Why Are Import Prices More Elastic to Local Currency Devaluations Than Revaluations?

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Abstract: A number of recent empirical studies established that exchange rate pass-through into import prices tends to be greater following a devaluation of the local currency compared to a revaluation. Unlike the majority of linear business cycle models with time-dependent nominal rigidity that are ill-equipped to explain such phenomenon, this paper models exchange rate pass-through endogenously in the context of state-dependent frictions inducing downward rigidity of wages, prices and investment as observed in many OECD economies. In a US-UK general equilibrium model, it is shown that the primary source of this asymmetry is the excessive stickiness of UK export prices in the downward direction combined with high dependence of UK exporters on imported raw materials (around 60% of total imports) such that US dollar devaluations, on average, lead to a unit-elastic response of US import prices with a slight overshoot in the short-run, unlike revaluations that give rise to around 30-80% lower pass-through at the border. By contrast, US consumer prices are less elastic to exchange rate changes, because around 40-50% of their composition is attributed to the remuneration for local distribution services that UK exporters hire to transport goods from the US docks to the retail sector. However, US retail prices do inherit some of the tendency from import prices to rise faster and by more than to fall justifying a more 'hawkish' monetary policy when the US dollar devalues than it would otherwise be 'doveish' in case of a revaluation.

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1 Introduction

Macroeconomists have long debated whether or not monetary policy based on the notion of inflation targeting in open economies is fundamentally different from that of the closed economies. Part of the dissimilarity comes from the fact that central banks must be able to accurately predict how the prices of imported goods respond to the exchange rate fluctuations and how it affects the prices facing the local consumers - a channel known as exchange rate pass-through - in order to be able to consistently hit the target. Many of the early empirical estimates established an overwhelmingly partial responsiveness of international prices to exchange rates - a situation commonly referred to as incompleteness - supporting the view that monetary policy is isomorphic in either open or closed economy environments[1].

Unfortunately, the policy implications are not as straight-forward as it may initially seem, since the data of consumer prices utilised back in the day are well-known to be distorted by auxiliary components such as transportation and distribution costs - non-traded services that constitute around 40-50% share of the downstream retail prices in OECD economies according to Burstein et al. (2003) and Goldberg & Campa (2010) - insulating consumer prices from exchange rate shocks. It turns out that focusing on the so-called unit value indices of imported goods, which proxy international price levels at the docks as the goods are being shipped into the country, reveals quite the opposite results. Firstly, Goldberg & Campa (2010) and Burstein & Gopinath (2014) show that the magnitude of exchange rate pass-through is significantly higher using the upstream import prices at the border compared to the downstream retail prices. Secondly, Brun-Aguerre et al. (2016) demonstrate that import prices at the border of many advanced economies tend to be unit-elastic following a devaluation of the local currency, but remarkably incomplete in the case of a revaluation[2]. These results bring back the discussion about the so-called Law of One Price that describes arbitrage-free price setting conditions around the globe. The international arbitrage forces may not be completely broken after all, only the conventional understanding of international prices is challenged by what is now known as the border effect, characterising the complex interactions of local intermediate industries along the pricing chain as part of the distribution process, acting as a shock absorbing mechanism and preventing floating exchange rates to fully manifest into the downstream prices of the retail sector.

Alas, most of the general equilibrium frameworks to-date have analysed just the average degree of pass-through without the distinction between currency devaluations and revaluations[3]. The problem is that devaluations may be more inflationary, even at the consumer level, than revaluations are deflationary, justifying monetary authorities to be more 'hawkish' than they would otherwise be 'doveish'. At the same time, it may be more difficult to boost aggregate trade balance by pursuing conventional currency weakening strategies. The workhorse modelling tools of the most contemporary macroeconomic models, however, rely on time-dependent nominal rigidity, which completely neglects this phenomenon and predicts a time-invariant pass-through controlled largely by the exogenously determined index of price stickiness [see Burstein & Gopinath (2014)]. For this reason, the empirical literature has re-

[1] Some of the most well known papers in the area are Goldberg & Knetter (1997), Taylor (2000), Wolf & Ghosh (2001) and Campa & Goldberg (2002).

[2] The asymmetry of exchange rate pass-through is now well established by Pollard & Coughlin (2004), Bussière (2007), Delatte & López-Villavicencio (2012), Brun-Aguerre et al. (2016) and Kilic (2016).

[3] Here is a non-exhaustive list of the most relevant literature: Obstfeld & Rogoff (1996), Engel (2002), Corsetti & Dedola (2002), Monacelli (2003), Devereux & Engel (2003), Lubik & Schorfheide (2006), Ravn et al. (2007) and Burstein & Gopinath (2014) among many others.

lied on alternative rationalisations that may characterise such unconventional dynamics of international prices more accurately[4]. Even so, the majority of the proposed arguments rely on the dramatic structural breaks that did not seem to occur often enough to account for the behaviour of import prices in the so-called great moderation period (1982-2008), which underlies their empirical findings. The focus of this paper is thus on determining the structural features of the economies that could explain the observed exchange rate pass-through asymmetry given the lack of understanding of such state-dependent phenomenon in the contemporary theoretical literature[5].

Instead, this paper adopts state-dependent nominal and real rigidity and integrates it into an inherently non-linear two-country New-Keynesian general equilibrium framework, where countries engage in international trade of both final and intermediate goods. In reality, the adjustment of wages prompts lobbyists and trade unions to negotiate wages with the employers on behalf of the workers that are more reluctant to accept a wage cut than a pay rise. Similarly, it is in the interest of the profit-maximising firms to maintain their abnormal profits above a certain threshold in order to meet the shareholder requirements. That is, when monetary authorities target positive inflation, rational firms update prices downwards following a negative shock only if it is sufficiently large and considered to be permanent, otherwise it implies readjusting them back upwards in the near future subject to twice the amount of resources it costs to implement the adjustment. In addition, price cuts are typically associated with extensive advertisement campaigns that require more resources to be allocated to the promotion of sales as opposed to price hikes that are typically unannounced - especially so when they are not accompanied with a significant improvement in the quality of the product. As a result, and consistent with the empirical findings of Peltzman (2000), agents attach a greater opportunity cost associated with the downward adjustment of wages and prices resulting in their tendency to rise by more and much faster than to fall. In this model, these less conventional dynamics are established by means of non-linear features such as wage bargaining and price adjustment costs entering the model in LINEX functional form due to Varian (1975).

The quantitative results are applied in the context of United Kingdom as a small domestic economy and United States as the foreign economy under the assumption that all of the traded goods are priced in currency units pertaining to the country from which the goods originate. In other words, firms subscribe to Producer Currency Pricing (PCP) in both countries, which is supported by the high estimated magnitudes of exchange rate pass-through at the border following local currency devaluations. It is demonstrated that exchange rate pass-through asymmetry is predominantly a higher-order phenomenon since linearised simulations of the model lead to a much less time-variant pass-through. That is, the asymmetry in the exchange rate pass-through primarily depends on the openness to trade in intermediate

[4]For example: State-Dependent Technology Switching [Ware & Winter (1988)], Market Share Hysteresis Effect [Froot & Klemperer (1989)] and Capacity Constraints [Knetter (1994)]. See a comprehensive literature survey in Brun-Aguerre et al. (2016).

[5]There are some notable contributions in this subject area. Firstly, Devereux et al. (2004) attempted to endogenise pass-through in a two country model based on the differences in the monetary policy regimes between two countries. Secondly, Devereux & Yetman (2010) showed that exchange rate pass-through is increasing in the magnitude of average inflation at a decreasing rate. However, neither of the above frameworks showed any discrepancy between devaluations and revaluations. Thirdly, Floden & Wilander (2006) introduce state-dependent menu costs where the producer prices may be set either in the exporter and importer currency units. They show that pass-through tends to be greater when importer currency devalues than revalues, but it is overwhelmingly incomplete either scenarios. In addition, they use an unconventional solution algorithm in a linear partial equilibrium context, whereas this paper shows a simple way to derive a state-dependent degree of pass-through in a standard non-linear general equilibrium model.

goods and the parameter capturing the degree of downward price rigidity, where the latter is calibrated to match the second and third moments of consumer price inflation observed in the UK data as closely as possible. Analogously to the empirical literature, when the model is solved using a higher order perturbation method, exchange rate pass-through into US import prices at the border is predicted to remain in the neighbourhood of unity when the US dollar (henceforth USD) devalues with a slight overshoot in the short-run, but it is 30-80% lower when the USD revalues. However, once the goods arrive at their destination market, producers must hire local non-traded distribution services, which in turn alters the composition of the downstream prices facing the consumers and largely insulates them from exchange rate fluctuations.

The so-called exchange rate channel - the mechanism of asymmetrically transmitted shocks to the value of the currency - encompasses two separate and counteracting effects. When the USD devalues, the first effect is the upward pressure on the US import prices due to a change in the relative price of the currencies. The second effect is the fall in the commodity price index facing the UK exporters relying on imported intermediate goods from abroad, which leads to a fall in their production costs and a modest reduction in the UK export prices. The inflationary effects of USD devaluation in the US are cushioned by the downwardly rigid of UK export prices and thus the first effect significantly dominates the second. Conversely, when the USD revalues, US import prices fall due to the change in the relative price of currencies. However, the UK export prices are much more flexible in the upward direction, which implies that the fall in the US import prices will be much more modest compared to the magnitude by which they rise in the opposite scenario. If exchange rate pass-through was to remain symmetric, then US import prices should respond more ferociously to USD revaluations as they do in the case of devaluations, but in a dynamic setting with state-dependent nominal rigidity this would lead to an excess smoothness of the price mark-up from the perspective of the profit-maximising UK exporters.

The remaining parts of the paper are organised in the following order. Section 2 introduces the properties of LINEX adjustment costs that are the main tools used to induce non-linearity in the model. Section 3 introduces the dynamic stochastic general equilibrium model in an open economy setting. Section 4 provides a detailed description of how the model parameters are calibrated and presents some preliminary results. Then section 5 sets out the measurement of endogenous exchange rate pass-through and presents the key findings. Finally, section 6 summarises and concludes.

2 State-Dependence

According to a large number of recent empirical studies conducted during the great moderation period (1982-2008), exchange rate pass-through is a state dependent phenomenon such that import prices of goods and services respond asymetrically to an identical exchange rate change to either direction. But what are the potential sources of this asymmetry? Ware & Winter (1988) argued that large and persistent local currency devaluations might prompt producers relying on imported intermediate goods to abandon existing technologies and opt for alternative locally substitutable factors of production. In the context of United Kingdom, which used to rely almost entirely on imports of petroleum, this may refer to the oil crisis in the 1970s that eventually lead to the discovery of the North Sea Oil reserves. However, the so-called technology-switching argument is not particularly convincing given that by the end of 1981 UK became a large net exporter of oil. Froot & Klemperer (1989) proposed a different idea, where firms in the export industry price their goods in order to maximise the long-run sales in the destination market, because a temporary loss of competitiveness was thought to have a permanent hysteresis effect on the market share. In other words, firms adopted Pricing-to-Market strategies, famously coined by Krugman (1986), where variable price mark-ups can lead to unconventional international price dynamics. However, this approach relies heavily on the inefficiency of international arbitrage forces and the idea that markets are completely segmented by borders. Consequently, exporting firms can set multiple prices in multiple currencies, which typically leads to very low estimated magnitudes of exchange rate pass-through contrary to the estimates at the border.

Figure 1: Volatility and Skewness in United Kingdom Data

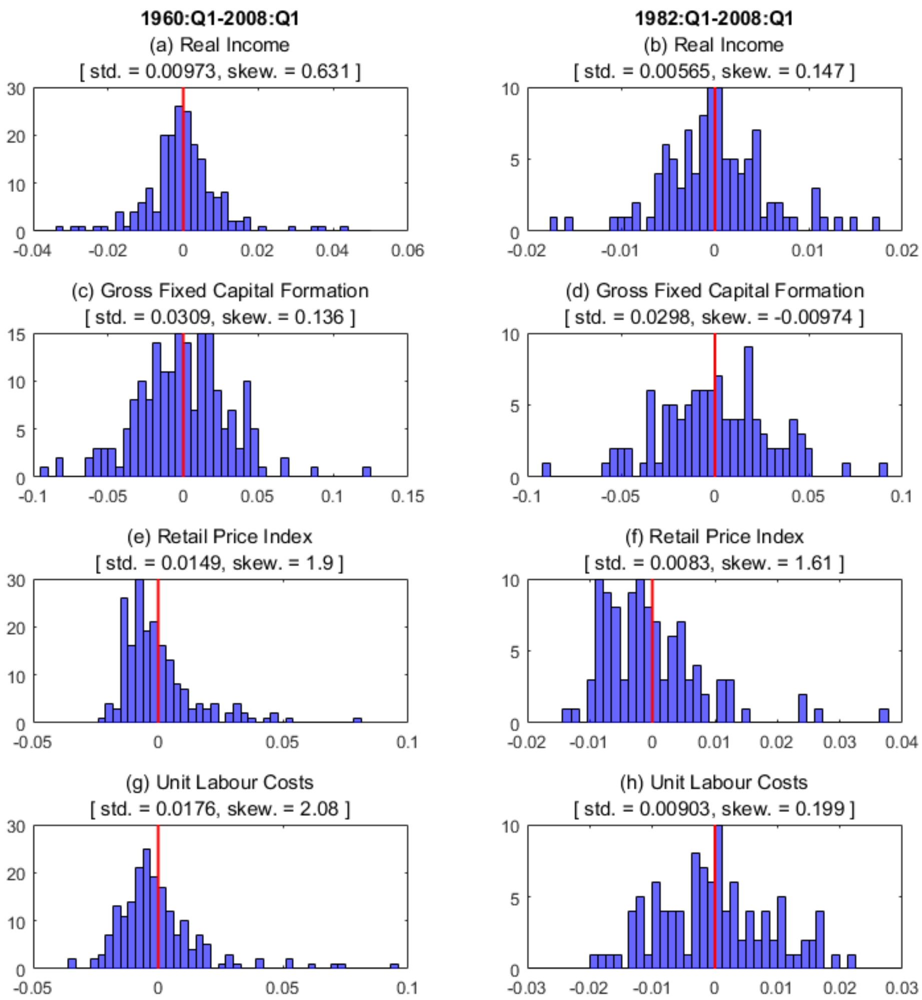

Figure 1: Quarterly de-meaned growth rate distributions of real income, gross fixed capital formation, consumer price index inflation and unit labour costs for two periods - one including the turbulent 1960s-70s and the other one based on the so-called great moderation horizon.

Another rationalisation was proposed by Knetter (1994), who thought that import prices may respond asymmetrically to exchange rate changes, because exporters face short-term capacity constraints and they are unable to immediately accommodate fluctuations in the demand for their products due to the time that it takes to deliver them. Unfortunately, even the capacity constraint idea is at odds with the evidence, which goes all the way back to

the work of Dixit (1980) who argued that imperfectly competitive incumbent firms typically operate at less than full levels of capacity utilisation so that new firms enterring the industry would require very high fixed costs of investment renderring entry itself unprofitable.
Despite the apparent lack of credible sources of asymmetry exclusive to the firms in the export industry, it is very clear that the distributions of both nominal and real variables in United Kingdom exhibit either significant skewness especially during the 1960-70s as demonstrated in figure 1. Naturally, whatever the structural features of economies explain the state-depedence in the labour, capital and product markets will show up in the dynamics of import and export prices. Although the skewness of wages, proxied by unit labour costs, fall dramatically in more recent times, the skewness of retail price inflation remains pervasive. As a result, this paper exploits the imperfections of the supply-side of the economy, particularly the price setters, where state-dependence is established by an introduction of non-linearities in a dynamic stochastic general equilibrium model. The simplest way to do this is by means of adjustment costs that enter the constraints of rational agents that aim to derive conditions summarising their optimal inter-temporal behaviour.
In reality, the adjustment of wages prompts lobbyists and trade unions to negotiate wages with the employers on behalf of the workers that are more reluctant to accept a wage cut than a pay rise. Similarly, it is in the interest of the profit-maximising firms to maintain their abnormal profits above a certain threshold in order to meet the shareholder requirements. That is, when monetary authorities target positive inflation, rational firms update prices downwards following a negative shock only if it is sufficiently large and considered to be permanent, otherwise it implies readjusting them back upwards in the near future subject to twice the amount of resources it costs to implement the adjustment. In addition, price cuts are typically associated with extensive advertisement campaigns that require more resources to be allocated to the promotion of sales as opposed to price hikes that are typically unannounced - especially so when they are not accompanied with a significant improvement in the quality of the product. As a result, agents attach a greater opportunity cost associated with the downward adjustment of wages and prices resulting in their tendency to rise by more and much faster than to fall.
The most convenient functional form of such adjustment costs is LINEX due to Varian (1975). Consider an arbitrary variable X_t. Suppose that adjustment of X_t is more costly in one direction than the other, such that the associated LINEX adjustment costs are given by:

$$\varDelta_x\left(\frac{X_t}{X_{t-1}}\right) = \frac{\phi_x\left[\exp(\zeta_x(\widetilde{X}_t-1)) - \zeta_x(\widetilde{X}_t-1) - 1\right]}{\zeta_x^2} \tag{1}$$

$$\varDelta_x'\left(\frac{X_t}{X_{t-1}}\right) = \frac{\phi_x\left[\exp(\zeta_x(\widetilde{X}_t-1)) - 1\right]}{\zeta_x} \lesseqgtr 0 \tag{2}$$

$$\varDelta_x''\left(\frac{X_t}{X_{t-1}}\right) = \phi_x\left[\exp(\zeta_x(\widetilde{X}_t-1))\right] \lesseqgtr 0 \tag{3}$$

where

$$\widetilde{X}_t = \frac{X_t}{X_{t-1}} \tag{4}$$

The name LINEX derives from its properties, namely $\varDelta_{x,t}(\cdot)$ rises exponentially in the case of $\zeta_x > 0$ ($\zeta_x < 0$) when $\widetilde{X}_t > 1$ ($\widetilde{X}_t < 1$), but approximately linearly when $\widetilde{X}_t < 1$ ($\widetilde{X}_t > 1$). Figure 2 demonstrates how the LINEX adjustment cost function is more convex on the one side compared to a quadratic function, but significantly less steep on the other.

Figure 2: LINEX Adjustment Costs

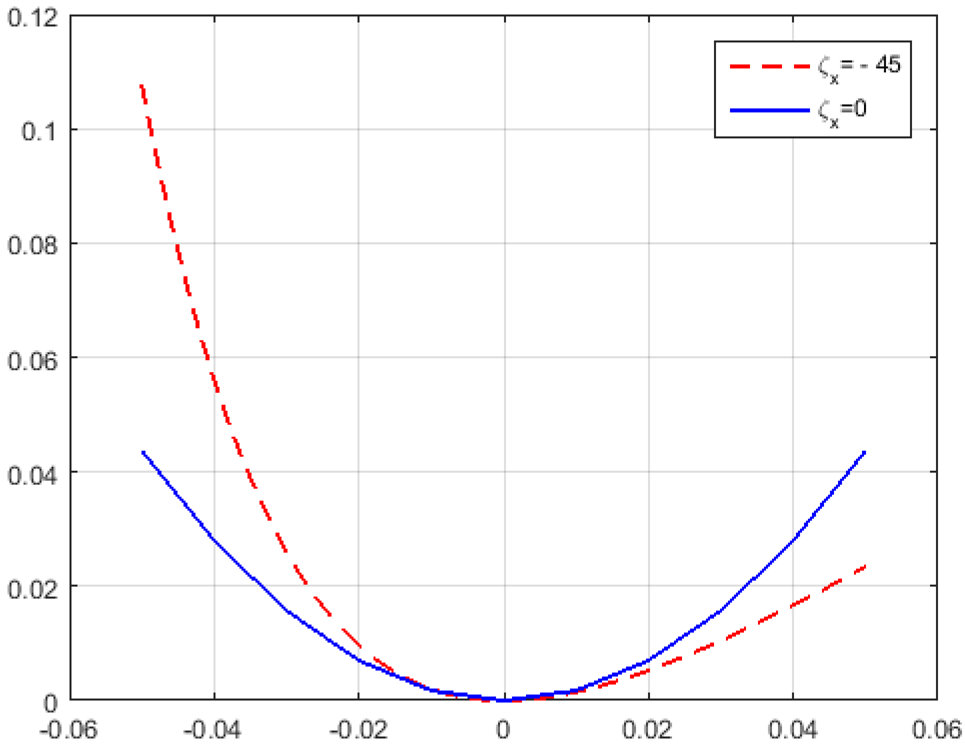

Figure 2: the graph above displays the LINEX adjustment costs of variable X_t when $\phi_x = 35$, where the vertical and horizontal axes measure $\varDelta_{x,t}(\cdot)$ and $\widetilde{X}_t - 1$ respectively.

Furthermore, the reason why LINEX functional form has attracted a lot of attention in recent years is because in the special case when $\zeta_x = 0$, neither upward or downward rigidity is present, and LINEX adjustment costs boil down to the quadratic functional form:

$$\lim_{\zeta_x \to 0} \varDelta_x \left(\frac{X_t}{X_{t-1}} \right) = \frac{\phi_x}{2} \left[\frac{X_t}{X_{t-1}} - 1 \right]^2 \tag{5}$$

$$\lim_{\zeta_x \to 0} \varDelta'_x \left(\frac{X_t}{X_{t-1}} \right) = \phi_x \left[\frac{X_t}{X_{t-1}} - 1 \right] \tag{6}$$

$$\lim_{\zeta_x \to 0} \varDelta''_x \left(\frac{X_t}{X_{t-1}} \right) = \phi_x \tag{7}$$

where the above can be verified more formally using the L'hopital's rule. The continuous nature of LINEX adjustment costs is particularly useful in the context of non-linear business cycle models since they are directly applicable to all of the non-linear estimation algorithms as opposed to a piecewise-quadratic counterpart. Although non-linear estimation is not conducted in this paper, the state-dependent nature of the adjustment costs greatly influences the solution of the model. It is easily seen that the state-dependent behaviour of X_t is derived by perturbating the model using a second or higher order approximation and the non-linear solution induces skewness of both nominal and real variables.

The application of LINEX adjustment cost functions to business cycle models is already widespread in the closed economy frameworks such as Kim & Ruge-Murcia (2009), Room & Dabusinskas (2011), Kim & Ruge-Murcia (2011), Abbritti & Fahr (2011) and Aruoba et al. (2013). However, they tend to focus on the downward rigidity of wages rather than prices, but this is seems less appropriate in the context of United Kingdom. Price adjustment costs are also commonly referred to as menu costs as famously coined by Mankiw (1985) and the literature on state-dependent pricing is growing rapidly. At the same time, the typical state-dependent pricing analysis follows a different methodology where menu costs are firm-specific and they are fixed[6]. In the latter scenario, firms adjust prices only if the marginal profits of doing so exceeds the associated fixed costs. Consequently, if the menu costs were constrained by a certain distribution across a continuum of firms, those that exhibit smaller menu costs would adjust prices more frequently and vice versa.

The conventional approach has the benefit of explaining the stylised empirical fact that an average firm adjust its price around every 3-4 quarters, but the magnitude and frequency of adjustment depends on the state of the economy. In the case of LINEX adjustment costs, all firms will adjust their prices no matter how small are the shocks associated with the state variables because all firms face a homogeneous price adjustment cost schedule somewhat in the fashion of Rotemberg (1982). It follows that the LINEX menu costs schedule corresponds to the opportunity cost of price adjustment across a continuum of firms in the economy, since at any point on the schedule firms equate the marginal profits to the marginal costs arising from the adjustment of prices and always react accordingly. While the two interpretations of generally the same idea are entirely different at the firm level, both approaches are observationally equivalent at the aggregate level, yet LINEX adjustment costs are much simpler to implement computationally. Most importantly, LINEX menu costs are consistent with the view expressed in the previous menu cost literature in that small nominal frictions can lead to sizeable aggregate effects as demonstrated by the dynamic stochastic general equilibrium model in the following section.

3 Model

There are three different types of agents in this dynamic stochastic general equilibrium framework: households, firms and the central bank. Households supply labour and rent capital to the firms and demand goods for consumption from both domestic and foreign firms. They are also allowed to trade assets with foreign households in order to smooth their consumption over the business cycle. On the other hand, firms demand labour and capital and produce goods that can be sold locally or abroad. The central bank aims to stabilise the aggregate activity so as to maximise household welfare. Each activity is subject to a varying degree of imperfections in the fashion of New-Keynesian literature described in more detail as follows.

3.1 Preferences

Consider an economy populated by a continuum of rational and infinitely-lived households indexed by $i \in [0, \pi]$ who derive disutility from the supply of labour services - one by each household - to the local firms in the wholesale sector and utility from the consumption of an infinitely-divisible consumption basket of retail goods that are either locally-produced or imported. The conditional household welfare $\mathbb{V}_t(i)$ over the expected life-time consumption $C_t(i)$ and hours spent in the labour force relative to the total endowment of time $L_t(i) \in (0, 1)$

[6]See for example the original work of Mankiw (1985) and the latter more sophisticated developments of this idea in Dotsey et al. (1999), Floden & Wilander (2006) or Golosov & Lucas (2007)

from date $t = 0, 1, 2, ...$ is assumed to be homothetic and expressed as a Bellman equation:

$$\mathbb{V}_t = \mathbb{U}_t + \beta \, \mathbb{E}_t[\mathbb{V}_{t+1}] \tag{8}$$

where $\mathbb{E}_t$ stands for the conditional expectations operator, $\beta \in (0, 1)$ is the parameter controlling household impatience and $\mathbb{U}_t$ is the period utility function specified as in Greenwood et al. (1988) with superficial consumption habits:

$$\mathbb{U}_t = \frac{[C_t - \chi C_{t-1} - \psi L_t^{\varphi}]^{1-\omega} - 1}{1 - \omega} \tag{9}$$

such that the parameter $\psi > 0$ denotes the relative disutility of labour and determines the optimal steady state of labour hours, $\varphi > 0$ stands for the elasticity of labour supply, the curvature of the utility function is measured by $\omega > 1$ and $\chi \in (0, 1)$ governs the strength of the superficial habits formed on the basis of the aggregate consumption basket[7].

3.2 Consumption Smoothing

Quasi-concavity of preferences is defined by a positive and diminishing marginal utility of consumption:

$$\mathbb{U}_{c,t} = \varPhi_{v,t} - \chi\beta \, \mathbb{E}_t \left[\varPhi_{v,t+1}\right] \tag{10}$$

$$\varPhi_{v,t} = (C_t - \chi C_{t-1} - \psi L_t^{\varphi})^{-\omega} \tag{11}$$

As is well known, these properties entail risk-aversion and provide households an incentive to maximise their conditional life-time welfare subject to an indefinite sequence of budget constraints - one for every discrete time period - in order to smooth their inter-temporal consumption by saving or borrowing throughout the business cycle:

$$C_t + I_t + \mathbb{E}_t \left[\frac{\varOmega_{t+1}}{r_t}\right] \leq \varOmega_t + \left[1 - \varDelta_w \left(\frac{w_t}{w_{t-1}}\right)\right] w_t L_t + x_t K_t + F_t \tag{12}$$

where investment expenditure I_t into capital stock K_t earns a real rate of return x_t per unit of capital in each period of time. The aggregate real wage is denoted by w_t, adjustment of which prompts the real wage bargaining costs $\varDelta_{w,t}(\cdot)$ specified in LINEX functional form. While the allocation of resources in this economy is efficient in the long-run, such that the steady state of the economy is unaffected by the wage bargaining outcome, the state-dependent labour market distortion is viewed as lobbying that is part of rent-seeking behaviour in the short-run. As such, wage bargaining costs are deducted from the total labour earnings as they are effectively sunk, which provides an incentive for risk-averse agents to adjust the real wage more gradually in order to minimise the volatility of labour income. Then the term F_t stands for the corporate profit dividend that accrues to the households as part of the firm ownership. The total expected asset wealth is denoted by $\mathbb{E}_t[\varOmega_{t+1}]$, the price of which is the opportunity cost of consumption today captured by the gross real interest rate r_t. The

[7] The choice of the shape of the utility function was mainly guided by the properties of quasi-concavity and additive non-separability, which is known to produce a rich autocorrelation structure of the business cycle models especially when combined with the formation of consumption habits. While Greenwood et al. (1988) preferences are known to produce labour supply independent of consumption, the presence of superficial consumption habits circumvents this special feature as is shown below. There is also little evidence for the role of time-inseparability of preferences in general equilibrium models (see Schmitt-Grohe & Uribe (2012)), which is why the more general Jaimovich & Rebelo (2009) preferences were not chosen.

inter-temporal consumption allocation of the households is assumed to be fully diversified across a continuum of local states of nature by purchasing state-contingent claims that are readily available in the local asset markets with Arrow-Debreu structure. Furthermore, the prevalence of the conventional Backus & Smith (1993) consumption risk-sharing relationship throughout the policy horizon is presumed:

$$q_t = \frac{Q_t P_t^*}{P_t} \tag{13}$$

$$= \frac{\gamma \mathbb{U}_{c,t}^*}{\mathbb{U}_{c,t}} \tag{14}$$

where $\gamma > 0$ measures the exogenous initial condition of the domestic net holdings of foreign assets, q_t denotes the real exchange rate, P_t and P_t^* stand for the domestic and foreign consumer price indices respectively, and Q_t denotes the nominal exchange rate defined as the domestic price of foreign currency such that a rise in its value implies domestic currency devaluation. Conversely, $Q_t^* = Q_t^{-1}$ such that a rise in Q_t^* implies a foreign currency devaluation. Henceforth, the asterisk $*$ stands for foreign variables. The efficient international consumption risk-sharing implicitly presumed a complete international asset market structure. Although in practice it may not be possible to fully diversify the aggregate risk arising from country-specific shocks in the local asset markets, such as the volatility of aggregate consumption in the rest of the world, for the sake of simplicity in an already complex framework, this framework eschews the possibility of incomplete international asset market structure. The presence of complete financial asset markets allows households to smooth their life-time consumption optimally, which is reflected in the first order condition with respect to the stock of assets otherwise known as the Euler equation:

$$1 = \beta r_t \mathbb{E}_t \left[\frac{\mathbb{U}_{c,t+1}}{\mathbb{U}_{c,t}} \right] \tag{15}$$

That is, the above equates the foregone utility from consumption today to the discounted marginal utility of consumption tomorrow given that households earn a time-varying rate of real interest on their current savings with certainty.

3.3 Investment

In each time period, the outstanding capital stock depreciates at a rate $\delta \in (0, 1)$. The wear and tear can be replaced by households investing part of their income into purchasing new capital stock, which gives rise to the following capital accumulation equation:

$$K_t = (1 - \delta) K_{t-1} + \left[1 - \Delta_k \left(\frac{I_t}{I_{t-1}} \right) \right] I_t \tag{16}$$

However, in addition to the cost of capital itself, households also incur LINEX costs of installing new hardware denoted by $\Delta_{k,t}(\cdot)$, which is one of the most important features in terms of inducing persistence of nominal and real variables in response to exogenous shocks[8]. The approach adopted here is very similar to Smets & Wouters (2007) or Fernandez-Villaverde (2010), where the shadow price of capital relative to consumption depends on the level of investment at any time period, which is captured by the marginal Tobin's Q denoted as

[8]Fixed costs of investment are not introduced in this model due to the findings of Thomas (2002) who argued that they have limited influence on the dynamics of investment at the aggregate level.

TQ_t and it is identified from the first order condition of the household welfare maximisation problem with respect to investment:

$$1 = \left[1 - \Delta_{k,t}(\cdot) - \Delta'_{k,t}(\cdot)\left(\frac{I_t}{I_{t-1}}\right)\right] TQ_t + \mathbb{E}_t\left[\Delta'_{k,t+1}(\cdot)\left(\frac{I_{t+1}}{I_t}\right)^2 \frac{TQ_{t+1}}{r_t}\right] \tag{17}$$

where the number of apostrophes alongside the adjustment costs henceforth indicates the order of the partial derivative. In other words, Tobin's Q measures the value of current capital stock relative to its replacement cost:

$$TQ_t = \mathbb{E}_t\left[\frac{x_{t+1} + TQ_{t+1}(1-\delta)}{r_t}\right] \tag{18}$$

and it is equal to the expected gross rate of return from purchasing one unit of capital. Both capital and consumption are implicitly infinitely divisible as indicated by continuous and well-behaved schedules outlined above. In short, households invest when they value an additional unit of capital more than an additional unit of consumption such that $TQ_t > 1$ and the converse is true when $TQ_t < 1$. The absence of any divergence between the cost of capital and consumption in this framework implies that, in the long-run, $TQ = 1$ such that capital stock remains constant over time.

3.4 Labour Supply

The depiction of the labour market based on state-dependent real rigidity is now standard in the contemporary literature. Here, the firms in the wholesale sector demand a bundle of labour services N_t. The aggregate labour supply consists a continuum of specialised labour services $L_t(i)$, which are aggregated into bundles by a competitive labour packer operating in the local economy. The labour packer production technology is given by the Constant Elasticity of Substitution (CES) functional form due to Dixit & Stiglitz (1977):

$$N_t = \left[\pi^{-\frac{1}{\epsilon}} \int_0^{\pi} L_t(i)^{\frac{\epsilon-1}{\epsilon}} di\right]^{\frac{\epsilon}{\epsilon-1}} \tag{19}$$

Where $\epsilon > 1$ denotes the elasticity of substitution between different labour services, the demand for which is described by the first order condition of the labour packer profit maximisation problem:

$$L_t(i) = \frac{N_t}{\pi}\left[\frac{w_t(i)}{w_t}\right]^{-\epsilon} \tag{20}$$

The aggregate labour supply can then be shown to be equivalent to the labour demand per worker so long as household preferences are homothetic and aggregate production exhibits constant returns to scale[9]:

$$L_t = \int_0^{\pi} L_t(i) di = \frac{N_t}{\pi} \tag{21}$$

[9]It is implicitly assumed that each household is composed of a continuum of family members all of which engage in insurance schemes against any changes in their labour participation at the extensive margin due to a change in the real wage, thus the preferences are well-behaved and full employment prevails throughout the horizon. In other words, labour hours are perfectly divisible such that the consumption-employment space does not exhibit any kinks or other unconventional behaviour.

In this framework, the wage bargaining outcome is state-dependent since the negotiated change in the real wage prompts wage bargaining costs incurred by the households. Consequently, households exert some bargaining power over wages with the wholesalers, the solution for which is obtained by maximising the life-time utility of the households subject to the above sequence of budget constraints and the service-specific labour demand schedules, which gives rise to the following first order condition:

$$w_t = \frac{\Phi_{w,1,t}}{\Phi_{w,2,t}} \tag{22}$$

where the auxiliary wage setting variables are given by:

$$\Phi_{w,1,t} = \left(\frac{\epsilon}{1-\epsilon}\right)\frac{\mathbb{U}_{l,t}}{\mathbb{U}_{c,t}} \tag{23}$$

$$\Phi_{w,2,t} = 1 - \Delta_{w,t}(\cdot) + \frac{\Delta'_{w,t}(\cdot)\Pi_{w,t}}{\epsilon-1} - \beta\mathbb{E}_t\left[\frac{\mathbb{U}_{c,t+1}}{\mathbb{U}_{c,t}}\frac{L_{t+1}}{L_t}\frac{\Delta'_{w,t+1}(\cdot)\Pi_{w,t+1}}{\epsilon-1}\right] \tag{24}$$

then $\Pi_{w,t}$ denotes the gross growth rate of the real wage and $\mathbb{U}_{l,t}$ stands for the economy-wide marginal disutility of labour:

$$\mathbb{U}_{l,t} = -\psi\varphi\Phi_{v,t}L_t^{\varphi-1} \tag{25}$$

Notice, firstly, that despite the Greenwood et al. (1988) preferences adopted in this framework, the labour supply is not independent of the wealth effects due to the presence of superficial consumption habits. Secondly, the preference homotheticity ensures that all households negotiating their wage find an identical optimal real wage level at any time period, which ultimately renders the index i redundant. Effectively, all of the worker-specific variables coincide with the market average that remunerates labour services with an identical wage for all of the labour services due to the subsequently presumed constant returns to scale technology.

3.5 Production Technology

There are three types of producers in this framework: wholesalers operating in the upstream market, retailers operating in the downstream market and distributors who transport goods from the upstream to the downstream market. Distribution services, and therefore the retail goods, are by their very nature hired locally and not traded internationally. The goods and services that are internationally traded pertain to the upstream market and thus they are considered to be final goods, where the production takes place according to Cobb-Douglas technology that exhibits constant returns to scale:

$$Y_t(j,h) = A_t M_t^{\kappa_m} K_t^{\kappa_k} N_t^{\kappa_n} \tag{26}$$

where h indicates the domestic upstream market index as opposed to f - the foreign upstream market and $j \in [0,\pi]$ denotes the continuum of sectors in the wholesale industry. The internationally traded intermediate goods are denoted by M_t and A_t stands for the stochastic total factor productivity. The factor shares are given by $\kappa_m = \xi$, $\kappa_k = (1-\xi)\kappa$ and $\kappa_n = (1-\xi)(1-\kappa)$ such that the share of imported commodities or raw materials $\xi \in (0,1)$ measures the openness to commodity trade as in Monacelli (2013), whereas $\kappa \in (0,1)$ stands for the capital share of income net of commodities. The price of imported commodities in real terms in this framework is proxied by the bilateral real exchange rate based on a highly significant positive relationship that prevails between both of these variables in short- and long-term horizons[10]. The wholesale firms are assumed to operate in a monopolistically competitive market structure, such that they exert an infinitesimally small market share and have no monopsony power to influence neither the aggregate price indices nor the factor prices. The real marginal costs of the wholesale firms can thus be expressed as a weighted average of the factor prices, which are equivalent across the entire industry:

$$MC_t(h) = \frac{\Phi_{mc,t}}{A_t} \tag{27}$$

$$\Phi_{mc,t} = \left(\frac{q_t}{\kappa_m}\right)^{\kappa_m} \left(\frac{x_t}{\kappa_k}\right)^{\kappa_k} \left(\frac{w_t}{\kappa_n}\right)^{\kappa_n} \tag{28}$$

Next, the wholesale goods are sold off to a competitive distributor, which aggregates all of the upstream varieties of goods into bundles in two separate stages. The first stage comprises of aggregating the output of domestic and foreign wholesalers separately:

$$Y_t(h) = \left[\pi^{-\frac{1}{\varepsilon}} \int_0^{\pi} Y_t(j,h)^{\frac{\varepsilon-1}{\varepsilon}} dj\right]^{\frac{\varepsilon}{\varepsilon-1}}, Y_t(f) = \left[(1-\pi)^{-\frac{1}{\varepsilon}} \int_0^{\pi} Y_t(j,f)^{\frac{\varepsilon-1}{\varepsilon}} dj\right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{29}$$

where $\varepsilon > 1$ stands for the elasticity of substitution between different upstream sectors such that the aggregate price indices of the domestic and foreign wholesale varieties are given by:

$$P_t(h) = \left[\frac{1}{\pi} \int_0^{\pi} P_t(j,h)^{1-\varepsilon} dj\right]^{\frac{1}{1-\varepsilon}}, P_t(f) = \left[\frac{1}{1-\pi} \int_0^{\pi} P_t(j,f)^{1-\varepsilon} dj\right]^{\frac{1}{1-\varepsilon}} \tag{30}$$

The second stage involves aggregating domestic and foreign varieties using CES technology:

$$Y_t(u) = \left[(1-\alpha)^{\frac{1}{\eta}} \; Y_t(h)^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} Y_t(f)^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \tag{31}$$

where $\eta > 1$ stands for the elasticity of substitution between the domestic and foreign goods, $\alpha \in (0,1)$ measures the degree of openness to trade in final goods in the domestic economy and the aggregate price index of traded goods can be expressed as a weighted average of domestic and foreign wholesale prices:

$$S_t = \left[(1-\alpha)P_t(h)^{1-\eta} + \alpha P_t(f)^{1-\eta}\right]^{\frac{1}{1-\eta}} \tag{32}$$

The bundles of wholesale goods are then delivered to the competitive retailers using $\theta \in (0,1)$ share of distribution services D_t to work as part of the transportation process, where distribution services and the bundle of wholesale goods are assumed to be complements:

$$Y_t = \min\left\{\frac{D_t}{\theta}, \frac{Y_t(u)}{1-\theta}\right\} \tag{33}$$

While von Neumann-Leontief technology specified above is less conventional in the general equilibrium literature, it is difficult to dispute the fact that the capacity of the logistical equipment cannot be easily substituted with more of the wholesale goods so that the latter could end up on the shelves of the downstream market. Following Balassa (1964), the

[10] A number of empirical studies have shown the importance of the real exchange rate in driving the dynamics of commodity prices, especially the price of oil, irrespective of whether or not the domestic economy is a net importer or a net exporter of raw materials. See for example Gilbert (1989), Huang & Feng (2007), Chen et al. (2010), Coudert et al. (2013) or Chung (2016) among many others.

standard presumption in the literature about the non-traded goods, and in particular the distribution services, is that they are highly labour-intensive. In fact, Burstein et al. (2003) and Atkeson & Burstein (2008) argue that the majority of the costs associated distributing and transporting goods pertain solely to the wage bill. For this reason, the distribution costs in real terms are assumed to be a concave function of the real wage:

$$\Theta_t = \lambda \left[\frac{w_t}{\mu}\right]^{\theta\kappa_n} \tag{34}$$

where $\lambda, \mu > 0$ are constant terms. Hence, when the distribution service sector is infinitesimally small such that $\theta \to 0$, the aggregate production function simplifies to the conventional wholesale production technology. As a result, consumer prices can be expressed as a weighted average of prices associated with traded and non-traded goods[11]:

$$P_t = \frac{(1-\theta)S_t}{1-\theta\Theta_t}$$

where the downstream prices are clearly less responsive to exchange rate fluctuations than the upstream prices, because the former take into the account the non-traded distribution services that are not directly related to the relative price of currency.

3.6 Terms of Trade

The primary goal of this paper is to determine the source of the widely-observed asymmetrical responsiveness of import prices to the devaluations and revaluations of the local currency. This requires some assumptions about the way in which international prices are linked. Traditionally, macroeconomists have argued against the prevalence of the so-called Absolute Purchasing Power Parity (APPP) hypothesis, which aims to equate the aggregate price levels across the globe based on the assumption that international arbitrage forces are efficient in mitigating any price level divergence. It is not difficult to see that APPP will generally not hold in this model even if foreign market structure is symmetrical:

$$Y_t^*(u) = \left[\alpha^{*\frac{1}{\eta}}\, Y_t^*(h)^{\frac{\eta-1}{\eta}} + (1-\alpha^*)^{\frac{1}{\eta}}\, Y_t^*(f)^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \tag{35}$$

because the foreign aggregate price index of the traded goods:

$$S_t^* = \left[\alpha^*\, P_t^*(h)^{1-\eta} + (1-\alpha^*)P_t^*(f)^{1-\eta}\right]^{\frac{1}{1-\eta}} \tag{36}$$

is influenced by the home-bias, which incorporates the legal frameworks of the customs unions in the foreign economy α^*, inducing reversion to an entirely different long-run mean compared to that in the domestic economy. The APPP is further violated due to the presence of distribution costs - remuneration for non-traded services contributing a sizeable proportion to the composition of the prices associated with the final goods in the downstream markets. Hence, when the wholesale goods are exported to the markets abroad, the downstream producers hire local distribution services, a large share of which is composed of the wage bill

[11]Similar results can be derived using Cobb-Douglas or CES production technology of the retail goods. However, it is well known that it becomes increasingly difficult to obtain a solution to the long-run terms of trade with a multi-layer industry aggregation approach in a highly non-linear technology setting and places more restrictions on the specification of Θ_t such as a very high share of distribution services relative to wholesale output. The von Neumann-Leontief technology is able to circumvent some of these difficulties by imposing a very simple and flexible specification of Θ_t compatible with empirically plausible values for θ.

and thus directly depend on the long-run macroeconomic fundamentals of the local economy such as productivity growth - not the efficiency of international arbitrage forces necessary to deliver APPP. As expected, differences in the extent of distribution costs across countries in this model can lead to price level divergence of the same variety in the downstream markets segmented by borders.

Instead, this framework makes use of the Relative Purchasing Power Parity (RPPP) hypothesis, which presumes that the rate at which prices grow, or inflation, remains constant across domestic and foreign economies, but only in the long-run. This is equivalent to the assumption of international inflation target alignment. Consequently, the complete financial market structure delivers a mean-reverting bilateral real exchange rate, but the relative price of currency, or the nominal exchange rate, contains a unit root. As is shown below, exchange rate pass-through is independent of the autocorrelation structure of the level of nominal exchange rate itself, therefore non-stationarity in the relative price of currency does not play an important role in this framework. However, stationary real exchange rate is crucial in terms of establishing saddle-path stability given its important impact on the extent of trade in goods and services prevalent in this business cycle model. In addition, the international arbitrage forces are assumed to be efficient, but only at the firm-level and only for the varieties of the wholesale goods, which are reflected in the following no-arbitrage conditions:

$$P_t(j,h) = Q_t P_t^*(j,h), \quad P_t^*(j,f) = Q_t^* P_t(j,f) \tag{37}$$

This assumption is supported by the recent empirical studies documenting a high elasticity of import prices when international prices are evaluated at the border, which excludes distribution costs [see Goldberg & Campa (2010), Burstein & Gopinath (2014) and Brun-Aguerre et al. (2016)]. Using the above Law of One Price, the conventional tool to evaluate the degree to which goods and services from any country of origin are internationally competitive, known as the terms of trade, can be expressed as a relative price ratio in either domestic or foreign currency:

$$e_t = \frac{P_t(f)}{P_t(h)} = \frac{P_t^*(f)}{P_t^*(h)} \tag{38}$$

such that a price hike of the domestic varieties relative to the foreign denominated in either currencies, or a fall in e_t, is interpreted as a deterioration of the domestic terms of trade and vice versa. As is well known, general equilibrium frameworks possess an unfortunate feature of price level indeterminacy such that only relative or second order dynamics of the nominal variables can be predicted. For this reason, most of the nominal variables introduced in this framework are henceforth expressed either in first differences or relative to the consumer price index, which measures the purchasing power of the households. In terms of the notation, s_t denotes the relative price of the traded good basket in the domestic economy:

$$s_t = \frac{1-\theta\Theta_t}{1-\theta} = \left[(1-\alpha)\Xi_t(h)^{1-\eta} + \alpha\Xi_t(f)^{1-\eta}\right]^{\frac{1}{1-\eta}} \tag{39}$$

where $\Xi_t(j,h)$ and $\Xi_t(j,f)$ denote the relative price of domestic and foreign varieties respectively. It follows that the terms of trade can be expressed in the following way:

$$e_t = \frac{q_t \Xi_t^*(f)}{\Xi_t(h)} \tag{40}$$

and in turn, the net exports of the domestic economy can be identified by making use of all of the above international price linkages:

$$NX_t = (1-\theta^*)\alpha^* Y_t^* \varXi_t^*(h)^{-\eta} - (1-\theta)\alpha Y_t \varXi_t(f)^{-\eta} - q_t M_t \tag{41}$$

where the domestic trade balance is defined as the sum of domestic exports less the domestic imports of goods and services as well as imports of commodities.

3.7 Nominal Rigidity

The prices in the upstream market are not perfectly flexible, but rather every time the wholesalers decide to adjust their price they incur one-off menu costs denoted as $\varDelta_{\pi,t}(h|\cdot)$. Consequently, the real profit dividend of domestic wholesalers can be expressed as follows:

$$F_t(j,h) = (Y_t(j,h) + Y_t^*(j,h))\left[\left(1 - \varDelta_\pi\left(\frac{P_t(j,h)}{\varPi P_{t-1}(j,h)}\right)\right)\varXi_t(j,h) - MC_t(h)\right] - B(h) \tag{42}$$

where the first term stands for the total revenue from the domestic and foreign markets, whereas $B(h) \geq 0$ are the fixed costs of production. To ease the notation, the deviation of domestic producer price inflation from the trend is henceforth denoted by:

$$\widetilde{\varPi}_t(h) = \frac{P_t(j,h)}{\varPi P_{t-1}(j,h)} \tag{43}$$

such that $\varPi$ measures the trend inflation. The optimal price that the j'th wholesaler decides to set is then derived under the assumption of Producer Currency Pricing (PCP) by maximising the present discounted value of the real profits subject to a sequence of demand schedules facing the wholesale firm and taking the foreign sales as given, which leads to the following first order condition

$$\varXi_t(h) = \frac{\varPhi_{\pi,t,1}(h)}{\varPhi_{\pi,t,2}(h)} \tag{44}$$

where the auxiliary price setting variables are expressed as follows:

$$\varPhi_{\pi,1,t}(h) = \left(\frac{\varepsilon}{\varepsilon-1}\right) MC_t(h) \tag{45}$$

$$\varPhi_{\pi,2,t}(h) = 1 - \varDelta_{\pi,t}(h|\cdot) + \frac{\varDelta'_{\pi,t}(h|\cdot)\widetilde{\varPi}_t(h)}{\varepsilon-1} - \mathbb{E}_t\left[\frac{Y_{t+1}(h)}{Y_t(h)}\frac{\varDelta'_{\pi,t+1}(h|\cdot)\widetilde{\varPi}_{t+1}(h)}{R_t\varPi_{t+1}(\varepsilon-1)}\right] \tag{46}$$

such that $R_t = r_t\mathbb{E}_t[\varPi_{t+1}]$ is the nominal interest rate and $\varPi_t$ stands for the consumer price index inflation. Notice that constant returns to scale production technology implies that all firms find an identical optimal level at any time period, which again renders the index j effectively redundant. By construction, the only wedge that prevails after the aggregation is between the downstream and upstream market prices since the latter takes the costs of distribution into the account. Consequently, the goods market clearing condition in the domestic economy:

$$(1 - \varDelta_{\pi,t}(h|\cdot))Y_t = C_t + (1 + \varDelta_{k,t}(\cdot))I_t + NX_t + \varDelta_{w,t}(\cdot)w_t L_t \tag{47}$$

is influenced by the rigidities associated with adjustment of prices, wages and investment, since they are compensated by sacrificing a proportion of real income.

3.8 Central Bank

The monetary policy intervention in the above economy is justified on the grounds of imperfectly flexible wage and price adjustments, which induce persistent deviations of output from the equilibrium and exacerbate the business cycle. A standard approach is taken here such that the central bank adopts an implementable dual-mandate Taylor rule:

$$\frac{R_t}{R} = \left[\Lambda_t \left(\frac{\Pi_t}{\Pi} \right)^{\nu_\pi} \left(\frac{Y_t}{Y} \right)^{\nu_y} \right]^{1-\rho_r} \left(\frac{R_{t-1}}{R} \right)^{\rho_r} \tag{48}$$

where Λ_t is the transitory monetary policy shock, ρ_r measures the persistence of the nominal interest rate and ν_π and ν_y are the parameters of the monetary policy responsiveness to the deviation of CPI inflation from the quarterly trend and output gap respectively.

4 Calibration and Preliminary Simulations

The quantitative results are applied in the context of United Kingdom as the domestic economy and United States as the foreign economy. In order to simplify the computations, United Kingdom is further assumed to be a small open economy that takes the real variables of the United States as given. The state variables explicitly introduced in the above general equilibrium model are all summarised by the following autoregressive structure:

$$\mathbf{H}_t = \mathbf{\Psi}_0 + \mathbf{\Psi}_1 \mathbf{H}_{t-1} + \mathbf{Z}_t \tag{49}$$

where

$$\mathbf{H}_t = \begin{bmatrix} \log(A_t) \\ \log(\Lambda_t) \\ \log(Y_t^*) \\ \log(\mathbb{U}_{c,t}^*) \end{bmatrix} \mathbf{\Psi}_0 = \begin{bmatrix} 0 \\ 0 \\ (1-\rho_y)\log(\varsigma_y Y) \\ (1-\rho_u)\log(\mathbb{U}_c) \end{bmatrix} \mathbf{\Psi}_1 = \begin{bmatrix} \rho_a & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & \rho_y & 0 \\ 0 & 0 & 0 & \rho_u \end{bmatrix} \mathbf{Z}_t = \begin{bmatrix} \sigma_a z_{a,t} \\ \sigma_\Lambda z_{\Lambda,t} \\ \sigma_y z_{y,t} \\ \sigma_u z_{u,t} \end{bmatrix}$$

such that $z_t(\cdot) \sim iid(0,1)$ denotes a white noise process associated with each of the stochastic variables, whereas $\rho(\cdot)$ and $\sigma(\cdot)$ measure the persistence and the standard deviation for each of the stochastic processes. The shocks are calibrated as shown in table 1 using the sample period of 1982:Q1-2008:Q1, corresponding to the time period considered in most of the relevant empirical studies on exchange rate pass-through. One of the exceptions is the unobserved state variable $\mathbb{U}_{c,t}^*$ denoting the foreign preference shocks, the persistence and standard deviation of should ideally be calibrated to match the second moments of the real exchange rate as closely as possible. As expected, the real exchange rate is very stable in the framework of perfect consumption risk-sharing approach and while outcome could be improved with the introduction of an incomplete international asset market structure, it was not pursued for the sake of simplicity of an already complicated model. As a result, the calibration $\mathbb{U}_{c,t}^*$ accommodates the accuracy of the moments associated with wage and price inflation. The calibration of the remaining parameters in this framework is mainly based on the previous business cycle models such as Adolfson et al. (2007), Smets & Wouters (2007) and Schmitt-Grohe & Uribe (2012). The demographic parameter π is normalised to unity, ς_c is estimated using the World Bank statistics, γ is proxied by the mean dollar price of the Pound-Sterling and ς_π is simply the annual target rate of inflation of 2% converted into quarterly frequency. The openness to trade α and α^* are measured as the shares of imported goods relative to aggregate income in the UK and US respectively. In this model, all of the varieties of goods sold within an economy are imperfectly substitutable, but less so than they are substitutable between the economies, which gives the following inequality relation: $1 < \eta < \varepsilon < \infty$. Similar assumption is made by Adolfson et al. (2007) or De Paoli (2009) for example. As for the share of the distribution costs in the total composition of retail prices, it is set equal to 40% in the United States - consistent with the estimate of Burstein et al. (2003) - and analogously in the United Kingdom. Parameter ξ, measuring the openness to trade in commodities, is less conventional. According to Chung (2016), around 60% of all the imported goods in the UK are intermediate and, in addition, total imports of goods and services constitute around 24% of GDP in the UK. Then, because ξ measures the share of commodities in the production of wholesale goods, $\xi(1-\theta) = 0.6 \times 0.24 = 0.144$ and $\xi = 0.24$ when $\theta = 0.4$, which is even lower than the estimate of 34% by Goldberg & Campa (2010).

Table 1: Calibration of Parameters

Parameter	**Description**	**Value**
β	Discount Factor	0.995
L	Steady State of Labour Hours	0.300
η	EOS Between International Goods	1.100
ε	EOS Between Local Goods	6.000
ϵ	EOS Between Labour Services	7.500
δ	Capital Depreciation Rate	0.025
ω	Utility Curvature	1.500
φ	Elasticity of Labour Supply	3.000
χ	Superficial Consumption Habits	0.700
ν_π	Inflation Aversion	1.500
ν_y	Output Gap Aversion	0.500
π	Size of Domestic Population	1.000
ς_π	Trend of Quarterly Inflation	0.005
γ	Average Pound-Sterling Price of US Dollar	0.610
ς_y	Average US-UK Per Capita Income Ratio	1.520
λ	Size of the Distribution Costs	2.000
θ	Share of Distribution Services in UK	0.400
θ^*	Share of Distribution Services in US	0.400
κ	Capital Share of Wholesale Output	0.230
ξ	Openness to Commodity Trade	0.240
α	UK Openness to Final Goods Trade	0.240
α^*	US Openness to Final Goods Trade	0.100
ϕ_π	Size of Menu Costs	30.000
ϕ_w	Size of Wage Bargaining Costs	5.000
ϕ_k	Size of Investment Adjustment Costs	0.350
ζ_π	Downward Rigidity of Prices	-1000.000
ζ_w	Downward Rigidity of Wages	-2500.000
ζ_k	Downward Rigidity of Investment	-10.000
ρ_a	Persistence of TFP Shocks	0.788
ρ_r	Persistence of Monetary Policy Shocks	0.820
ρ_y	Persistence of US Output Shocks	0.905
ρ_u	Persistence of US Preference Shocks	0.800
σ_a	Std. Dev. of TFP Shocks	0.0056
σ_Λ	Std. Dev. of Monetary Policy Shocks	0.0033
σ_y	Std. Dev. of US Consumption Shocks	0.0056
σ_u	Std. Dev. of US Preference Shocks	0.0065

As for the size of the distribution costs λ, they are set to as large magnitude as the non-linear computations of the steady state of distribution costs permit so as to obtain enough volatility of consumer prices. Recall that the distribution costs are driven purely by the dynamics of the wage bill and they are greatly influenced by labour productivity growth, which renders the retail price inflation more volatile and less skewed the higher is the magnitude of λ.

Figure 3: Data-to-Model Moment Matching

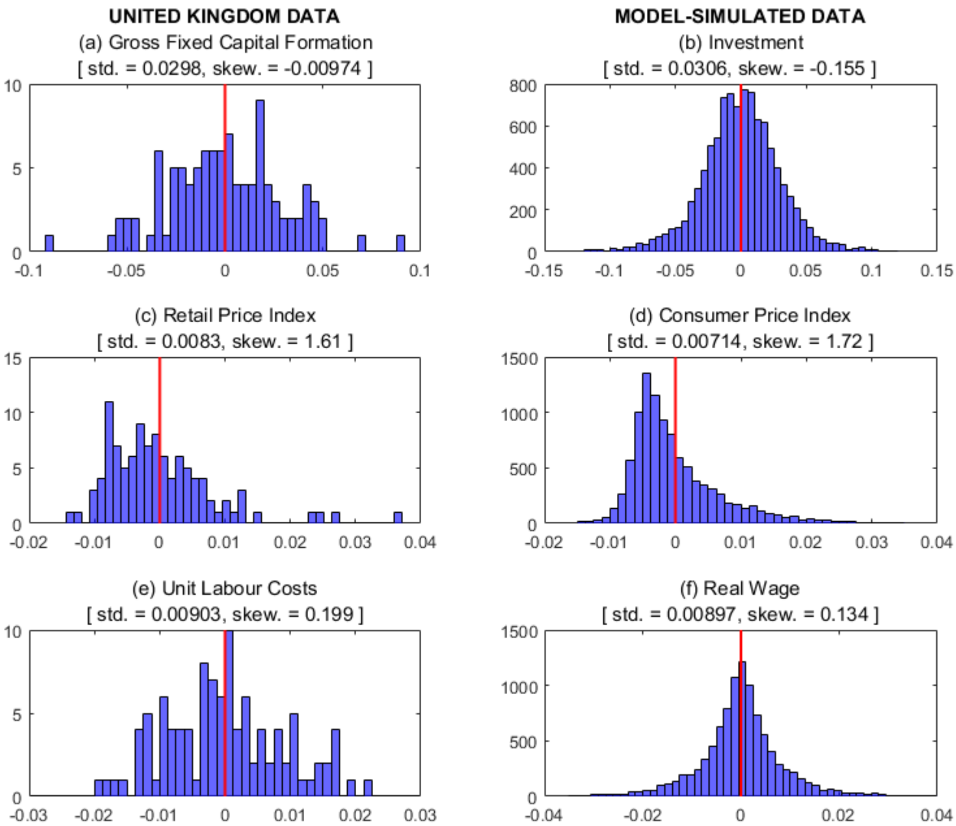

Figure 3 Quarterly de-meaned growth rate distributions of gross capital formation, unit labour costs and the retail price index for the period 1982Q:1-2008Q:1 (panels a, c and e) are plotted alongside with growth rate of investment and inflation of prices and wages for 10000 observations simulated by the model (panels b, d and f), where the numbers in the square brackets measure the standard deviation and skewness respectively.

In turn, the parameters driving the size and the downward rigidity of wages, prices and investment were chosen so as to match the second and third moments of the growth of the British unit labour costs, retail price inflation and gross capital formation as closely as possible. Figure 3 demonstrates that retail price inflation in the UK are highly positively skewed, thus $\zeta_\pi < 0$, whereas real wage and investment growth are hardly skewed at all, but nevertheless $\zeta_w < 0$ and $\zeta_k < 0$ in order to compensate for the effects of the former. Intuitively, the adjustment of wages prompts lobbyists and trade unions to negotiate wages with the employers on behalf of the workers that are more reluctant to accept a wage cut than a pay rise. Similarly, it is in the interest of the profit-maximising firms to maintain their abnormal profits above a certain threshold in order to meet the shareholder requirements. That is, when monetary authorities target positive inflation, rational firms update prices downwards following a negative shock only if it is sufficiently large and considered to be permanent, otherwise it implies readjusting them back upwards in the near future subject to twice the amount of resources it costs to implement the adjustment. In addition, price cuts are typically associated with extensive advertisement campaigns that require more resources to be allocated to the promotion of sales as opposed to price hikes that are typically unannounced

- especially so when they are not accompanied with a significant improvement in the quality of the product. Therefore, consistent with the empirical hypothesis of Peltzman (2000), the outcome of LINEX adjustment cost approach is that agents attach a greater opportunity cost associated with the downward adjustment of wages and prices resulting in their tendency to rise by more and much faster than to fall.

Given the above parameter values and autoregressive specification of the shocks, the general equilibrium model can then be solved numerically using conventional perturbation techniques. In particular, the quantitative results presented in this paper are based on a standard approach of implementing a second order Taylor series approximation of all variables around the steady state and then reorganising the model in state-space form. In turn, so long as there are as many eigenvalues greater than unity as there are forward-looking variables associated with the resulting Jacobian matrix of the dynamic stochastic general equilibrium model - in essence, if the Blanchard & Kahn (1980) conditions hold - the system of difference equations will be characterised by saddle-path stability.

Figure 4: Monetary Policy Shock

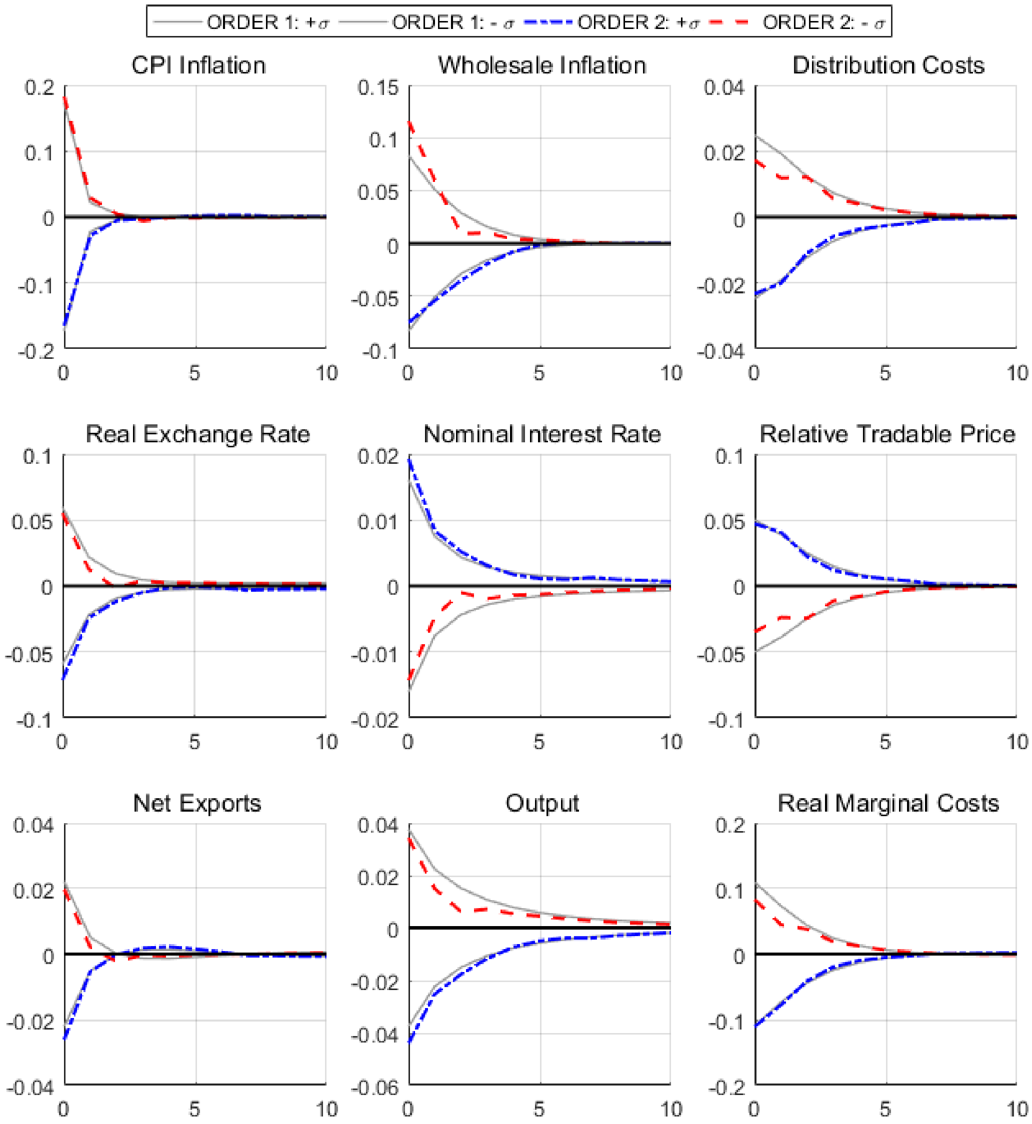

Figure 4: The impulse response functions are plotted for both first and second order perturbations where the vertical axes measure the percentage deviations from the steady state and the horizontal axes stand for time in quarterly frequency. The dashed red line corresponds to a negative shock, whereas the dashed-dot blue line - positive. The thin grey lines represent the linearised solution to the model and provide a symmetric benchmark for comparison with the non-linear solutions. In all cases, the size of the shock is set to the size of 1 standard deviation.

Figure 4 demonstrates the extent of the asymmetry attributed to the downward rigidity of wages and prices that a monetary policy shock, exerts on the impulse response functions characterising the dynamics of the framework as a whole. The influence of LINEX menu costs and wage bargaining costs is very clear in the impulse response functions of PPI inflation and distribution costs in that prices tend to rise faster and by more than they fall consistent with Peltzman (2000). In turn, the monetary authorities are more hawkish following a weakening of the Pound-Sterling than they are doveish when the GBP revalues. Consequently, output is slightly negatively skewed, which reinforces a widely-acknowledged stylised fact that recessions tend to sharper than expansions. As expected, despite the overall downward stickiness of wages, distribution costs tend to fall by more than they rise in response to monetary shocks and act as a shock absorbing mechanism for the downstream prices facing the consumers as is shown by an almost symmetric response of CPI inflation. This is partly the outcome because wage growth is not sufficiently skewed in the upward direction and at the same time output is negatively skewed, which implies that both employment and wages do not rise by as much as they fall, which in turn leads to a diminished asymmetry on the retail prices compared to the wholesale prices. Finally, despite a rise in the wholesale production costs due to more expensive imported raw materials, the aggregate trade balance of the UK improves following a devaluation of the GBP such that the Marshall-Lerner condition holds as reinforced by a high overall positive correlation (0.78).

Interestingly, the consumer prices in the UK turn out to be more responsive to the monetary shocks than the wholesale prices, but on average wholesale prices are 40% more volatile than consumer prices. This is mainly the outcome of the calibration of distribution costs that turn out to be twice as volatile as the real wage and the efficiency of international arbitrage forces in the flows of financial capital across borders, which makes the real interest rate and thus consumer price inflation particularly responsive to exchange rate fluctuations. In addition, exchange rate pass-through ought to look at the relationship between nominal rather than real fluctuations of the currency, because the latter has very strong income effects on the demand side, rather than the latter that tends to hit the supply-side disproportionately. Even so, simply visually inspecting the impulse response function that characterise the numerical solution of the model does not demonstrate how exactly - in quantitative and analytical terms - the model contributes to the debate on the US import price elasticity of the nominal exchange rate and its disparity depending on the direction towards which the exchange rate is driven. For this reason, a more direct and analytical relationship between the UK export prices, US import prices and the nominal exchange rate, otherwise known as exchange rate pass-through, is derived and presented in the next section.

5 Exchange Rate Pass-Through

The term exchange rate pass-through, first coined by Goldberg & Knetter (1997), refers to the incidence of exchange rate volatility on the price index of imported goods. It captures the channel through which international prices are influenced - both directly and indirectly - by the value of currency in the destination market. There are many different reasons why prices may respond to exchange rate fluctuations, but the primary source analysed in the present paper is the international trade of intermediate goods constituting around 60% of UK imports according to Chung (2016) and has a tremendous effect on the production costs of the British wholesale industry. Some previous literature has already analysed the effects of international trade in intermediate goods on exchange rate pass-through such as Amiti et al. (2014) or Burstein & Gopinath (2014). However, the approach adopted here is fundamentally different, because the emphasis is placed on the influence of state-dependent nominal rigidity that induces endogenous variability and asymmetry of exchange rate pass-through that previous frameworks were unable to capture. In addition, the model demonstrates a compatibility of high exchange rate pass-through at the border in the upstream industry with a low exchange rate pass-through at the downstream retail level. As is emphasised above, both final and intermediate goods are internationally traded in this model, but once the UK exports of final goods arrive at the US border, they are sold off to the local distributors that deliver the goods to the US retail market, which comes at a cost that is proportional to the average US wage bill. Consumer prices are thus somewhat insulated from the volatility of exchange rates, because these distribution services are hired locally and they are inherently non-traded internationally such that distribution costs are not directly related to the value of the currency.

5.1 Consequences of Efficient International Arbitrage Forces

Suppose that the international arbitrage forces of the traded final goods pertaining solely to the upstream industry are perfectly efficient as is assumed in the above general equilibrium model. This implies that after taking into the account the relative price of currency, the price of the same variety is equivalent in both countries at the border (i.e. before the distribution costs stack on top of the upstream prices):

$$P_t(h) = Q_t P_t^*(h) \tag{50}$$

Then the resulting link between international prices, otherwise known as the Law of One Price, identifies a simple direct relationship between the exchange rate elasticity of foreign import prices ($erpt_t^*(h)$) and the domestic export prices ($erpt_t(h)$):

$$\begin{aligned} erpt_t^*(h) &= \frac{\partial P_t^*(h)}{\partial Q_t^*} \frac{Q_t^*}{P_t^*(h)} > 0 && (51) \\ &= 1 - \frac{\partial P_t(h)}{\partial Q_t} \frac{Q_t}{P_t(h)} && (52) \\ &= 1 - erpt_t(h) && (53) \end{aligned}$$

In other words, due to the Law of One Price, foreign currency devaluations will generally lead to a rise in the foreign import prices in foreign currency terms, but the degree to which they do depends not just on the extent of the weakening of the foreign currency, but also on the responsiveness of domestic export prices in domestic currency terms. The idea here is that imports of intermediate goods provides a direct link between the commodity prices and the real marginal costs of production and in turn domestic export prices. Since commodity prices are generally highly responsive to exchange rate fluctuations [see Chen et al. (2010) for example], this paper adopts the view that commodity import channel combined with state-dependent nominal rigidity is the predominant cause of the unconventional dynamics of international prices observed in the recent empirical literature.

5.2 Micro-Founded Measurement

In what follows it is firstly assumed that all of the internationally traded goods are priced in the currency pertaining to the country from which the goods originate. In other words, producers subscribe to Producer Currency Pricing (PCP) in both countries, which is supported by the high estimated magnitudes of exchange rate pass-through at the border in both the United States and United Kingdom [see Goldberg & Campa (2010) and Burstein & Gopinath (2014)]. Secondly, all goods are assumed to be priced in the monopolistically competitive market structure, where the market shares of all firms are considered to be infinitesimally small and play no role in the adjustment of prices. Thirdly, factor markets are assumed to be perfectly competitive such that wholesale firms do not have the monopsony power to influence aggregate commodity price index. The framework also eliminates all the strategic interactions that may prevail between the wholesale and retail sectors such that each sector take the other ones prices as given at the time of the decision to adjust prices. This last assumption is made in order to limit the scope of the model to the direct influence of commodity prices on the elasticity of the import prices. As a result, the pricing chain involves three separate stages. The exchange rate transmission channel originates from the volatility of commodity price index, which in this framework is proxied by the exchange rate itself. Secondly, the wholesalers take the commodity price pass-through as given and respond in accordance with their profit-maximising conditions depicted in equations (44) and (45), which gives:

$$erpt_t(h) = \frac{\xi}{1 + \Phi_{\Delta,t}(h)} \tag{54}$$

where the auxiliary variable $\Phi_{\Delta,t}(h)$ captures the dynamic and non-linear effects of exchange rate volatility on domestic export prices attributed to the state-dependent nominal rigidity:

$$\Phi_{\Delta,t}(h) = \frac{\widetilde{\Pi}_t(h)}{\varepsilon - 1} \frac{\Phi_{\pi,3,t}(h)}{\Phi_{\pi,2,t}(h)} \tag{55}$$

$$\begin{aligned} \Phi_{\pi,3,t}(h) = & \, \Delta'_{\pi,t}(h|\cdot)(1 - (\varepsilon - 1)) + \Delta''_{\pi,t}(h|\cdot)\widetilde{\Pi}_t(h) \\ & + \mathbb{E}_t \left[\frac{Y_{t+1}(h)}{Y_t(h)} \frac{\widetilde{\Pi}_{t+1}(h)}{\widetilde{\Pi}_t(h)} \frac{\Delta'_{\pi,t+1}(h|\cdot) + \Delta''_{\pi,t+1}(h|\cdot)\widetilde{\Pi}_{t+1}(h)}{R_t \Pi_{t+1}} \right] \end{aligned} \tag{56}$$

Thirdly, retailers take the wholesale price pass-through as given, which eventually leads to the volatility of prices facing the consumers in the domestic economy:

$$\begin{aligned} erpt^*_t = & \frac{\partial P^*_t}{\partial Q^*_t} \frac{Q^*_t}{P^*_t} > 0 \\ = & \, \alpha^*(1 - \theta^*) \left(\frac{\Xi_t(h)}{q_t} \right)^{1-\eta} erpt^*_t(h) \end{aligned}$$

Consequently, exchange rate pass-through can be simulated as part of the non-linear general equilibrium model in order to analyse its properties over the business cycle.

5.3 Long-Run Pass-Through

In a special case when the domestic exporters use only the domestic factors of production (as is implicitly assumed for the foreign producers) such that $\xi \to 0$, exchange rate pass-through to foreign import prices would be time-invariant and equal to unity - a situation consistent with the most restrictive version of the Law of One Price more commonly referred to as complete or full pass-through at all times. However, more generally, exchange rate pass-through as an endogenous variable gradually converges to its long-run mean when the effects of the shocks fade away and prices adjust fully, such that the long-run import price elasticity of exchange rate in the foreign economy is given by:

$$erpt^{*}(h) = 1 - \frac{\xi}{1 + \frac{\phi_\pi}{\varepsilon - 1}\left(1 + \frac{\beta}{\varPi^2}\right)} \tag{57}$$

Consistent with the hypothesis of Taylor (2000) and the analytical results of Devereux & Yetman (2010), the domestic export prices are more elastic to exchange rate fluctuations in an environment when the trend inflation ($\varPi$) is high, which has a stabilising effect on the foreign import prices. Conversely, the greater is the short-run stickiness of prices (the greater the value of ϕ_π), the less responsive are the domestic export prices in domestic currency terms and, as a result, foreign import prices absorb most of the currency fluctuations. As expected, greater market power of the firms (lower the value of ε) also leads to greater exchange rate pass-through into foreign import prices, because domestic export price stickiness tends to exhibit an inverse relationship to the degree of competition in the product markets [see evidence from Gopinath & Rigobon (2008) or Berman et al. (2012) for example]. At the consumer level, however, exchange rate pass-through is much less responsive to exchange rate fluctuations mainly due to the prevalence of distribution costs constituting a sizeable share θ^* in the composition of the the foreign retail price index. Although the so-called home-bias (α^*), which incorporates the legal frameworks of the customs unions in the foreign economy, also dampens the impact of currency fluctuations on consumer prices.

5.4 Non-Linear Simulation Results

Due to the state-dependent nominal rigidity in the form of LINEX menu costs, the magnitude of exchange rate pass-through in this framework depends both on the size and the direction of the exogenous shocks. Consider firstly, the non-linear simulation results summarised in figure 5 below. Because wholesale prices are sticky, the long-run mean of US import price elasticity at the border is very close to unity despite the involvement in commodity trade. Consequently, UK export prices are virtually neutral to exchange rates in the long-run. This is where the present approach based on nominal rigidity differs in its predictions from Amiti et al. (2014) or Burstein & Gopinath (2014) - international trade of intermediate goods does not lead to incomplete long-run pass-through so long as prices are imperfectly flexible. However, in the short-run, the exchange rate effects on the UK export industry are unprecedented. On average, the model predicts that USD devaluations induce exchange rate pass-through into US import prices at the border that remains in the neighbourhood of unity with a slight overshoot in the short-run, but USD revaluations, on the other hand, lead to around 30-80% lower exchange rate pass-through, where the upper bound is measured as two standard deviations away from the long-run mean of the nominal appreication sub-sample. In more technical terms, the standard deviation of pass-through for appreciations is more than 5 times larger than it is for devaluations as is indicated by the fat tail on the left hand side of the distribution below.

Intuitively, when the USD devalues, the first effect is the upward pressure on the US import prices due to a change in the relative price of the currencies. The second effect is the fall in the commodity price index facing the UK exporters relying on imported intermediate goods from abroad, which leads to a fall in their production costs and a reduction in the UK export prices. The inflationary effects of a USD devaluation in the US is thus cushioned by the reduction of UK export prices, but given their downwardly rigid nature, the first effect significantly dominates the second. Conversely, when the USD revalues, US import prices fall due to the change in the relative price of currencies. However, the UK export prices are much more flexible in the upward direction following a cost-push shock driven by a rise in commodity prices facing the British wholesalers, which implies that the fall in the US import prices at the border will be more modest compared to the magnitude by which they rise in the opposite scenario. If exchange rate pass-through was to remain symmetric, then US import prices should respond more ferociously to USD revaluations as they do in the case of devaluations, but in a dynamic setting with state-dependent nominal rigidity this would lead to an excess smoothness of the price mark-up from the perspective of the profit-maximising US exporters.

Figure 5: Predicted US Import and Consumer Price Elasticities of USD/GBP Exchange Rate

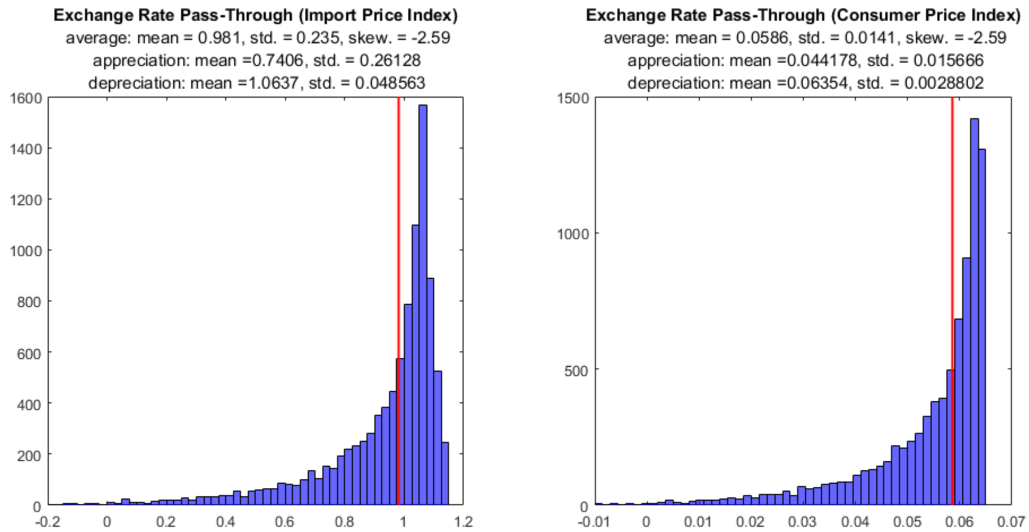

Figure 5: The histograms are plotted using 10000 observations of model-generated data. The thick red line denotes the long-run steady-state such that values to the right correspond to pass-through following USD devaluation and to the left - revaluation. The entire sample is then split into two sub-samples to the left and right hand side of the steady state and descriptive statistics are provided at the top of each graph.

How does this compare to the empirical results? Burstein & Gopinath (2014) estimate and average of 51% pass-through into US import prices at the border with an 8% standard deviation, but they do not distinguish between revaluations and devaluations of the USD. Similarly, Goldberg & Campa (2010) find an average of 42% pass-through into US import prices at the border. On the other hand, Brun-Aguerre et al. (2016) estimate full (i.e. 100%) pass-through in the case of USD devaluations, but only around 28% pass-through in the case of revaluations. In addition, they cannot reject completeness hypothesis in the case of devaluations and similarly cannot reject incompleteness in the case of revaluations even at 1% level of significance. Clearly, looking at the subsamples of devaluations and revaluations paints a broader perspective on the degree exchange rate pass-through asymmetry (as large as 84%) and the median of Brun-Aguerre et al. (2016) estimate does not seem to be far off the estimates of Burstein & Gopinath (2014) or Goldberg & Campa (2010). The present model is able to account for large part of the observed discrepancy and, in the light of the absence of alternative explanations, it is arguably fairly accurate description of the real world realisations.

However, once the goods arrive at their destination market, producers must hire local non-traded distribution services, remuneration for which contributes a sizeable share to the downstream prices facing the consumers and as a result the retail price index is largely insulated from exchange rate shocks. That is, exchange rate pass-through into US CPI is predicted to be only around 0.64% on average and around 0.2-0.4% lower when USD revalues. In other words, suppose that USD devalues by 10% - then US CPI is expected to rise by around 0.64%. On the other hand, if USD revalues by the same amount, then US CPI would only fall by around 1.4-4.4%. Converted into annual frequency, this translates to around 2.52% inflation following a USD devaluation compared with 0.8-1.6% deflation. Therefore, it would seem that the structural features of the economy generally lead to a highly incomplete level exchange rate pass-through at the consumer level, but as long as the international arbitrage forces are efficient, pass-through into import prices remains high at the border. This finding is generally in line with the propositions of Burstein & Gopinath (2014) who estimate 17% and exchange rate pass-through to consumer prices with a standard deviation of 4%. On the other hand, Goldberg & Campa (2010) estimate only around 1% pass-through to the US CPI. In fairness, the above framework does implicitly assume that the US producers are completely unresponsive to the value of USD/GBP exchange rate, which corresponds to the assumption of $\xi^* = 0$, and as a result $erpt_t^*(f) = 0$ at all times. Clearly, this is an oversimplification and indeed it is expected to lead to an underestimation of the level and the asymmetry of exchange rate pass-through into US consumer prices. As things stand, however, the policy implications of this model seem to point to the original conjectures of Taylor (2000) that monetary policy in closed and open economy models, at least from the perspective of the United States during the great moderation era, may not have been that different after all, but these conclusions are stated cautiously.

5.5 Sensitivity Analysis

As a robustness check, the import price elasticities are also simulated using a first order perturbation, which gives rise to a linearised solution of the model. It is arguably more accurate to compare a first and second order perturbation results keeping all the parameters constant as opposed to an example of a scenario when $\zeta_\pi \to 0$ or $\zeta_\pi < 0$, since the former way, unlike the latter, leaves the slope of the Phillips curve unaltered. Table 2 demonstrates that exchange rate pass-through asymmetry is predominantly a higher-order phenomenon and, in particular, second order effects lead to a superior fit of the UK CPI inflation moments. The focus here is on the degree of exchange rate pass-through asymmetry, because the long-run mean is unaffected by the order of the perturbation as demonstrated above. As expected, when the model is linearised, the short-run pass-through becomes much more stable, particularly for low values of ζ_π. This finding is mainly attributed to the fact that linearised solutions are unable to incorporate parameter ζ_π into the numerical solution algorithms at higher orders, resulting in normally distributed aggregate variables - analogously to the distributions of the exogenous shocks - eliminating the fat tail on the left hand side of the distribution. Consequently, even if some parameter combinations in a linearised setting generate some asymmetry, it overpredicts the degree of pass-through following a devaluation of the local currency, since it will tend to overshoot as much as it undershoots contradicting the empirical estimates. As mentioned above, there are infinitely many combinations of ϕ_π

Table 2: Moments of United Kindom CPI Inflation and Exchange Rate Pass-Through Asymmetry in the United States Import Prices

		1st Order Perturbation				2nd Order Perturbation			
		(i) $\zeta_\pi = -100$	**(ii)** $\zeta_\pi = -250$	**(iii)** $\zeta_\pi = -500$	**(iv)** $\zeta_\pi = -1000$	**(v)** $\zeta_\pi = -100$	**(vi)** $\zeta_\pi = -250$	**(vii)** $\zeta_\pi = -500$	**(viii)** $\zeta_\pi = -1000$
(a) $\phi_\pi = 30$	std.(Π_t)	0.0058	0.0058	0.0058	0.0058	0.0063	0.0063	0.0065	0.0071
	skew.(Π_t)	0.0171	0.0171	0.0171	0.0171	0.5065	0.7536	1.1342	1.7184
	asy.$(erpt_t^*(h))$	1.14-2.00%	2.78-4.90%	5.53-9.73%	11.02-19.39%	1.20-2.53%	3.44-8.32%	9.45-24.35%	32.31-84.57%
(b) $\phi_\pi = 60$	std.(Π_t)		0.0051	0.0051	0.0051		0.0058	0.0059	0.0066
	skew.(Π_t)		0.0180	0.0180	0.0180		0.6302	0.8225	1.6198
	asy.$(erpt_t^*(h))$		1.25-2.21%	2.49-4.37%	4.95-8.70%		0.54-1.14%	1.50-3.68%	13.30-36.35%
(c) $\phi_\pi = 120$	std.(Π_t)			0.0044	0.0044			0.0055	0.0058
	skew.(Π_t)			0.0182	0.0182			1.0342	1.3912
	asy.$(erpt_t^*(h))$			0.99-1.74%	1.97-3.46%			1.41-3.79%	4.50-12.55%
(d) $\phi_\pi = 200$	std.(Π_t)				0.0039				0.0052
	skew.(Π_t)				0.0180				1.1855
	asy.$(erpt_t^*(h))$				0.92-1.63%				1.78-5.01%

Table 2: Results of linear and non-linear simulations are presented in large column sections respectively - each consisting of four exponentially increasing values of downward price rigidity parameter. The first column specifies the value for the size of the menu costs (rows a-d) and second column indicates the moment corresponding to a combination of both parameters: standard deviation of CPI inflation, skewness of CPI inflation and the asymmetry of exchange rate pass-through of import prices at the border. The asymmetry is measured as the mean of exchange rate pass-through in two sub-samples: depreciations and appreciations, and adds two standard deviations in case of appreciations (fat tail on the left hand side of the distribution) in order to obtain the estimate of the upper bound.

and ζ_π that may lead to similar results, but it is generally found that the model fit is best for $\phi_\pi > 30$ below which the predicted volatility of pass-through becomes too large. It can also be seen that sizeable exchange rate pass-through asymmetry can only be obtained when the degree of downward price rigidity is sufficiently large. Similarly, the volatility of inflation is decreasing with the magnitude of ϕ_π. However, there is a trade-off between how well the model fits the second or third moment of inflation and at the end a compromise is made in choosing the default calibration, which corresponds to row "a" column "viii" the the table above. While the skewness of inflation is slightly overrpredicted and volatility - underpredicted in the default parameter calibration, it generally gives a much more superior fit of the third moment than the linearised solution or alternative parameter calibrations.

6 Concluding Remarks

A number of recent empirical studies established that exchange rate pass-through into import prices tends to be greater following a devaluation of the local currency compared to a revaluation. Unlike the majority of linear business cycle models with time-dependent nominal rigidity that are ill-equipped to explain such phenomenon, this paper models exchange rate pass-through endogenously in the context of state-dependent frictions inducing downward rigidity of wages, prices and investment as observed in many OECD economies. In a US-UK general equilibrium model, it is shown that the primary source of this asymmetry is the excessive stickiness of UK export prices in the downward direction combined with high dependence of UK exporters on imported raw materials (around 60% of total imports) such that US dollar devaluations, on average, lead to a unit-elastic response of US import prices with a slight overshoot in the short-run, unlike revaluations that give rise to around 30-80% lower pass-through at the border. By contrast, US consumer prices are less elastic to exchange rate changes, because around 40-50% of their composition is attributed to the remuneration for local distribution services that UK exporters hire to transport goods from the US docks to the retail sector. However, US retail prices do inherit some of the tendency from import prices to rise faster and by more than to fall justifying a more 'hawkish' monetary policy when the US dollar devalues than it would otherwise be 'doveish' in case of a revaluation.

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