma} - 1\right] \tag{7}$$

where the parameters η and γ determine the shape of the demand function.

The demand aggregator defined in this way departs from the standard assumption of constant price-elasticity of demand and introduces strategic complementarity in

firms' price setting decisions which generates variable desired mark-ups. It is shown in Appendix 1.1 that the demand function associated with the consumption aggregator can be written as:

$$\frac{C_{X,i,t}}{C_t} = \frac{1}{1+\eta}\left(\frac{P_{X,i,t}}{\widetilde{P}_t}\right)^{\frac{1}{\gamma-1}} + \frac{\eta}{1+\eta} \tag{8}$$

where $\frac{C_{Xi,t}}{C_t}$ is a firm's market share and $\widetilde{P}_t$ is an aggregate price index[8] which is given by:

$$\widetilde{P}_t = \left[\int_0^1 (P_{H,i,t})^{\frac{\gamma}{\gamma-1}} di + \int_1^{1+N^*} (P_{F,i,t})^{\frac{\gamma}{\gamma-1}} di\right]^{\frac{\gamma-1}{\gamma}} \tag{9}$$

Its derivation is shown in Appendix 2.1.

In the framework adopted, the price elasticity of demand, $\theta_{X,i,t}$, is not constant, as is usually assumed, but is a function of a firm's relative price and its market share:

$$\theta_{X,t}\left(\frac{C_{X,i,t}}{C_t}\right) = -\frac{f'(\frac{C_{X,i,t}}{C_t})}{\frac{C_{X,i,t}}{C_t} f''(\frac{C_{X,i,t}}{C_t})} = -\frac{1}{\gamma-1}\frac{(\frac{P_{X,i,t}}{\widetilde{P}_t})^{\frac{1}{\gamma-1}}}{(\frac{P_{X,i,t}}{\widetilde{P}_t})^{\frac{1}{\gamma-1}} + \eta} \tag{10}$$

In consequence, a firm's desired mark-up, $\mu_{X,t}$, is also a function of the firm's relative price[9]:

$$\mu_{X,t}\left(\frac{C_{X,i,t}}{C_t}\right) = \frac{\theta_t(\frac{C_{X,i,t}}{C_t})}{\theta_t(\frac{C_{X,i,t}}{C_t}) - 1} = \frac{1}{\gamma + \eta(\gamma-1)(\frac{P_{X,i,t}}{\widetilde{P}_t})^{\frac{1}{1-\gamma}}} \tag{11}$$

In an equilibrium with symmetric prices, firms' market share is a function of the number of variaties traded in the economy, given by:

$$\frac{C_{X,i}}{C} = f^{-1}\left(\frac{1}{1+N^*}\right) = \frac{1}{1+\eta}\left[\left(\frac{1}{1+N^*}\right)^{\frac{1}{\gamma}} + \eta\right] \tag{12}$$

As a result, the steady-state price elasticity of demand, θ, and mark-up, μ, are also determined by the number of varieties traded and therefore the level of competition

[8] This competition-based aggregate price index differs from the utility-based price index, P_t, defined as the cost of a unit of the composite good, C_t, but is also a homogenous function of degree one.

[9] Surveys conducted among firms in the Euro Area and in the UK indicate that pricing strategies based on variable mark-ups are widespread (Fabiani *et al.*, 2005; Greenslade and Parker, 2008).

in the economy:

$$\theta = -\frac{1}{(\gamma - 1)} \frac{1}{1 + \eta(1 + N^*)^{\frac{1}{\gamma}}} \tag{13}$$

$$\mu = \frac{1}{1 + (\gamma - 1)[1 + \eta(1 + N^*)^{\frac{1}{\gamma}}]} \tag{14}$$

The positive relationship between the number of varieties sold in a market and the steady-state price elasticity of demand, which is incorporated into the model through the specification of households' preferences, is in line with the theory developed by Lancaster (1979) according to which firms' entry causes 'crowding' of the varieties space. As more firms sell their differentiated products in the market, varieties become more substitutable and their own price elasticity of demand increases. The existence of a positive link between the number of varieties and the price elasticity of demand has been empirically supported by Hummels and Lugovskyy (2008).

The number of traded varieties also affects the curvature of the demand function, denoted by ϵ, which is the steady-state value of the elasticity of the price elasticity of demand with respect to the relative price, also referred to as the superelasticity of demand, and is given by:

$$\epsilon = \frac{1}{(\gamma - 1)} \frac{\eta}{\eta + (1 + N^*)^{-\frac{1}{\gamma}}} \tag{15}$$

The functional form of the demand aggregator adopted in the analysis has the convenient property that in the special case of $\eta = 0$ it is equivalent to a standard CES Dixit-Stiglitz consumption aggregator.

2.4 Monetary policy

As in Taylor (1993), the monetary authority sets the nominal interest rate, i_t, according to a simple rule:

$$\widehat{i}_t = \phi_\pi \widehat{\pi}_t + \phi_y \widehat{x}_t + v_t \tag{16}$$

where $\widehat{\pi}_t$ is the deviation of inflation from its target, $\widehat{x}_t$ is the domestic output gap, defined as the difference between actual and potential output, and v_t is a monetary policy shock such that $v_t = \rho_v v_{t-1} + \xi_t^v$ and $\xi_t^v \sim N(0, \sigma_v^2)$.

Determinacy of the model solution is ensured by choosing policy parameters ϕ_π and ϕ_y such that the Taylor principle is satisfied.

3 Parametrisation

In the benchmark calibration of the model parameters, firms' probability of not receiving a price adjustment signal in a given period, denoted by α, is set to 0.75. The discount factor β is assumed to be equal to 0.995, which implies an annual steady-state real interest rate of 2 per cent. The parameters of the monetary policy rule corresponding to the weights that the central bank places on inflation and output stabilisation, given by ϕ_π and ϕ_x, are set to 1.5 and 0.5 respectively, as in Taylor (1993). The calibration of the inverse of the elasticity of intertemporal substitution in consumption, σ, and the inverse of the Frisch elasticity of labor supply, φ, as well as the parametrisation of the shock processes are based on Smets and Wouters' (2007) estimates for the Euro Area. Their values are listed in Table 1.

Table 1

Structural parameters						
Parameter	β	σ	φ	α	ϕ_π	ϕ_y
Value	0.995	1.38	1.83	0.75	1.5	0.5
Shocks						
Parameter	ρ_a	σ_a	ρ_u	σ_u	ρ_v	σ_v
Value	0.95	0.45	0.97	0.53	0.15	0.24

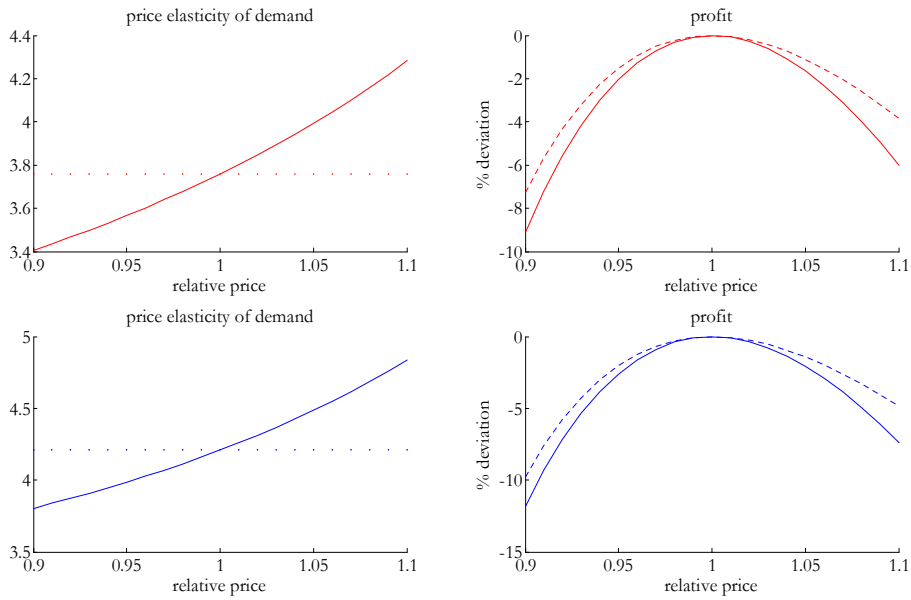
The parameters γ and η, which control the shape of the demand function, are calibrated based on the study by Dossche, Heylen and Poel (2007). The authors use scanner price data to estimate the price elasticity and curvature of demand for a wide range of products. They provide empirical evidence that the price elasticity of demand rises with relative price, which supports the introduction of concave demand functions into macroeconomic models. The study shows that the degree of strategic complementarity in firms' price setting decisions, determined by the curvature of the demand function, is quite small and that it is strongly positively correlated with the price elasticity of demand. The values of the demand function parameters adopted in this paper, which are shown in Table 2, are based on these results.

Table 2

Parameter	η_1	γ_1	η_2	γ_2
Value	-0.30	0.62	-0.28	0.67

Figures 1 and 2 illustrate the properties of the demand function for two calibrations adopted throughout the analysis. Figure 1 shows how firms' price elasticity of demand and profits alter with changes in the relative price and how they compare with those obtained for a CES demand function. The figure demonstrates that in the case of a concave demand function and the associated strategic complementarity in firms' price setting decisions, a firm's price elasticity of demand is an increasing function of its relative price. As a result, the firm's profits are more sensitive to changes in relative prices than in the case of the Dixit-Stiglitz consumption aggregator with constant price elasticity of demand.

Figure 1

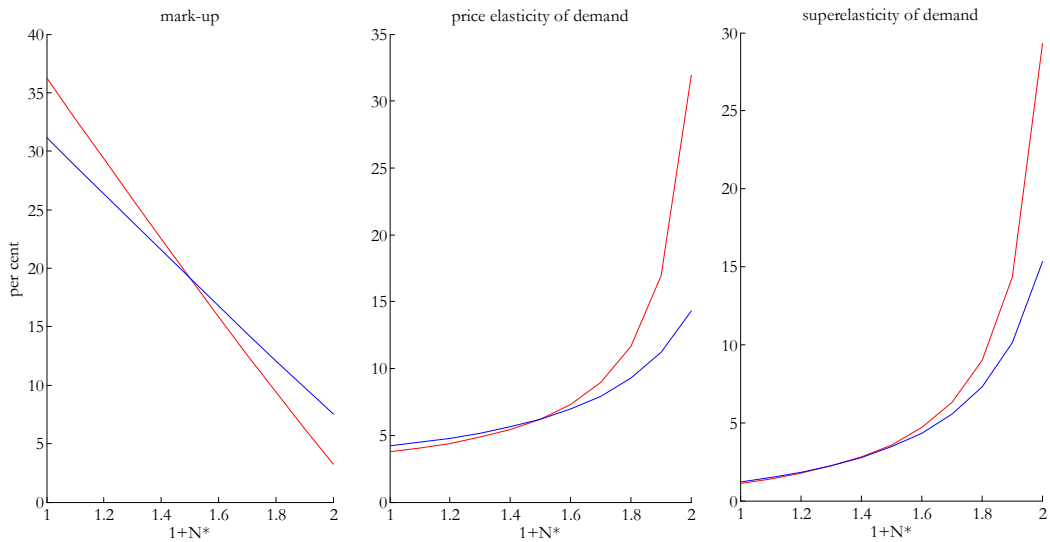


Note: red line: $\eta = -0.30, \gamma = 0.62$; blue line: $\eta = -0.28, \gamma = 0.67$;
dotted line: CES demand function; solid line: non-CES demand function

In the framework adopted, the price elasticity of demand varies not only with a firm's relative price but also with the degree of competition in the economy. The relationships between the level of competition, measured by $(1 + N^*)$, the steady-state mark-up, μ, the corresponding price elasticity of demand, θ, and the superelasticity of demand, ϵ, are shown in Figure 2. The figure demonstrates a negative relationship between competition and firms' desired mark-ups. As the number of foreign firms in the domestic market increases from 0 to 1, which corresponds to a 100 per

cent increase in the number of all varieties traded in the economy, the steady-state mark-up declines from about 31 – 36 per cent to about 3 – 8 per cent, depending on calibration.

Figure 2



Note: red line: $\eta = -0.30, \gamma = 0.62$; blue line: $\eta = -0.28, \gamma = 0.67$

4 Competition and real rigidities

In the framework with non-constant price elasticity of demand and a variable number of traded varieties developed above, inflation in the sector of domestically produced goods, $\widehat{\pi}_{H,t}$, is determined according to the following Phillips Curve[10]:

$$\widehat{\pi}_{H,t} = \beta E_t \widehat{\pi}_{H,t+1} + \lambda \frac{(1-\alpha)(1-\alpha\beta)}{\alpha} \left[\widehat{mcr}_t - \frac{d}{\theta - 1} \varpi (\widehat{p}_{H,t} - \widehat{p}_{F,t}) \right] \tag{17}$$

where $\lambda = \frac{\theta-1}{\theta-1+d}$ is a structural parameter reflecting the degree of strategic complementarity in firms' price setting decisions, $d = \frac{1}{\gamma-1} + \theta$ and $\varpi = \frac{N^*}{1+N^*}$ is the share of imported goods in the consumption basket; $\widehat{mcr}_t$ is the log deviation of the domestic

[10] The equation is derived in Appendix 4.1. The derivations of domestic and imported price indices, both utility-based and competition-based, as well as domestic and foreign demand functions, which are necessary in order to derive the Phillips Curve equations for inflation in the domestic and imported goods sectors are presented in Appendices 1 – 3.

real marginal cost from its steady state at time t; $\widehat{p}_{H,t}$ and $\widehat{p}_{F,t}$ denote the log deviations of the domestic and imported price indices, which are derived in Appendix 3, from their respective steady states.

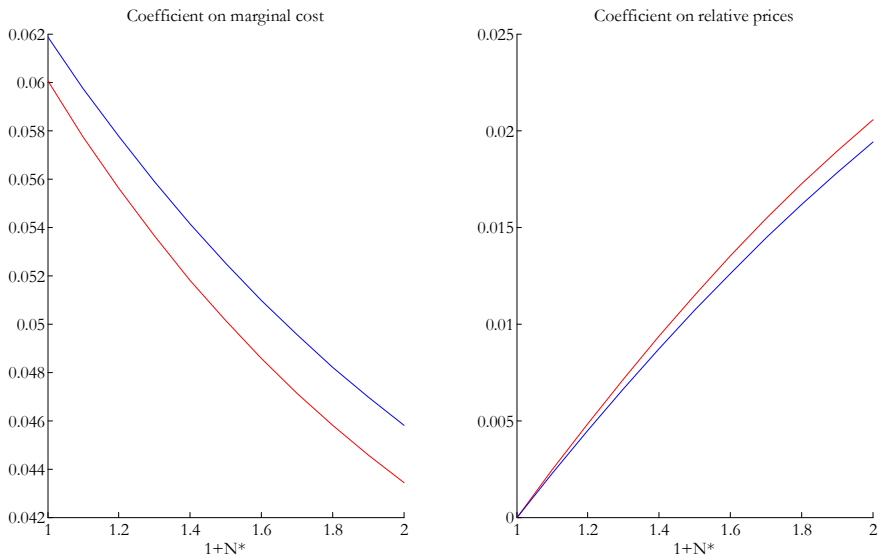
The equation shows that in the presence of strategic complementarity in firms' price setting decisions, domestic inflation depends not only on marginal cost but also on the difference between the prices of domestic and imported goods. This is due to the fact that changes in the ratio of domestic to import prices affect the price elasticity of demand and firms' desired mark-ups. To give an example, following a decrease in the price of imports which leads to an increase in the relative price of domestic goods, domestic producers face higher price elasticity of demand which prompts them to lower their mark-ups. As a result, domestic prices decline even if marginal cost remains unchanged.

Furthermore, the coefficients of the Phillips Curve depend on the number of varieties traded and the level of competition in the economy. Changes in competition affect firms' price elasticity of demand and the sensitivity of their optimal price to the prices charged by their competitors. Firstly, an increase in competitive pressures in the domestic economy, corresponding to an increase in $1 + N^*$, leads to a decrease in λ and therefore also a decline in the elasticity of domestic inflation with respect to domestic marginal cost and an increase in the degree of real rigidities in price setting. Secondly, an increase in the number of imported varieties in the domestic market, resulting in higher ϖ, raises the sensitivity of domestic inflation to changes in the ratio of domestic to import prices[11].

Figure 3 shows the relationship between the level of competition and the coefficients of the Phillips Curve. For the two calibrations of the model adopted in the analysis, an increase in the number of traded varieties by 100 per cent leads to a decrease in the slope of the Phillips Curve by about 35 – 38 per cent. At the same time, the coefficient on relative international prices rises from 0 to about 0.02.

[11] Guerrieri, Gust and López-Salido (2009) also find that in the presence of strategic complementarity domestic inflation depends on the relative price of domestic and imported goods. However, as their analysis does not take into account the impact of trade integration and competition on steady-state mark-ups, the elasticity of inflation with regard to marginal cost is independent of the level of competition. In contrast, Sbordone (2007) accounts for the impact of competition on the sensitivity of inflation to marginal cost but ignores the role of international relative prices in the determination of domestic inflation.

Figure 3



Note: red line: $\eta = -0.30, \gamma = 0.62$; blue line: $\eta = -0.28, \gamma = 0.67$

The considerable increase in the sensitivity of domestic inflation to changes in the price ratio of domestic to imported goods may suggest that an increase in the openness of the economy and competition leads to a dramatic increase in the importance of foreign economic developments in the determination of domestic inflation. However, it should be noted that this effect is partly counterbalanced by the fact that an increase in competition and the resulting increase in the degree of strategic complementarity among firms raises the impact of the prices of domestic goods on the prices of goods which are imported. This is evident from the equation for imported goods inflation, $\widehat{\pi}_{Ft}$, given by[12]:

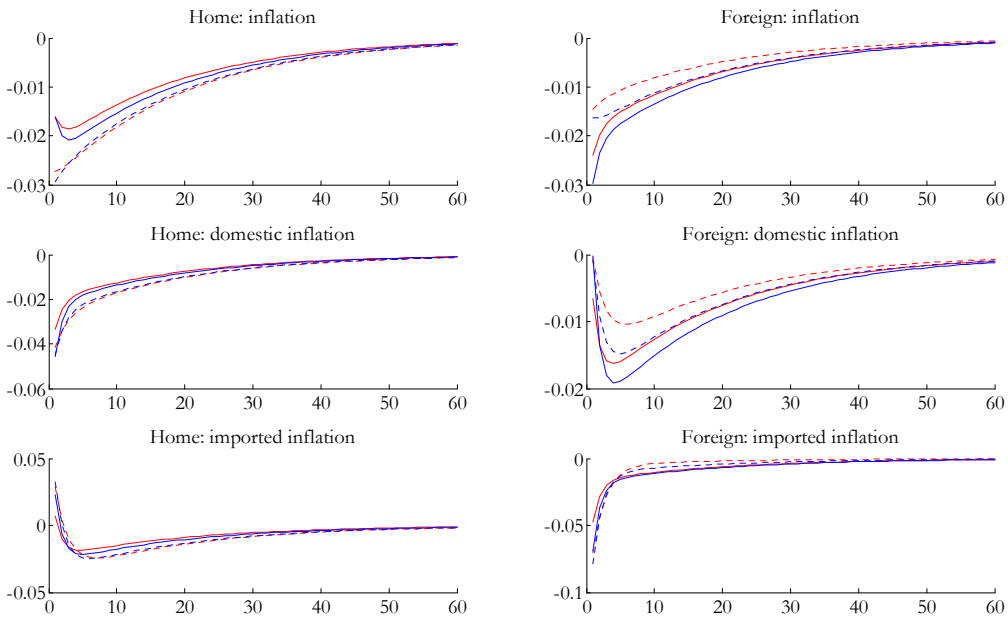
$$\widehat{\pi}_{F,t} = \beta E_t \widehat{\pi}_{F,t+1} + \lambda \frac{(1-\alpha)(1-\alpha\beta)}{\alpha} \left[m\widehat{cr}_t^* + \widehat{z}_t - \frac{d}{\theta - 1}(1-\varpi)(\widehat{p}_{F,t} - \widehat{p}_{H,t}) \right] \quad (18)$$

where $\lambda = \frac{\theta-1}{\theta-1+d}$, $d = \frac{1}{\gamma-1} + \theta$ and $(1-\varpi) = \frac{1}{1+N^*}$ is the share of domestically produced goods in the consumption basket; $m\widehat{cr}_t^*$ is the log deviation of the real marginal cost of the Foreign firms from its steady state at time t; $\widehat{z}_t$, given by: $\widehat{z}_t = \widehat{p}_{H,t}^* - \widehat{p}_{F,t} + \widehat{s}_t$, denotes the deviation from the law of one price at time t – the discrepancy between the prices of the imported goods charged in the Foreign and Home markets and

[12]For derivation see Appendix 4.2.

expressed in the Home currency[13].

Figure 4



Note: red line: non-CES; blue line: CES; dotted line: relatively closed economy ($N^* = 0.25$); solid line: relatively open economy ($N^* = 0.75$)

The effects of changes in the openness of the economy on inflation dynamics are illustrated by examining the impact of a positive one-standard-deviation productivity shock in the Home economy on inflation and its components in both the Home and Foreign economies, which is shown in Figure 4[14]. The graph compares the responses of inflation to the shock in models with constant and non-constant price elasticity of demand.[15] As would be expected, in the more open economy, the responses of Home

[13] $\widehat{p}^*_{Ht}$ is the log deviation of the price of the Foreign good in the Foreign market expressed in the Foreign currency from its steady state, whereas $\widehat{p}_{Ft}$ denotes the log deviation of the price of the Foreign good in the Home market expressed in the Home currency from its steady state.

[14] Two levels of openness are considered - one in which foreign goods constitute 20 per cent of all goods sold in the domestic economy and one in which the share of foreign goods in the consumption basket is equal to 43 per cent, which corresponds to $N^* = 0.25$ and $N^* = 0.75$ respectively.

[15] In the model with constant price elasticity of demand, firms' desired mark-ups are set to 19 per cent, which corresponds to the desired mark-ups obtained for $N^* = 0.5$ in the non-constant price elasticity model.

price indices to a Home shock are relatively weaker and the responses of Foreign variables to such a shock are relatively stronger than in the less open economy. However, the effects of changes in openness on inflation are more pronouced in the presence of strategic complementarity in firms' price setting behaviour due to the additional competitive effects of trade integration discussed above.

5 Endogenous frequency of price adjustment

In the analysis so far, it has been assumed that the fraction of firms which adjust their prices in each period, given by $(1 - \alpha)$, is exogenously determined and does not depend on the level of competition in the economy. However, surveys of firms' price setting behaviour as well as empirical studies based on micro price data strongly suggest that the intensity of competitive pressures faced by firms affect the frequency with which they change their prices. In order to take this effect into account, in what follows the frequency of price adjustment is endogenised by assuming that for a given set of structural features of the economy, including the level of competition, firms are able to choose the frequency of price adjustment optimally.

5.1 Firms' price setting decisions

In this framework, firms' pricing decisions can be thought of as being taken in two stages. In the first stage, firms decide on their pricing policy – they choose a frequency of price adjustment which, for a given structure of the economy and a given cost of price adjustment, maximises the expected discounted value of their lifetime profits.[16] In the second stage, firms set their prices optimally in line with their chosen pricing policy. In other words, once the frequency of price adjustment has been chosen, firms take it as given in subsequent periods and adjust their prices accordingly as long as the structure of the economy remains unchanged.

[16] The assumption that firms use time-dependent pricing policies can be motivated by the presence of information-gathering and decision-making costs which do not make it optimal for firms to review their prices in each period. It is consistent with survey evidence. Firms' surveys indicate that in the Euro Area 34 per cent of firms use purely time-dependent pricing policies, whereas about 46 per cent of them use a combination of time- and state-dependent strategies (Fabiani *et al.*, 2005). In the US the fraction of firms reviewing their prices on a periodic basis is even higher and equals 40 per cent (Blinder *et al.*, 1998).

Firm i's problem of profit maximisation associated with its choice of optimal pricing policy is equivalent to the problem of minimisation of the unconditional expected value of the following loss function:

$$\begin{aligned} L_t(\alpha_i, \alpha) &= G + \min_{P^o_{i,t}} E_t \sum_{k=0}^{\infty} (\beta\alpha_i)^k \left[\Pi_{t+k}\left(\frac{P^f_{i,t+k}}{P_{t+k}}\right) - \Pi_{t+k}\left(\frac{P^o_{i,t}}{P_{t+k}}\right)\right] \\ &\quad + \beta(1-\alpha_i) \sum_{k=1}^{\infty} (\beta\alpha_i)^{k-1} E_t L_{t+k}(\alpha_i, \alpha) \end{aligned} \tag{19}$$

where G is the cost of price adjustment; α_i is the probability that the firm i keeps its price unchanged in a given period; α is the fraction of all firms which do not adjust their price in a given period; $\frac{P^f_{i,t}}{P_t}$ is the optimal relative price in period t if prices were adjusted costlessly in each period; $\frac{P^o_{i,t}}{P_t}$ is the optimal relative price in period t in the presence of nominal rigidities and price adjustments costs. $\Pi_{t+k}(\frac{P^f_{i,t+k}}{P_{t+k}})$ denotes a firm's profit at time $t+k$ if its price is equal to $\frac{P(i)^f_{t+k}}{P_{t+k}}$, and $\Pi_{t+k}(\frac{P^o_{i,t}}{P_{t+k}})$ is a firm's profit at time $t+k$ if its price is equal to $\frac{P^o_{i,t}}{P_{t+k}}$.

The loss function represents the difference in the expected present value of firm i's profits in the case when it adjusts its price in a given period with probability $(1-\alpha_i)$ and incurs a fixed cost of price adjustment and the case when it adjusts its price in each period without any costs. The first term on the right hand side of the equation reflects the cost of setting a new price in period t, the second term denotes a loss in profit resulting from keeping this price unchanged thereafter, whereas the last term represents the sum of losses in profit from setting a new price in some future period and keeping it unchanged thereafter.

As $E_0\left[E_t L_{t+k}(\alpha_i, \alpha)\right] = E_0\left[L_t(\alpha_i, \alpha)\right]$, the unconditional expected value of the loss function (19), given by $L_E = E_0\left[L_t(\alpha_i, \alpha)\right]$, can be expressed as follows:

$$L_E(\alpha_i, \alpha) = \frac{1-\alpha_i\beta}{1-\beta}\left[G + E_0 \sum_{k=0}^{\infty} (\alpha_i\beta)^k \left(\Pi_{t+k}\left(\frac{P^f_{i,t+k}}{P_{t+k}}\right) - \Pi_{t+k}\left(\frac{P^o_{i,t}}{P_{t+k}}\right)\right)\right] \tag{20}$$

Minimisation of (20) with respect to α_i gives rise to the following first order condition, which in equilibrium must hold for all firms:

$$G + E_0 \sum_{k=0}^{\infty} (\alpha_i\beta)^{k-1} \left[\alpha_i\beta - k(1-\alpha_i\beta)\right] \left[\Pi_{t+k}\left(\frac{P^f_{i,t+k}}{P_{t+k}}\right) - \Pi_{t+k}\left(\frac{P^o_{i,t}}{P_{t+k}}\right)\right] = 0 \tag{21}$$

When choosing their frequency of price adjustment $(1-\alpha_i)$, firms take the frequency of price adjustment of other firms as given. The condition for the economy-wide frequency of price adjustment $(1-\alpha)$ to be a Nash equilibrium is that the optimality condition holds at α_i equal to α for all firms. Therefore, the frequency of price adjustment $(1-\alpha_i)$ which satisfies (21) with $\alpha_i = \alpha$ for all firms is the equilibrium frequency of price adjustment.

5.2 Forces driving the optimal frequency of price adjustment

The first order condition (21) shows that the optimal frequency of price adjustment equalises the cost of price adjustment with the opportunity cost of not adjusting prices. This opportunity cost depends on the expected discounted sum of the differences between profits obtained at the optimal flexible price and the actual price. The greater the difference, the greater incentive firms have to adjust their prices. In order to understand the determinants of the frequency of price adjustment, it is therefore crucial to understand the determinants of the 'period loss function' - the difference between profits obtained at a price which would be optimal for that period if firms were able to adjust their prices in each period costlessly and profits obtained at the prevailing price in that period.

After a second-order approximation, the period loss function can be expressed as follows[17]:

$$\Pi_{t+k}\left(\frac{P^f_{i,t+k}}{P_{t+k}}\right) - \Pi_{t+k}\left(\frac{P^o_{i,t}}{P_{t+k}}\right) \approx -\frac{1}{2}\Pi''_{t+k}\left(\frac{P^f_{i,t+k}}{P_{t+k}}\right)\left(\frac{P^f_{i,t+k}}{P_{t+k}} - \frac{P^o_{i,t}}{P_{t+k}}\right)^2 \tag{22}$$

The approximation (22) reveals that the loss in profits in a given period depends on two factors: the deviation of the optimal relative price from the actual price in that period, $(\frac{P^f_{i,t+k}}{P_{t+k}} - \frac{P^o_{i,t}}{P_{t+k}})$, and the curvature of the profit function, $\Pi''_{t+k}(\frac{P^f_{i,t+k}}{P_{t+k}})$, which determines the cost of a given deviation of the actual price from the optimal flexible price.

The opportunity cost of a given deviation of the actual price from the optimal price depends on the sensitivity of the demand for a firm's product to the deviation of the actual price from the optimal price, which is determined by the steady-state price elasticity of demand and by the superelasticity of demand. It also depends on

[17] See Appendix 5 for derivation.

the demand for the firm's good in the steady state, which is determined by firms' steady state market share and the equilibrium level of output.

The profit loss function can be further approximated and rewritten as a function of the steady-state values of the model variables and the log deviations of the optimal flexible price and the actual price from their steady states:

$$\Pi_{t+k}\left(\frac{P^f_{i,t+k}}{P_{t+k}}\right) - \Pi_{t+k}\left(\frac{P^o_{i,t}}{P_{t+k}}\right) \approx \frac{1}{2}\left(\frac{P_i}{P}\right)\left(\frac{Y_i}{Y}\right) Y(\theta+\epsilon-1)(\widehat{p}^f_{i,t+k} - \widehat{p}^o_{i,t})^2 \quad (23)$$

where $(\frac{P_i}{P})(\frac{Y_i}{Y}) = \frac{1}{1+N^*}$, Y is the equilibrium level of output, $\frac{Y_i}{Y}$ is a firm's market share in a steady state with symmetric prices, $\frac{P_i}{P}$ is the relative price of a firm's product in a steady state with symmetric prices, $\widehat{p}^f_{i,t+k}$ is the log deviation of $\frac{P^f_{i,t+k}}{P_{t+k}}$ from its steady state and $\widehat{p}^o_{i,t}$ is the log deviation of $\frac{P^o_{i,t}}{P_{t+k}}$ from its steady state.

5.3 Competition and nominal rigidities

Having identified the factors determining the opportunity cost of not adjusting prices, it is now possible to analyse how they are affected by changes in the degree of competition. Firstly, an increase in competition affects firms' steady-state revenues and profits. There are two forces acting in opposite directions. On one hand, an increase in the number of competitors lowers firms' market shares and mark-ups which has a negative impact on firms' profits and drives the opportunity cost of not adjusting prices down. On the other hand, however, an increase in competition reduces the distortion associated with imperfect competition and increases the steady-state level of output which raises firms' profits and thereby strengthens their incentives to adjust prices. Secondly, a rise in competition increases the sensitivity of firms' profits to a given deviation of the actual price from the desired price. Greater competition is associated with higher price elasticity of demand and higher superelasticity of demand, which makes it more costly for firms to keep their prices unchanged. Finally, an increase in trade integration and competition increases the impact of relative international prices on domestic prices and raises strategic complementarity in firms' price setting decisions, which influence the deviations of firms' actual prices from their desired prices and thereby also the costs and benefits of price adjustment.

The analysis shows that competition affects a number of determinants of the opportunity cost of adjusting prices and that there are divergent forces at work. The

net effect of changes in competition on the degree of nominal price rigidities can be determined numerically.

It can be noted that the equilibrium condition associated with the choice of a firm's pricing policy can be written as follows:

$$G + E_0 \sum_{k=0}^{\infty} (\alpha_i \beta)^{k-1} \left[\alpha_i \beta - k(1-\alpha_i \beta)\right] \frac{1}{2} \left(\frac{P_i}{P}\right) \left(\frac{Y_i}{Y}\right) Y(\theta + \epsilon - 1)(\widehat{p}^f_{i,t+k} - \widehat{p}^o_{i,t})^2 = 0 \tag{24}$$

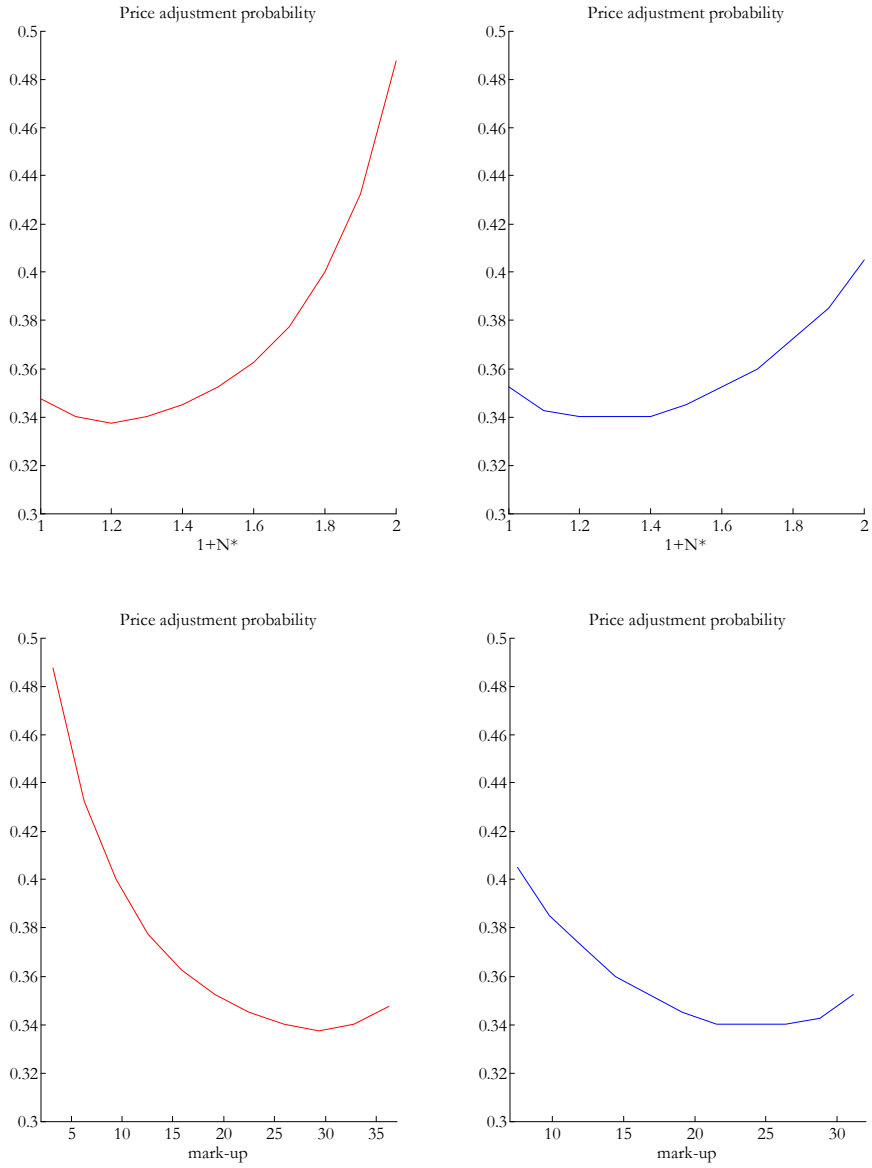
For a given level of competition, the equilibrium frequency of price adjustment can be obtained in the following way. Firstly, the model described in section two is solved for a given level of α. Secondly, the obtained solution is substituted into equation (24) and it is examined whether the condition holds with α_i equal to α. The α for which this is the case determines the equilibrium frequency of price adjustment. This strategy can be used to find the optimal frequency of price adjustment for different levels of competition.

Figure 5 illustrates the relationship between the level of competition and the frequency of price adjustment for two different calibrations of the demand function. It shows that an increase in competition leads to an increase in the optimal frequency of price adjustment. A 100 per cent increase in the number of varieties available to domestic consumers, associated with a decline in mark-ups from about 31 – 36 per cent to about 3 – 8 per cent, leads to an increase in the share of firms adjusting their prices in a given period from about 35 per cent to 41 – 49 per cent, depending on the demand function parameters.[18] The effects of changes in competition are relatively small when the initial levels of the openness of the economy and competition are low and they are much larger for greater initial openness and competitive pressure. This is due to the fact that when a firm enjoys high market power and its steady-state mark-up is high, an increase in competition resulting in a decline in this mark-up by one percentage point is associated with relatively small increases in the steady-state price elasticity and superelasticity of demand. While these increases raise the firm's profit loss resulting from a given deviation of its actual price from the optimal price,

[18] When solving for the optimal frequency of price adjustment, the value of the price adjustment cost, G, is calibrated based on a study by Zbaracki *et al.* (2004), who estimate that these costs constitute 1.22 per cent of firms' revenues. Setting these costs equal to about 4 per cent of firms' revenues, an estimate obtained by Willis (2000), reduces the optimal probability of price adjustment by about 6 – 8 percentage points for any given level of competition as compared to the benchmark calibration.

their impact on firms' opportunity cost of not adjusting prices is to some extent offset by a decrease in the volatility of desired prices induced by higher competition. In turn, when a firm's steady-state mark-up is low, a decrease in this mark-up by one percentage point gives rise to a substantial increase in both the price elasticity and superelasticity of demand and this increase has a strong and dominating effect on firms incentives to adjust their prices.

Figure 5



Note: red line: $\eta = -0.30, \gamma = 0.62$; blue line: $\eta = -0.28, \gamma = 0.67$

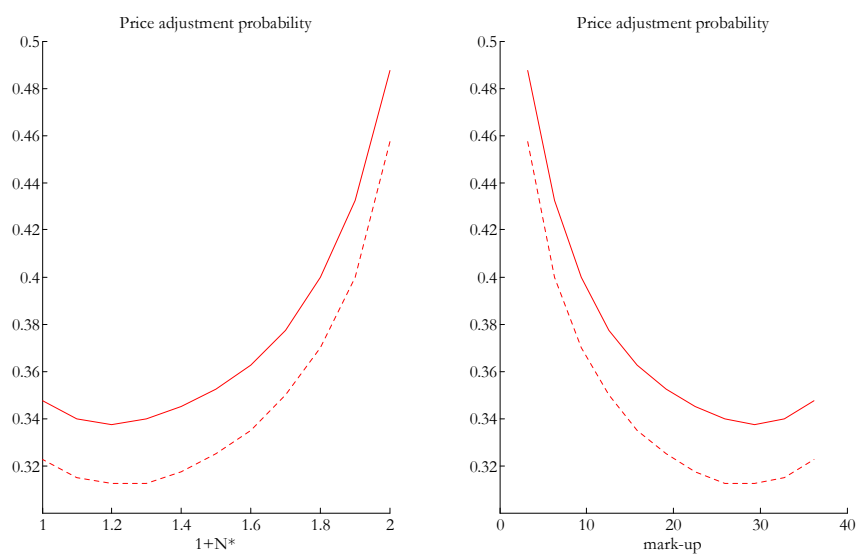
The analysis therefore demonstrates that an increase in competition reduces the degree of nominal rigidities in the economy, which is consistent with empirical and survey evidence concerning firms' price setting behaviour.

5.4 Other determinants of the frequency of price adjustment

Competition is not the only factor affecting the optimal frequency with which firms change their prices. Any changes in the structural features of the economy which influence the variability of desired prices also affect the average deviation of the actual price from the optimal price and therefore the optimal frequency of price adjustment. One such feature is the variance of shocks hitting the economy.

Figure 6 shows the optimal frequency of price adjustment for different values of the variance of shocks. A 20 per cent decrease in the standard deviation of all shocks reduces the opportunity cost of not adjusting prices and leads to a decrease in the probability of price adjustment in a given period by about 3 percentage points for any given level of competition.[19]

Figure 6



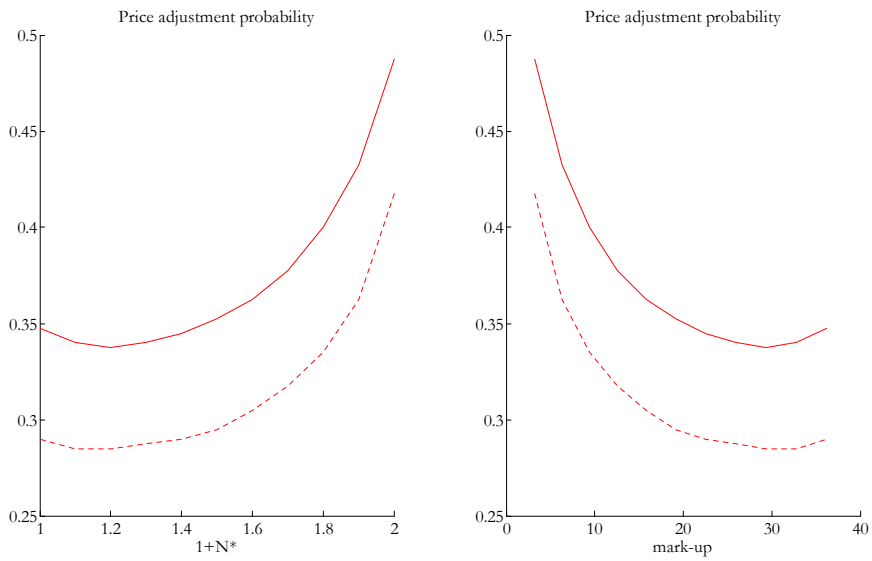
Note: solid line: $\sigma_{1,a} = 0.45; \sigma_{1,u} = 0.53; \sigma_{1,v} = 0.24$

dotted line: $\sigma_{2,a} = 0.8\sigma_{1,a}; \sigma_{2,u} = 0.8\sigma_{1,u}; \sigma_{2,v} = 0.8\sigma_{1,v}$

[19] A similar result has been obtained by Romer (1990) who also finds a positive relationship between the frequency of price changes and the variance of nominal shocks.

For a similar reason, the frequency of price adjustment also depends on the parameters of the monetary policy rule. The higher the weight which the central bank attaches to inflation stabilisation, the less variable is inflation and the less frequent price adjustment.[20] An increase in ϕ_π from 1.5 to 2.0 reduces the fraction of firms adjusting their prices in a given period by about 5 – 7 percentage points, which is illustrated in Figure 7.

Figure 7



Note: solid line: $\phi_\pi = 1.5$; dotted line: $\phi_\pi = 2.0$

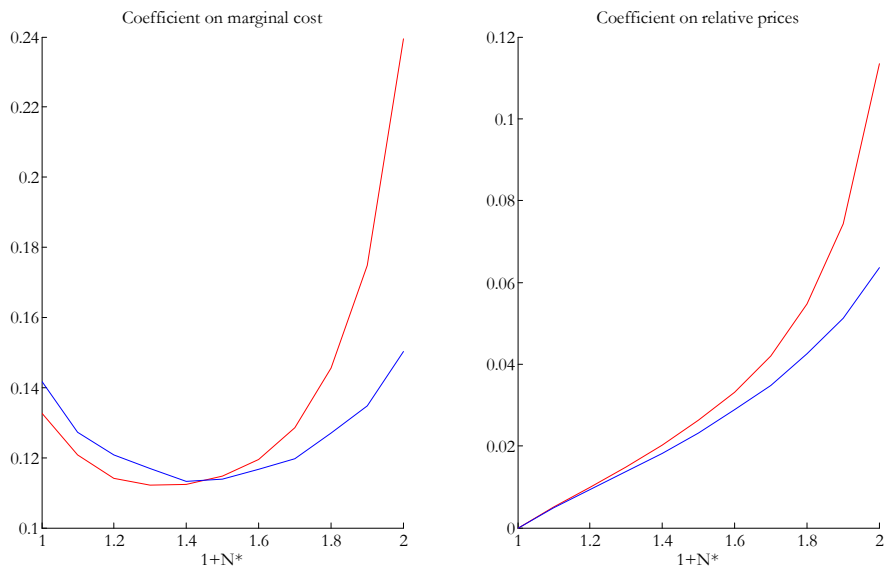
5.5 Competition and the degree of price stickiness

Having examined the impact of competition on both the degree of real and nominal price rigidities, it is now possible to analyse the net effect of these changes on inflation. The relationship between the level of competition and the parameters of the Phillips Curve is shown in Figure 8. An increase in the frequency of price adjustment enhances the positive impact of competition on the elasticity of inflation with respect to relative international prices and this effect is particularly strong for highly integrated economies. The influence of an increase in competition on the sensitivity of inflation to marginal cost depends on the initial level of the openness of the economy.

[20] This result confirms findings by Kimura, Kurozumi and Hara (2008) obtained in a simpler, closed-economy model. They also show that the frequency of price adjustment is negatively related to the weight that the central bank places on inflation stabilisation.

For a relatively closed economy the effect is small and negative. For a high initial level of openness, an increase in the frequency of price adjustment associated with trade integration more than offsets the increase in real rigidities and, as a result, the elasticity of inflation with respect to marginal cost increases.

Figure 8



Note: red line: $\eta = -0.30, \gamma = 0.62$; blue line: $\eta = -0.28, \gamma = 0.67$

6 Conclusions

This paper examined the impact of trade integration and product market competition on firms' price setting decisions and provided new insights into the determinants of real and nominal price rigidities. The analysis demonstrates that an increase in competition, driven by changes in the number of varieties available in the domestic market, raises the sensitivity of firms' optimal price to the prices charged by their competitors and the degree of real price rigidities. Changes in competition and the resulting changes in strategic complementarity affect firms' opportunity cost of not adjusting prices. There are two divergent forces at work. On one hand, an increase in competition and the degree of real rigidities leads to an increase in inflation persistence and a decline in the average deviation of firms' optimal price from their actual price, which reduces incentives to adjust their prices. On the other hand, an increase in the steady-state price elasticity of demand associated with an increase in competition

raises the loss of profit resulting from a given deviation of the desired price from the actual price, which makes it more profitable for firms to adjust their prices. For plausible calibration of the model parameters the latter effect dominates and, as a result, an increase in competition leads to more frequent price adjustment and a lower degree of nominal rigidities in the economy. The study therefore provides a theoretical explanation of the positive link between competition and the frequency of price adjustment observed in the data.

Accounting for the effects of competition on the degree of real and nominal rigidities sheds new light on the impact of trade integration on the Phillips Curve and inflation dynamics. In the presence of strategic complementarity in firms' price setting decisions, domestic inflation depends not only on domestic real marginal cost but also on the ratio of the prices of imported goods to the prices of domestically produced goods. Changes in competition affect both the sensitivity of inflation to marginal cost and to relative international prices. An increase in competition leads to an increase in the importance of the ratio of prices of imported to domestic goods in the determination of domestic inflation. Due to the fact that changes in competition lead to changes in real and nominal rigidities in opposite directions, the overall impact of trade integration on the sensitivity of inflation to changes in domestic marginal cost is ambiguous and depends on the initial level of the openness of the economy.

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A Appendix

A.1 Derivation of demand functions

A.1.1 Demand for individual varieties as a fraction of aggregate consumption

The consumption aggregator C_t is implicitly defined by equations (6) and (7). Therefore, households choose the levels of consumption of individual Home and Foreign varieties, $C_{H,i,t}$ and $C_{F,i,t}$, in order to minimise their expenditure D_t given by:

$$D_t = \int_0^1 P_{H,i,t} C_{H,i,t} di + \int_1^{1+N^*} P_{F,i,t} C_{F,i,t} di \tag{25}$$

subject to (6).
The Lagrangian for the optimisation problem is:

$$L = \int_0^1 P_{H,i,t} C_{H,i,t} di + \int_1^{1+N^*} P_{F,i,t} C_{F,i,t} di - \Lambda \left[\int_0^1 f\left(\frac{C_{H,i,t}}{C_t}\right) di + \int_1^{1+N^*} f\left(\frac{C_{F,i,t}}{C_t}\right) di - 1 \right] \tag{26}$$

The first order condition with respect to $C_{X,i,t}$, where $X = \{H, F\}$, is given by:

$$P_{X,i,t} = \frac{\Lambda}{C_t} [(1+\eta)\frac{C_{X,i,t}}{C_t} - \eta]^{\gamma-1} \tag{27}$$

We define the competition-based aggregate price index $\widetilde{P}_t = \frac{\Lambda}{C_t}$. After substitution:

$$\frac{P_{X,i,t}}{\widetilde{P}_t} = [(1+\eta)\frac{C_{X,i,t}}{C_t} - \eta]^{\gamma-1} \tag{28}$$

The demand function for an individual variety is therefore given by equation (8).

A.1.2 Demand for individual domestic varieties as a fraction of the consumption of domestic goods

The demand aggregator for the consumption of domestic goods, denoted by $C_{H,t}$, is implicitly defined by:

$$\int_0^1 f\left(\frac{C_{H,i,t}}{C_{H,t}}\right) di = 1 \tag{29}$$

$$\text{where } f\left(\frac{C_{H,i,t}}{C_{H,t}}\right) = \frac{1}{(1+\eta)\gamma}\left[(1+\eta)\frac{C_{H,i,t}}{C_{H,t}} - \eta\right]^{\gamma} - \left[\frac{1}{(1+\eta)\gamma} - 1\right] \tag{30}$$

Households choose the levels of consumption of individual domestic varieties, $C_{H,i,t}$, in order to minimise their expenditure:

$$D_{H,t} = \int_0^1 P_{H,i,t} C_{H,i,t} di \tag{31}$$

subject to (29).

The Lagrangian for the optimisation problem is:

$$L = \int_0^1 P_{H,i,t} C_{H,i,t} di - \Lambda_H \left[\int_0^1 f\left(\frac{C_{H,i,t}}{C_{H,t}}\right) di - 1\right] \tag{32}$$

The first order condition with respect to $C_{H,i,t}$ is given by:

$$P_{H,i,t} = \frac{\Lambda_H}{C_{H,t}}[(1+\eta)\frac{C_{H,i,t}}{C_{H,t}} - \eta]^{\gamma-1} \tag{33}$$

We define the competition-based domestic price index $\widetilde{P}_{H,t} = \frac{\Lambda_H}{C_{H,t}}$. After substitution:

$$\frac{P_{H,i,t}}{\widetilde{P}_{H,t}} = [(1+\eta)\frac{C_{H,i,t}}{C_{H,t}} - \eta]^{\gamma-1} \tag{34}$$

The demand function for the domestic good as a fraction of the domestic consumption aggregator is therefore given by:

$$\frac{C_{H,i,t}}{C_{H,t}} = \frac{1}{(1+\eta)}\left(\frac{P_{H,i,t}}{\widetilde{P}_{H,t}}\right)^{\frac{1}{\gamma-1}} + \frac{\eta}{(1+\eta)} \tag{35}$$

A.1.3 Demand for individual imported varieties as a fraction of the consumption of imported goods

The demand aggregator for the consumption of imported goods, denoted by $C_{F,t}$, is implicitly defined by:

$$\int_{1}^{1+N^*} f(\frac{C_{F,i,t}}{C_{F,t}})di = 1 \tag{36}$$

$$\text{where } f(\frac{C_{F,i,t}}{C_{F,t}}) = \frac{1}{(1+\eta)\gamma}\left[(1+\eta)\frac{C_{F,i,t}}{C_{F,t}} - \eta\right]^{\gamma} - \frac{1}{N^*}\left[\frac{1}{(1+\eta)\gamma} - 1\right] \tag{37}$$

Households choose the levels of consumption of individual imported varieties, $C_{F,i,t}$, in order to minimise their expenditure:

$$D_{F,t} = \int_{1}^{1+N^*} P_{F,i,t}C_{F,i,t}di \tag{38}$$

subject to (36).
The Lagrangian for the optimisation problem is:

$$L = \int_{1}^{1+N^*} P_{F,i,t}C_{F,i,t}di - \Lambda_F\left[\int_{1}^{1+N^*} f(\frac{C_{F,i,t}}{C_{F,t}})di - 1\right] \tag{39}$$

The first order condition with respect to $C_{F,i,t}$ is given by:

$$P_{F,i,t} = \frac{\Lambda_F}{C_{F,t}}[(1+\eta)\frac{C_{F,i,t}}{C_{F,t}} - \eta]^{\gamma-1} \tag{40}$$

We define the competition-based imported price index $\widetilde{P}_{F,t} = \frac{\Lambda_F}{C_{F,t}}$. After substitution:

$$\frac{P_{F,i,t}}{\widetilde{P}_{F,t}} = [(1+\eta)\frac{C_{F,i,t}}{C_{F,t}} - \eta]^{\gamma-1} \tag{41}$$

The demand function for the imported good as a fraction of domestic consumption aggregator is:

$$\frac{C_{F,i,t}}{C_{F,t}} = \frac{1}{(1+\eta)}\left(\frac{P_{F,i,t}}{\widetilde{P}_{F,t}}\right)^{\frac{1}{\gamma-1}} + \frac{\eta}{(1+\eta)} \tag{42}$$

A.2 Derivation of competition-based price indices

A.2.1 Aggregate competition-based price index

After substituting the demand function (8) into (6) we obtain:

$$\int_0^1 \left[\frac{1}{(1+\eta)\gamma} \left(\frac{P_{H,i,t}}{\widetilde{P}_t} \right)^{\frac{\gamma}{\gamma-1}} - \frac{1}{1+N^*} \left(\frac{1}{(1+\eta)\gamma} - 1 \right) \right] di + \tag{43}$$

$$+ \int_1^{1+N^*} \left[\frac{1}{(1+\eta)\gamma} \left(\frac{P_{F,i,t}}{\widetilde{P}_t} \right)^{\frac{\gamma}{\gamma-1}} - \frac{1}{1+N^*} \left(\frac{1}{(1+\eta)\gamma} - 1 \right) \right] di \quad = \quad 1$$

After some manipulation, the competition-based aggregate price index can be expressed as (9).

A.2.2 Domestic competition-based price index

After substituting the demand function (35) into (29) we obtain:

$$\int_0^1 \left[\frac{1}{(1+\eta)\gamma} \left(\frac{P_{H,i,t}}{\widetilde{P}_{H,t}} \right)^{\frac{\gamma}{\gamma-1}} - \left(\frac{1}{(1+\eta)\gamma} - 1 \right) \right] di = 1 \tag{44}$$

After some manipulation, the competition-based domestic price index can be written as:

$$\widetilde{P}_{H,t} = \left[\int_0^1 (P_{H,i,t})^{\frac{\gamma}{\gamma-1}} di \right]^{\frac{\gamma-1}{\gamma}} \tag{45}$$

A.2.3 Imported competition-based price index

After substituting the demand function (42) into (36) we obtain:

$$\int_1^{1+N^*} \left[\frac{1}{(1+\eta)\gamma} \left(\frac{P_{F,i,t}}{\widetilde{P}_{F,t}} \right)^{\frac{\gamma}{\gamma-1}} - \frac{1}{N^*} \left(\frac{1}{(1+\eta)\gamma} - 1 \right) \right] di = 1 \tag{46}$$

After some manipulation, the competition-based imported price index can be written as:

$$\widetilde{P}_{F,t} = \left[\int_{1}^{1+N^*} (P_{F,i,t})^{\frac{\gamma}{\gamma-1}} di \right]^{\frac{\gamma-1}{\gamma}} \tag{47}$$

A.3 Derivation of utility-based price indices

A.3.1 Aggregate utility-based price index

The aggregate utility-based consumption index, P_t, defined as the minimum expenditure necessary to obtain a unit level of aggregate consumption C_t, satisfies the following condition:

$$P_t C_t = \int_{0}^{1} P_{H,i,t} C_{H,i,t} di + \int_{1}^{1+N^*} P_{F,i,t} C_{F,i,t} di = \int_{0}^{1+N^*} P_{i,t} C_{i,t} di \tag{48}$$

Substituting the demand function (8) into (48) we have:

$$P_t = \frac{1}{C_t} \int_{0}^{1+N^*} P_{i,t} \left[\frac{1}{1+\eta} \left(\frac{P_{i,t}}{\widetilde{P}_t} \right)^{\frac{1}{\gamma-1}} + \frac{\eta}{1+\eta} \right] C_t di \tag{49}$$

After some manipulation and using (9) we obtain:

$$P_t = \frac{1}{(1+\eta)} \left[\widetilde{P}_t + \eta \int_{0}^{1+N^*} P_{i,t} di \right] = \frac{1}{(1+\eta)} \left[\left(\int_{0}^{1+N^*} P_{i,t}^{\frac{\gamma}{\gamma-1}} di \right)^{\frac{\gamma-1}{\gamma}} + \eta \int_{0}^{1+N^*} P_{i,t} di \right] \tag{50}$$

A.3.2 Domestic utility-based price index

The domestic utility-based consumption index, $P_{H,t}$, defined as the minimum expenditure necessary to obtain a unit level of domestic consumption $C_{H,t}$, satisfies the following condition:

$$P_{H,t} C_{H,t} = \int_{0}^{1} P_{H,i,t} C_{H,i,t} di \tag{51}$$

Substituting the demand function (35) into (51) we have:

$$P_{H,t} = \frac{1}{C_{H,t}} \int_0^1 P_{H,i,t} \left[\frac{1}{1+\eta} \left(\frac{P_{H,i,t}}{\widetilde{P}_{H,t}} \right)^{\frac{1}{\gamma-1}} + \frac{\eta}{1+\eta} \right] C_{H,t} di \tag{52}$$

After some manipulation and using (45) we obtain:

$$P_{H,t} = \frac{1}{(1+\eta)} \left[\widetilde{P}_{H,t} + \eta \int_0^1 P_{H,i,t} di \right] \tag{53}$$

A.3.3 Imported utility-based price index

The imported utility-based consumption index, $P_{F,t}$, defined as the minimum expenditure necessary to obtain a unit level of imported consumption $C_{F,t}$, satisfies the following condition:

$$P_{F,t} C_{F,t} = \int_1^{1+N^*} P_{F,i,t} C_{F,i,t} di \tag{54}$$

Substituting the demand function (42) into (54) we have:

$$P_{F,t} = \frac{1}{C_{F,t}} \int_1^{1+N^*} P_{F,i,t} \left[\frac{1}{1+\eta} \left(\frac{P_{F,i,t}}{\widetilde{P}_{F,t}} \right)^{\frac{1}{\gamma-1}} + \frac{\eta}{1+\eta} \right] C_{F,t} di \tag{55}$$

After some manipulation and using (47) we obtain:

$$P_{F,t} = \frac{1}{(1+\eta)} \left[\widetilde{P}_{F,t} + \eta \int_1^{1+N^*} P_{F,i,t} di \right] \tag{56}$$

A.4 Derivation of the Phillips Curve equations

A.4.1 Domestic price inflation

In order to derive the Phillips Curve for domestic inflation, it is necessary to solve the optimisation problem of a domestic firm setting the price of its good in the domestic market, $P_{D,i,t}$. When receiving a signal to update its price, a domestic non-exporter chooses a price of its good in the domestic market to maximise (2) subject to (8),

whereas a domestic exporter chooses a price of its good in the domestic market such that it maximises (3) subject to (8).

The first order condition with respect to $P_{H,i,t}$ is the same for both the exporter and the non-exporter and is given by:

$$E_t \sum_{k=0}^{\infty} \alpha^k Q_{k,t+k}[C_{H,i,t+k} - C_{H,i,t+k}\theta_{H,i,t+k} + MC_{t+k}\theta_{H,i,t+k}\frac{C_{H,i,t+k}}{P^o_{H,i,t}}] = 0 \tag{57}$$

The equation can be rewritten as:

$$E_t \sum_{k=0}^{\infty} \alpha^k Q_{k,t+k} C_{H,i,t+k}[\frac{P^o_{H,i,t}}{P_{H,t}}(1-\theta_{D,i,t+k}) + \frac{MC_{t+k}}{P_{H,t+k}}\frac{P_{H,t+k}}{P_{H,t-1}}\frac{P_{H,t-1}}{P_{H,t}}\theta_{H,i,t+k}] = 0 \tag{58}$$

We will now define the relative optimal domestic price $R_{H,i,t} = \frac{P^o_{H,i,t}}{P_{H,t}}$, real domestic marginal cost $MCR_{t+k} = \frac{MC_{t+k}}{P_{H,t+k}}$ and domestic inflation $\Pi_{H,t} = \frac{P_{H,t}}{P_{H,t-1}}$. After substitution, (58) can be expressed as:

$$E_t \sum_{k=0}^{\infty} \alpha^k Q_{k,t+k} C_{H,i,t+k}[R_{H,i,t}(1-\theta_{H,i,t+k}) + MCR_{t+k}\frac{\prod_{s=0}^{k}\Pi_{H,t+s}}{\Pi_{H,t}}\theta_{H,i,t+k}] = 0 \tag{59}$$

Using the fact that $Q_{k,t+k} = \beta^k \left(\frac{C_{t+k}}{C_t}\right)^{-\sigma} \frac{P_t}{P_{t+k}} e^{u_{t+k}-u_t}$ and after log-linearizing (59) around a symmetric steady state we have:

$$\widehat{r}_{H,i,t} = (1-\alpha\beta)E_t \sum_{k=0}^{\infty}(\alpha\beta)^k(m\widehat{c}r_{t+k} + \sum_{s=0}^{k}\widehat{\pi}_{H,t+s} - \widehat{\pi}_{H,t} - \frac{1}{\theta-1}\widehat{\theta}_{H,i,t+k}) \tag{60}$$

The log deviation of the price elasticity of demand from its steady state is given by:

$$\widehat{\theta}_{H,i,t+k} = (\frac{1}{\gamma-1}+\theta)\left[\widehat{r}_{H,i,t} + \widehat{\pi}_{H,t} - \sum_{s=0}^{k}\widehat{\pi}_{H,t+s} + \frac{N^*}{1+N^*}(\widehat{p}_{H,t} - \widehat{p}_{F,t})\right] \tag{61}$$

Therefore, after substitution, (60) can be expressed as follows:

$$\widehat{r}_{H,i,t} = -\widehat{\pi}_{H,t} + (1-\alpha\beta)E_t \sum_{k=0}^{\infty}(\alpha\beta)^k \sum_{s=0}^{k} \widehat{\pi}_{H,t+s} + \tag{62}$$
$$+\frac{1}{1+b}(1-\alpha\beta)E_t \sum_{k=0}^{\infty}(\alpha\beta)^k \left[m\widehat{c}r_{t+k} - b\varpi(\widehat{p}_{H,t} - \widehat{p}_{F,t})\right]$$

where $b = \frac{1}{\theta-1}(\frac{1}{\gamma-1} + \theta)$ and $\varpi = \frac{N^*}{1+N^*}$.
It therefore follows that:

$$\widehat{r}_{H,i,t} - \alpha\beta E_t \widehat{r}_{H,i,t+1} = \alpha\beta E_t \widehat{\pi}_{H,t+1} - \widehat{\pi}_{H,t} + (1-\alpha\beta)E_t \sum_{k=0}^{\infty}(\alpha\beta)^k \widehat{\pi}_{H,t} +$$
$$+\frac{1}{1+b}(1-\alpha\beta)\left[m\widehat{c}r_t - b\varpi(\widehat{p}_{Ht} - \widehat{p}_{Ft})\right] \tag{63}$$

Using the fact that under Calvo price setting $\widehat{r}_{H,i,t} = \frac{\alpha}{1-\alpha}\widehat{\pi}_{H,t}$ we have:

$$\frac{\alpha}{1-\alpha}(\widehat{\pi}_{H,t} - \alpha\beta E_t \widehat{\pi}_{H,t+1}) = \alpha\beta E_t \widehat{\pi}_{H,t+1} + \frac{1}{1+b}(1-\alpha\beta)\left[m\widehat{c}r_t - b\varpi(\widehat{p}_{H,t} - \widehat{p}_{F,t})\right] \tag{64}$$

After some manipulation, the equation can be expressed as (17).

A.4.2 Imported price inflation

In order to derive the Phillips Curve for inflation in the imported goods sector, it is necessary to solve the optimisation problem of foreign firms setting the price of their goods in the domestic market. When receiving a signal to update its price, a foreign exporter chooses the price of its good in the domestic market $P_{F,i,t}$ to maximise:

$$\sum_{k=0}^{\infty} E_t(\alpha^k Q^*_{t,t+k}\left[C^*_{H,i,t+k}(P^*_{H,i,t} - MC^*_{i,t+k}) + C_{F,i,t+k}(\frac{P_{F,i,t}}{S_{t+k}} - MC^*_{i,t+k})\right] \tag{65}$$

subject to (8).
The first order condition with respect to $P_{F,i,t}$ is given by:

$$E_t \sum_{k=0}^{\infty} \alpha^k Q^*_{t,t+k}[\frac{1}{S_{t+k}}C_{F,i,t+k} - \frac{1}{S_{t+k}}C_{F,i,t+k}\theta_{F,i,t+k} + MC^*_{t+k}\theta_{F,i,t+k}\frac{C_{F,i,t+k}}{P^o_{F,i,t}}] = 0 \tag{66}$$

The equation can be rewritten as:

$$E_t \sum_{k=0}^{\infty} \alpha^k Q^*_{t,t+k} C_{F,i,t+k} [\frac{1}{S_{t+k}} \frac{P^o_{F,i,t}}{P_{F,t}} (1-\theta_{F,i,t+k}) + \frac{MC^*_{t+k}}{P^*_{H,t+k}} \frac{P^*_{H,t+k}}{P_{F,t}} \theta_{F,i,t+k}] = 0 \quad (67)$$

We will now define the relative optimal imported price $R_{F,i,t} = \frac{P^o_{F,i,t}}{P_{F,t}}$, real foreign marginal cost $MCR^*_{t+k} = \frac{MC^*_{t+k}}{P^*_{H,t+k}}$, imported inflation $\Pi_{F,t} = \frac{P_{F,t}}{P_{F,t-1}}$ and the deviation from the law of one price $Z_{t+k} = \frac{P^*_{H,t+k}}{P_{F,t}} S_{t+k}$. After substitution, (67) can be expressed as:

$$E_t \sum_{k=0}^{\infty} \alpha^k Q^*_{t,t+k} C_{F,i,t+k} [\frac{1}{S_{t+k}} R_{F,i,t} (1-\theta_{F,i,t+k}) + MCR^*_{t+k} \frac{Z_{t+k}}{S_{t+k}} \frac{P_{F,t+k}}{P_{F,t}} \theta_{F,i,t+k}] = 0 \quad (68)$$

Using the fact that $Q^*_{k,t+k} = \beta^k \left(\frac{C^*_{t+k}}{C^*_t}\right)^{-\sigma} \frac{P^*_t}{P^*_{t+k}} e^{u^*_{t+k} - u^*_t}$ and after log-linearizing (68) around a symmetric steady state we have:

$$\widehat{r}_{F,i,t} = (1-\alpha\beta) E_t \sum_{k=0}^{\infty} (\alpha\beta)^k (m\widehat{c}r^*_{t+k} + \widehat{z}_{t+k} + \sum_{s=0}^{k} \widehat{\pi}_{F,t+s} - \widehat{\pi}_{F,t} - \frac{1}{\theta-1} \widehat{\theta}_{F,i,t+k}) \quad (69)$$

The log deviation of the price elasticity of demand from its steady state is given by:

$$\widehat{\theta}_{F,i,t+k} = \left(\frac{1}{\gamma-1} + \theta\right) \left[\widehat{r}_{F,i,t} + \widehat{\pi}_{F,t} - \sum_{s=0}^{k} \widehat{\pi}_{F,t+s} + \frac{1}{1+N^*} (\widehat{p}_{F,t} - \widehat{p}_{H,t})\right] \quad (70)$$

Therefore, after substitution, (69) can be expressed as follows:

$$\begin{aligned} \widehat{r}_{F,i,t} = & -\widehat{\pi}_{F,t} + (1-\alpha\beta) E_t \sum_{k=0}^{\infty} (\alpha\beta)^k \sum_{s=0}^{k} \widehat{\pi}_{F,t+s} + \\ & + \frac{1}{1+b} (1-\alpha\beta) E_t \sum_{k=0}^{\infty} (\alpha\beta)^k \left[m\widehat{c}r^*_{t+k} + \widehat{z}_{t+k} - b(1-\varpi)(\widehat{p}_{F,t} - \widehat{p}_{H,t})\right] \end{aligned} \quad (71)$$

where $b = \frac{1}{\theta-1}(\frac{1}{\gamma-1} + \theta)$ and $(1-\varpi) = \frac{1}{1+N^*}$.

It therefore follows that:

$$\widehat{r}_{F,i,t} - \alpha\beta E_t \widehat{r}_{F,i,t+1} = \alpha\beta E_t \widehat{\pi}_{F,t+1} - \widehat{\pi}_{F,t} + (1-\alpha\beta) E_t \sum_{k=0}^{\infty} (\alpha\beta)^k \widehat{\pi}_{F,t} +$$
$$+ \frac{1}{1+b}(1-\alpha\beta)\left[\widehat{mcr}^*_{t+k} + \widehat{z}_{t+k} - b(1-\varpi)(\widehat{p}_{F,t} - \widehat{p}_{H,t})\right] \tag{72}$$

Using the fact that under Calvo price setting $\widehat{r}_{F,i,t} = \frac{\alpha}{1-\alpha}\widehat{\pi}_{F,t}$ we have:

$$\frac{\alpha}{1-\alpha}(\widehat{\pi}_{F,t} - \alpha\beta E_t \widehat{\pi}_{F,t+1}) = \alpha\beta E_t \widehat{\pi}_{F,t+1} + \tag{73}$$
$$+ \frac{1}{1+b}(1-\alpha\beta)\left[\widehat{mcr}^*_{t+k} + \widehat{z}_{t+k} - b(1-\varpi)(\widehat{p}_{F,t} - \widehat{p}_{H,t})\right]$$

After some manipulation, the equation can be expressed as (18).

A.5 Approximation of a firm's profit loss function

Using Taylor series expansion, the quadratic approximation of firm i's profits $\Pi_{t+k}\left(\frac{P^o_{i,t}}{P_{t+k}}\right)$ around $\frac{P^f_{i,t+k}}{P_{t+k}}$, which corresponds to the price which would be optimal for firm i at time $t+k$ if the firm was able to adjust its price costlessly in each period, is given by:

$$\Pi_{t+k}\left(\frac{P^o_{i,t}}{P_{t+k}}\right) \approx \Pi_{t+k}\left(\frac{P^f_{i,t+k}}{P_{t+k}}\right) + \Pi'_{t+k}\left(\frac{P^f_{i,t+k}}{P_{t+k}}\right)\left(\frac{P^f_{i,t+k}}{P_{t+k}} - \frac{P^o_{i,t}}{P_{t+k}}\right) +$$
$$+ \frac{1}{2}\Pi''_{t+k}\left(\frac{P^f_{i,t+k}}{P_{t+k}}\right)\left(\frac{P^f_{i,t+k}}{P_{t+k}} - \frac{P^o_{i,t}}{P_{t+k}}\right)^2 \tag{74}$$

From the Envelope Theorem, the first-order term is equal to zero. Therefore, the difference in profits obtained at price $\frac{P^o_{i,t}}{P_{t+k}}$ prevailing at time $t+k$ and profits obtained at the optimal flexible price in that period, $\frac{P^f_{i,t+k}}{P_{t+k}}$, is given by (22).
A firm's profit (in real terms) at time $t+k$ is equal to:

$$\Pi_{t+k}\left(\frac{P_{i,t+k}}{P_{t+k}}\right) = \left(\frac{P_{i,t+k}}{P_{t+k}}\right) Y_{i,t+k} - MCR_{t+k} Y_{i,t+k} \tag{75}$$

The second derivative of the profit function with respect to $\left(\frac{P_{i,t+k}}{P_{t+k}}\right)$, evaluated at the

optimal flexible price $\frac{P^f_{i,t+k}}{P_{t+k}} = \frac{\theta_{t+k}}{\theta_{t+k}-1} MCR_{t+k}$, is equal to:

$$\Pi''_{t+k}\left(\frac{P^f_{i,t+k}}{P_{t+k}}\right) = -\left[\theta_{i,t+k} + \epsilon_{i,t+k} - 1\right] Y_{i,t+k}\left(\frac{P^f_{i,t+k}}{P_{t+k}}\right)^{-1} \tag{76}$$

The first-order approximation of (76) around a symmetric steady state is given by:

$$\begin{aligned}\Pi''_{t+k}\left(\frac{P^f_{i,t+k}}{P_{t+k}}\right) \approx\ & -(\theta+\epsilon-1)\left(1-\widehat{y}_{i,t+k}+\widehat{p}^f_{i,t+k}\right) Y_i\left(\frac{P_i}{P}\right)^{-1} + \\ & +(\theta+\epsilon)\left(\widehat{\theta}_{i,t+k}+\widehat{\epsilon}_{i,t+k}\right) Y_i\left(\frac{P_i}{P}\right)^{-1}\end{aligned} \tag{77}$$

Using (77), the difference in profits obtained at the optimal flexible price $\frac{P^f_{i,t+k}}{P_{t+k}}$ and the price $\frac{P^o_{i,t}}{P_{t+k}}$, which prevails at time $t+k$, can be written as:

$$\begin{aligned}&\Pi_{t+k}\left(\frac{P^f_{i,t+k}}{P_{t+k}}\right) - \Pi_{t+k}\left(\frac{P^o_{i,t}}{P_{t+k}}\right) \approx \\ \approx\ & \frac{1}{2}\left[(\theta+\epsilon-1)\left(1-\widehat{y}_{i,t+k}+\widehat{p}^f_{i,t+k}\right) - (\theta+\epsilon)\left(\widehat{\theta}_{i,t+k}+\widehat{\epsilon}_{i,t+k}\right)\right]\left(\frac{P_i}{P}\right) Y_i(\widehat{p}^f_{i,t+k}-\widehat{p}^o_{i,t})^2\end{aligned} \tag{78}$$

Therefore, up to the second order, the period loss function can be approximated as in (23).