Import prices and exchange rate pass-through: theory and evidence from the United Kingdom

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Abstract

The appreciation of sterling that began in 1996 appeared to pass through into import prices very slowly, an apparent example of incomplete exchange rate pass-through. Incomplete pass-through has typically been explained by a combination of sticky prices and pricing to market. This can have implications for the monetary transmission mechanism, making it important to establish whether this phenomenon exists in practice. One implication for firms' import (and domestic) price setting is that competitors' prices might affect the mark-up, although this is not a necessary condition. Some of the factors supporting pricing to market may also introduce non-linear responses to exchange rate shocks. It is established that a model of pricing to market including a role for competitors' prices fits the data, but no evidence of non-linearity is found.

Key words: Import prices, exchange rates, pass-through, thresholds.

JEL classification: D43, F12, F41.

Summary

The appreciation of sterling that began in 1996 appeared to feed through into import prices slowly, although there has been considerable downward pressure. Importers appear to have taken the opportunity to raise their margins. This is the topic examined in this paper. We begin by discussing competing theories to explain this phenomenon. We then estimate a model capturing some aspects of the process, focusing on the role of competitors' prices.

The presence of nominal rigidities has often provided a useful explanation for short-run variations in the real exchange rate. But in order to explain the persistent failure of import prices to fall fully in line with the exchange rate, we need more than simple nominal rigidity. Such persistent changes in the real exchange rate suggest the presence of pervasive market segmentation across countries. This is defined as the ability of firms to charge different prices for an identical good in different markets, or alternatively as the ability of firms to price to market (PTM). International market segmentation and imperfect competition then imply that there may be relatively little pass-through of exchange rates to import prices.

On the time series properties of the data, real exchange rate movements are well known to be volatile, but are also highly persistent. Furthermore, there is evidence that most of the real exchange rate variability is due to *traded* goods prices. Moreover, the new open economy macro models show that when such structures are embedded in complete general equilibrium models, there are profound implications for the monetary transmission mechanism. It seems that variable margins, sticky prices and (implicitly) transport costs are crucial elements in explaining the persistence in relative price changes, although not everything can be explained.

One possible implication for firms' import (and domestic) price setting is that competitors' prices affect the mark-up over marginal costs, and it is on this that we focus in this paper. Some of the factors supporting pricing to market may also introduce non-linear responses to exchange rate shocks. That is, small changes in the exchange rate may leave the prices of imported goods unchanged in sterling terms, but large changes that cross a 'threshold' may trigger an adjustment. However, although this kind of behaviour is plausible for firms, the case for aggregate effects is less certain. Aggregation may lead to smooth non-linearities, however, and we discuss ways of testing for this.

We establish that there is evidence for pricing to market and a role for competitors' prices by estimating a mark-up equation with a role for UK prices. The mark-up is over the major six (M6) countries unit labour costs, which implies that the underlying technology is Cobb-Douglas. The mark-up is affected by domestic demand, measured by a measure of capacity utilisation, and by domestic prices. The Johansen results suggest that there is no cointegration, but the method is known to be sensitive to the maintained assumptions and specification. Given weak exogeneity,

single-equation methods are a robust method, and we are able to show that the explanatory variables are indeed weakly exogenous to the long-run relationship. The equation gives a weight of 0.36 to labour costs and 0.64 to UK prices, so PTM appears to be dominant. It is possible that some import pricing may be characterised by purchasing power parity (PPP), although the adjustment coefficients in the system's individual equations suggest this is not a major factor, so we think of our estimates as offering an upper bound on the degree of PTM.

There are potential identification problems. In particular, if PPP held then our equation might conflate the firm's mark-up equation with the PPP relationship. But there is no evidence for multiple long-run relationships. And the evidence from the adjustment coefficients supports PTM as well, as the direction of causality indicated by the adjustment coefficients is from the long-run relationship to import prices. Thus we are confident that there is indeed some pricing to market in UK imports.

By contrast, there is no evidence for non-linearity, either in extreme threshold behaviour or smooth-transition models. We base this conclusion on the results of general tests that are powerful against a range of non-linear alternatives: a specific on-off threshold model where there is an abrupt transition between regimes; a simple spline model allowing differential adjustment speed at positive and negative disequilibria; and a flexible smooth-transition model that allows for continuous variation between regimes, but still nests the extreme case.

1 Introduction

The sterling effective exchange rate (ERI) appreciated sharply by just under 20% between mid-1996 and early 1997, and has subsequently largely maintained this value. Import prices have fallen by less than would be implied by the nominal appreciation. In other words, there has been incomplete exchange rate pass-through. The presence of nominal rigidities has often provided a useful explanation for short-run variations in the real exchange rate.[1] But in order to explain the persistent failure of import prices to fall fully in line with the exchange rate, we need more than simple nominal rigidity. These persistent changes in the real exchange rate suggest the presence of pervasive market segmentation across countries. This is defined as the ability of firms to charge different prices for an identical good in different markets, or alternatively as the ability of firms to price to market (PTM). International market segmentation (and imperfect competition) then imply that there may be relatively little pass-through of exchange rates to import prices. Moreover, the new open economy macro models show that when such structures are embedded in complete GE models, there are profound implications for the monetary transmission mechanism. So it is important for policy to establish whether PTM exists.

In order to explore the rationale for imperfect pass-through, this note reviews several competing theories of price-setting behaviour. These theories also suggest some scope for non-linear adjustment. Small changes in the exchange rate may leave the price of imported goods unchanged in sterling terms, but large changes that cross a 'threshold' may trigger an adjustment. However, while this is plausible for individual firms, the case for aggregate effects is less certain. We next sketch some methods for estimating such non-linear models. We then consider a model of the price mark-up. This provides clear evidence for pricing to market effects, and no evidence of threshold effects or other non-linearity.

2   Price-setting behaviour

2.1   Integrated markets

The law of one price (LOP) is a good place to start. If agents are profit and utility maximising and transportation, resale and distribution are costless then, due to arbitrage, identical goods will command the same price in common currency terms. If firms are also price takers, this is the perfectly competitive paradigm. Markets are non-contestable and fully integrated; there is full pass-through.

If the LOP held for all traded goods and preferences were identical across countries, then absolute[2] purchasing power parity (PPP) would hold. In practice, transport and distribution

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[1] We need to be careful to define the real exchange rate, as there are several candidates. One is the 'Samuelson-Balassa' version, which can be thought of as the ratio of traded to non-traded prices, where the TOT are assumed to be fixed. The implicit economic model here is one where traded goods obey purchasing power parity. In that case, a change in the nominal exchange rate cannot change competitiveness in the traded sector. In our imperfectly competitive world, the more relevant concept is the ratio of domestic to foreign traded prices, or the terms of trade. These concepts can in turn be measured in different ways.

[2] Absolute PPP is where all (common currency) prices for identical products are equal.

costs drive a wedge between domestic and foreign prices. But if these were constant, then relative[3] PPP would hold, and pass-through would still be complete. Moreover, integrated markets remain possible within a framework of imperfect competition. If transport costs are low and buyers organised, local monopolists would be incapable of price discrimination. Firms producing identical goods would have identical mark-ups and one would still expect complete pass-through.

But empirical studies have on the whole rejected the LOP and PPP.[4] Research on prices and exchange rate movements has shown that relative prices of goods are systematically related to the exchange rate. For example, following Engel's (1999) approach, Obstfeld and Rogoff (2000) computed the correlation between the real exchange rate and the relative prices of tradables and non-tradables over time in the United States, Germany, France and Japan and showed that even relative prices of tradables exhibited very little mean-reversion.

In line with these results, researchers have typically found incomplete exchange rate pass-through.[5] However, a number of empirical problems emerged which suggested that this was not sufficient evidence against PPP, mainly because of aggregation issues and the failure to compare like-for-like when comparing prices across countries. Researchers therefore focused on industry data. These provided evidence that pass-through was more complete and somewhat faster. Feenstra (1989) analysed US import prices for cars, trucks and motorcycles from Japan between 1974 and 1987.[6] Pass-through was found to vary between 60% and 100% and occurred within two to three quarters, slightly more and faster than suggested by aggregate estimates. In our work using aggregate data reported below, we hope to avoid this by the use of a matched price index, and then to qualify the extent of pass-through by paying attention to a possible identification problem.

Aggregation issues were not the only arguments against writing off market integration. In open economies, changes in exchange rates impinge on producers' costs, but cost measures may often fail to pick up exchange rate effects. Some studies also found that the larger the importing economy, the smaller was estimated import price pass-through.[7] If the importing country were large enough, then world prices would change after an exchange rate shock. This suggests that although markets may be fully integrated, the estimated exchange rate pass-through may appear incomplete. Nevertheless, the weight of evidence is against PPP and complete pass-through, and our results are consistent with this.

2.2   *Market segmentation and pricing to market*

The repeated empirical failures of PPP encouraged the development of theories based on strategic interaction and market segmentation. The argument in brief is that firms with monopoly power selling differentiated products have an incentive to charge different prices in markets where

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[3] Relative PPP is where (common currency) prices grow at the same rate.

[4] Rogoff (1996).

[5] Goldberg and Knetter (1997).

[6] Feenstra (1989).

[7] Krenin (1977).

preferences differ. In a given market, their monopoly power (which depends on the elasticity of demand they face for their products) and thus their pricing power is determined by the price they charge relative to their competitors'. Changes in the exchange rate affect this relative price, and therefore the monopoly power and thus firms' pricing decisions: as a result, the exchange rate pass-through may only be partial.

This analysis reveals that imperfect competition and market segmentation (due to say transport costs) are insufficient for persistent lack of pass-through. Marston (1990), in a partial equilibrium model, and Bergin and Feenstra (2001), in general equilibrium models, showed that, even with segmented markets, if preferences are identical and demand elasticity unchanged following a shock to the exchange rate, firms have no incentive to set different prices in different markets. Firms will *ex ante* set prices at a constant mark-up over marginal costs and hence PPP will hold. In the event of a shock, if prices are sticky, relative prices may change *ex post*. But these relative price changes can only be transitory, even when exporters price in local currency. The intuition is that, given that the desired mark-up is constant, firms will make the price adjustments once they have the chance to do so.

To achieve persistent [8] exchange rate effects on relative prices following an exchange rate shock,[9] there has to be real strategic interaction between firms; that is, the pricing behaviour of domestic firms has to affect the pricing behaviour of foreign firms. Such effects were modelled by the so-called hysteresis models, in the late 1980s (Krugman (1987), Baldwin (1988), Froot and Klemperer (1989)) and the effects incorporated into the New Open Economy Macromodels very recently (for example by Bergin and Feenstra (2001)). In a standard Dixit-Stiglitz imperfect competition model, a firm's mark-up is inversely related to the elasticity of demand it faces. The greater the elasticity of demand, say because of greater availability of substitutes, the lower is the monopoly power of a firm and hence the lower is the margin. And in some models this elasticity of demand may depend on the price of its output relative to the price of the domestic firm's output. An exchange rate depreciation leads to a rise in the foreign firm's price, and exporters lose market power; the demand curve becomes more elastic. Foreign firms have therefore the incentive to lower their price, and import prices rise by less than suggested by the exchange rate change.

We need to ask whether this hypothesis that the elasticity of demand depends on competitors' prices is properly grounded in theory. The literature can be sorted into two types. First, the elasticity of demand is simply assumed to be a function of foreign prices, for example by assuming a linear demand curve. For example, Dornbusch (1987) presents a model of a Cournot equilibrium between domestic and foreign producers of an homogenous good sold in an oligopolistic domestic market, where the domestic price equilibrium is a weighted average of the domestic and exchange-rate-adjusted foreign marginal costs.[10] The elasticity of demand has two factors: the relative number of domestic to foreign firms, and the ratio of marginal cost to price of

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[8] Persistent does not necessarily imply permanent.

[9] Of course, in a GE framework the idea of an exogenous exchange rate shock is not well defined.

[10] Despite the apparent appeal to strategic interaction arguments, the results are driven by the assumption of a linear (non-constant elasticity) demand curve.

foreign suppliers; the effect of an exchange rate appreciation on domestic prices is unambiguously negative but may well be less than one-for-one. In Appendix B we set out a simple model which makes explicit this interdependence. Second, models of strategic interaction draw from the industrial organisation literature for theories of oligopolistic interaction between domestic and foreign firms in the domestic economy. For example, Froot and Klemperer (1989) present a model in which market share matters for future profits. Given a real exchange rate appreciation, firms will decide whether to raise margins (raising present profits) or lower margins (raising future share and future profits) depending on whether they think that the movement is temporary or permanent. Hence the elasticity of demand can be negative as well as positive, depending on agents' judgments of the nature of the exchange rate shock, their expectations of future paths, and their expectations of their competitors' actions in the (Nash) game. This more securely based theory is therefore ambiguous about effects. In recent New Open Economy Macro models, firms are generally modelled in a simpler imperfectly competitive framework, so the arguments revert to the first type, although the argument is pushed back one step by specifying utility functions which generate the required demand curves, for example by introducing a preference bias towards domestic goods.

In the Baldwin (1988) and Froot and Klemperer (1989) models, there are sunk costs of market entry (eg due to advertising, setting up distribution networks or customer allegiance), which give firms a certain degree of monopoly power. Forward-looking firms take into account a trade-off between raising market share (and thus future profits) and increasing current profits when setting their price. As market share also depends on their competitors' current and future expected price, any change in the expected profile of that price has a bearing on their optimal pricing strategies. This, together with fixed entry costs, suggest that a firm's price change will depend on both the size and duration of an expected exchange rate change. For example, temporary appreciations will encourage foreign firms to raise margins rather than invest in market share. In contrast, permanent appreciations encourage firms to compete for market share, thus pushing down their price—possibly beyond the 'neutral' long run. Permanent appreciation's may also encourage more entry of firms and thus raise the number of varieties of goods. This again affects the elasticity of demand of each firm and hence the margin.

Finally, there may be another route to incomplete pass-through in imperfectly competitive markets. Final 'imported' goods can be thought of as a product produced with the aid of an intermediate good, imports. What might be described as 'distribution' costs are a large part of the final good. Under these circumstances, import cost changes can lead to changes in the elasticity of demand (and hence the mark-up) even if preferences are such that there is constant elasticity of final goods; see Corsetti and Dedola (2002) for an example of such a model, where there is long-run incomplete pass-through.

2.3   Inflation and activity

There are implications for inflation and activity from the models discussed above. This forms part of the New Open Economy Macro literature, surveyed in Obstfeld and Rogoff (2000) and Engel (2001).

The first aspect is the time series properties of the data, which has consequences for inflation. Real exchange rate movements are well known to be volatile, but are also highly persistent. For example, a key stylised fact is that the half-life of real exchange rate movements ranges from 2.5 to as long as 5 years.[11] Rogoff (1996) provides a good summary of the literature on the empirical finding of persistent deviations from PPP. Recent estimates for the UK-US bilateral real exchange rate find a half life of over 5 years over the 1900-96 sample, which appears to have reduced to just under 3 years for the more recent 1973-98 sample. Furthermore, and crucially for our purposes, Engel (1999) finds evidence that most of the real exchange rate variability is due to *traded* goods prices. Roughly speaking, he finds that over 50% of the variability of the real exchange rate is attributable to variability in traded goods prices. For the UK-US bilateral real exchange rate, the traded goods component of the real exchange rate was found to account for 95% of the variability of the real exchange rate. This traded good aspect is consistent with our pricing to market analysis.

It turns out we can also explain the persistence. The effects of pricing to market and non-constant elasticity of demand discussed above have been incorporated into general equilibrium frameworks. Pricing to market alone in GE models seems unable to generate the real exchange rate stickiness observed in the data (Chang and Devereux (1998)). Bergin and Feenstra (2001) add staggered price contracts and find the resulting endogenous persistence is higher than with simple exogenously imposed rigidity, but nevertheless cannot replicate observed persistence on plausible parameter values. It nevertheless seems that variable margins, sticky prices and (implicitly) transport costs are crucial elements in explaining the persistence in relative price changes.

2.4   Summary

There are two implications that flow from the discussion above. The first and most important is that pricing to market may imply that relative competitors' prices enter the firm's pricing equation. The second is that exchange rate or other shocks can have hysteresis effects, where large shocks knock the economy into a new equilibrium. Conceivably, this could be modelled with regime-shifting models, perhaps driven by a Markov process; we do not pursue this route in the current work.

3   An empirical specification

In the standard model of price-setting behaviour prices are a mark-up over marginal costs. Under the assumption of Cobb-Douglas technology, marginal costs may be measured by unit labour costs. In that case [12] we expect that

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[11] However, some argue that this persistence is an artefact following misspecifiation of the true non-linear (often, threshold) model as a linear specification. See Taylor (2000), or Taylor *et al* (2001) for a discussion. But in our work we find no evidence for non-linearity.

[12] See Appendix A, where a more general CES case is explored, of which Cobb-Douglas technology is a special case.

$$p*+e = \mu + (w*+l*-q*+e) \qquad \qquad \textbf{(1)}$$

where $p*+e$ is the (log) sterling import price, $(w*+l*-q*+e)$ is (log) foreign unit labour costs in sterling terms and μ is the mark-up. The point is that the mark-up depends inversely on the elasticity of demand, and PTM theory suggest that this depends upon the relative competitors' price (and possibly other factors). Thus we might have

$$p*+e = \mu_0 + \mu_1(p - p*-e) + (w*+l*-q*+e) \qquad \qquad \textbf{(2)}$$

where $\mu_1(p-p*-e)$ states that the mark-up depends upon the relative price. This is the specification that we estimate in this section. One way of describing it is as a 'margins' equation, as it essentially explains the margin over marginal costs (measured by unit labour costs).

Some imports are of products where pricing to market is implausible – for example, commodities. In those cases **(1)** continues to hold, but the mark-up is simply the competitive return. In addition, PPP holds. Thus for these goods

$$p*+e = p \qquad \qquad \textbf{(3)}$$

Were there two types of good, then any estimated version of **(2)** would lead to estimated mark-ups which were a weighted average of the PPP and imperfectly competitive goods. The possible problematic issue is identification. The estimated equation could be a combination of **(3)** for the PPP goods and **(2)** for the imperfectly competitive pricing to market category. The equation might therefore overstate the role of domestic prices. We return to this and a connected issue in Section 6.3.

4   Data

Our dependent variable is the UK import price deflator, PM. We need a measure of marginal (unit labour; UL) costs, for which data are notoriously poor. We proxy this by the major six (M6) countries, trade weighted to reflect UK trade patterns, using the corresponding trade-weighted effective exchange rate. M6 accounts for about 45% of UK trade in 2000, and data is relatively well measured for these countries. Moreover, the EU and US together account for about 68% of trade (in 1999), so M6 may be a reasonable proxy. There is also the question of the appropriate relative price, the PTM variable ($p-p*-e$). Roughly 85% of imported goods are manufactured, so p might be well proxied by producer prices. But import prices behave quite differently from domestic producer prices taken as a whole: the ratio has trended strongly upwards (Chart 1). This could reflect a real appreciation, but it is more likely to reflect compositional changes. Otherwise our theory suggests that there must have been large and trended shifts in margins, systematically and substantially raising the profitability of imports over three decades.[13]

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[13] Of course, 'imports' are a far from homogenous sector and compositional or taste changes might explain some of the movements in the data. Had we sub-sectoral costs, we would like to look at the disaggregated data. But we do not.

Fortunately, the Office for National Statistics (ONS) constructs an 'import competitiveness' series for manufactures that matches up producer price components to the import price. Based on this, we constructed a series which has been much less trended, as Chart 1 reveals, although formal tests (reported below) reveal it is non-stationary. Even if it were stationary, which is possible given the low power of unit root tests, it is clearly highly persistent. An apparently stationary AR(8) process can be estimated, and after a one-off shock it takes five years to return to the mean.[14] What is particularly interesting, though, is the relationship with the margin. Chart 2 suggests that a relationship does exist. In our econometric analysis we confirm this informal impression.

Chart 1: Producer prices relative to import prices of manufactured goods
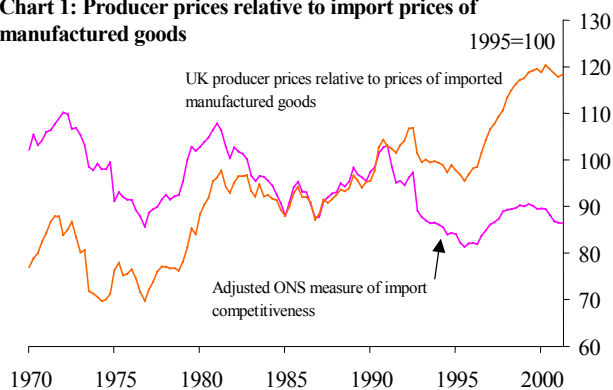
Chart 2: Exporters' mark up over costs and ONS import price competitiveness
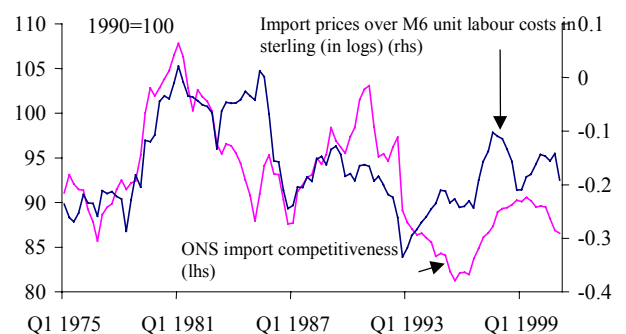
5 Results for the linear margins specification

It is indeed possible to find an econometric relationship between competitiveness and margins, and to estimate a linear equation using equation **(7)**. We began with a specification including four lags in the dynamic terms, where the long-run margin is driven by our import competitiveness variable and a measure of capacity utilisation.[15] Capacity utilisation is included as a proxy for the domestic demand cycle, which may affect margins.[16] Margins are just

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[14] The dynamics are not monotonic so adjustment continues longer than this, overshooting the mean.

[15] Capacity utilisation is constructed from a Cobb-Douglas production function assuming a profit share of 0.3, and an exogenous time trend. Details are given in Bank of England (2001).

[16] The sign of the effect is uncertain. It is commonly assumed the elasticity depends negatively on capacity utilisation as an index of demand. This is not totally uncontroversial. There are arguments suggesting the mark-up is countercyclical. Bils (1989) or more recently Ireland (1998) argue that firms use booms to attract new customers; Rotemberg and Saloner (1986) and (eg) Rotemberg and Woodford (1995) argue that collusive behaviour is less likely in booms, although their argument is restricted to exceptional price wars. Chevalier and Scharfstein (1996) have a model in which capital market imperfections lead to countercyclical pricing. Rotemberg and Woodford (1991) provide evidence of countercyclical mark-ups for the US. Note that a positive coefficient on capacity utilisation may also indicate rising marginal cost. Bils' (1987) paper relies largely on estimated countercyclicality in marginal costs, following inflexible employment levels, to provide evidence for countercyclical mark-ups. The overall evidence, discussed in Layard, Nickell and Jackman (1991, pages 339-40), is mixed. Price (1991) and Smith (2000) report positive effects of capacity utilisation on UK data.

non-stationary: ADF(3)[17] is –2.65, between the 5% and 10% levels. Competitiveness is barely trended but is non-stationary. An ADF(1) test is –1.91, well above the 10% critical value. Thus the relationship we seek to estimate is a cointegrating one. In estimation, we include capacity utilisation inside the ECM term, but this is for economic reasons rather than statistical, as the economic interpretation of the ECM is to do with the margin, and capacity utilisation is stationary. A Johansen test strongly rejects the null of no cointegration at 5% (trace test statistic 40.3; 5% critical value 31.5).[18] However, static homogeneity is rejected.[19] Johansen tests are based on an almost surely overparametrised VAR, and are known to suffer from low power. Given the result that a unique cointegrating relationship exists, a single equation ECM may offer a robust alternative to the Johansen method.[20] Validity is conditional on the regressors being weakly exogenous, but we show below that this condition is satisfied. Thus estimation of the parameters proceeds in a single-equation framework.

The results are presented in Table A. We are able to restrict the dynamics to two lags in import price growth and an acceleration term in M6 ULC. Capacity utilisation is marginally significant and positively signed.[21] Dynamic homogeneity [22] is rejected (p-value = 0.00). The error correction term is 0.095 and well determined. Estimation of a VAR (Table B) with PM, M6 ULC and COM (defined below Table A) with the estimated long-run relationship included as an exogenous variable revealed that it was significant only in the import price equation. Thus competitiveness and (unsurprisingly) M6 ULC are weakly exogenous, single-equation estimates should be reliable, and the well-determined t statistic on the ECM term is further evidence for cointegration. Static homogeneity is maintained in the reported equation, but it can be tested by decomposing COM into PM and the domestic price, PDOM. The test statistic has a p-value of 0.17, so we cannot reject homogeneity. The equation diagnostics are satisfactory for the most part. There is no autocorrelation: an LM(4) test has a p-value of 0.32. The residuals are normal: Jarque-Bera p-value 0.42. Not surprisingly, there is evidence of heteroscedasticity as the estimation period starts in the mid-1970s and spans several monetary and exchange rate regime periods; the White test has a p-value of 0.04, and we report robust (Newey-West) standard errors: the competitiveness term becomes more significant than in the unadjusted case. There is also no evidence of structural instability. Chow breakpoint tests at 1985, 1990 and 1995 have p-values of 0.30, 0.71 and 0.96 respectively.

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[17] Lag lengths are selected to remove autocorrelation from the test regression.

[18] The lag length of 2 was sufficient to ensure white-noise residuals in all equations in the VAR, with a dummy for ERM exit to control of a competitiveness outlier. The test was also passed using lag lengths of 1, 3 and 6.

[19] Static homogeneity is the condition that if all prices and costs affecting import prices rise by a given proportion the import price will rise by the same proportion. It is a fundamental condition required by optimising behaviour.

[20] See Banerjee *et al* (1986), Kremers *et al* (1992) and the survey in Maddala and Kim (1999).

[21] Capacity utilisation is a generated regressor and although estimates are consistent, the standard error may be biased. Estimation instrumenting capacity utilisation returns a coefficient close to that reported in the table (2.44) but significance falls: t ratio 1.25. Other parameter estimates are very close to those reported. If we exclude it the results on the other coefficients are quantitatively similar. In any case, this will affect mainly the short-run coefficients.

[22] Dynamic homogeneity implies that the long-run level of the import price is unaffected by the growth rate of prices and costs. Equivalently, the mark-up is invariant to inflation. This is often seen as a desirable property but, unlike static homogeneity, is not a fundamental economic condition.

The long-run results indicate that margins are very responsive to competitiveness.[23] Decomposing the term, the long-run equation can be rewritten [24] as follows.

$$p* + e = const + 0.36(w* + l* - q* + e) + 0.64p \qquad \textbf{(4)}$$

These coefficients are very well determined: the coefficient on UK prices in this parametrisation has a (robust) t ratio of 11.9. This would seem to indicate that there is substantial potential for imperfect pass-through, consistent with recent experience, and also evidence that adjustment is relatively slow. The relative weights of labour costs and domestic prices are 36:64. On the speed of adjustment, ignoring the short-run dynamics, the error correction implies that 50% of adjustment to the long run has occurred after seven quarters. However, it is important to recognise that this adjustment is conditional on a constant level of import competitiveness. If the equation is reparametrised to condition on constant domestic prices (as written in **(9)**), the error correction term rises to 0.26 (robust t ratio 3.64) and the adjustment is correspondingly more rapid.[25] This constitutes strong evidence for cointegration.

As a final check, we re-estimated the equation using the dynamic OLS method (Saikkonen (1991) and Stock and Watson (1993)). The results for the comparable specification are remarkably similar. Static homogeneity cannot be rejected (p-value 0.81), and the robust t ratio on the domestic price term is 9.47. Moreover, very similar results were obtained from the ECM version of this test due to Banerjee *et al* (1998).[26]

$$p* + e = const + 0.38(w* + l* - q* + e) + 0.62p \qquad \textbf{(5)}$$

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[23] However, the large coefficient on domestic prices could overstate the effect, due to the identification problem mentioned above, where there are 'PPP' as well as PTM goods. We address this in the next sub-section.

[24] The domestic price here is the implicit price that ONS have constructed as the counterpart to imports, rather than the standard producer price index.

[25] This linear transformation does not affect the estimates. Other evidence suggests, as one would expect from our theory and results, that UK domestic prices are affected by competitors' prices; for example, Price (1991) and Smith (2000). This would slow the system dynamics so that the adjustment speed lies somewhere between the two extremes. This argument is formalised in Appendix B.

[26] This method involves adding leads in the regressors to an ECM specification. Static homogeneity is again accepted, and the t test for cointegration is -2.84. This lies below the tabulated critical value at the 25% level, -2.67, but still remains above the 10% level, -3.22. So this is weak evidence for cointegration.

Table A. A linear import price equation: mark-up on M6 labour costs

Sample: 1976:1 2001:2
DLPM =a0 + a1*DLPM(-1) + a2*DLPM(-2) + a3*(DLM6ULC(-1) -(DLM6ULC(-2) + DLM6ULC(-3))) – a4*(MARGIN(-1) - b1*CAPU(-1) – b2*LCOM(-1))

	Coefficient	Std. error	t-statistic	Prob.
a0	-0.770556	0.188783	-4.081698	0.0004
a2	0.175365	0.136357	1.286073	0.0753
a3	0.332852	0.161405	2.062216	0.0033
a4	0.092747	0.047589	1.948909	0.0166
a5	0.094343	0.035211	2.679352	0.0038
b1	2.705995	1.474523	1.835167	0.1168
b2	1.780646	0.415734	4.283143	0.0005

R-squared	0.308192	Mean dependent var	0.009001
Adjusted R-squared	0.264499	S.D. dependent var	0.023816
S.E. of regression	0.020425	Akaike info criterion	-4.877928
Sum squared resid	0.039633	Schwarz criterion	-4.697783

DX = first difference of X; LX = log of X; PM = import price; M6ULC = sterling M6 ULC; MARGIN = PM – M6ULC; CAPU = capacity utilisation; COM = ONS import competitiveness; PDOM = domestic price index corresponding to COM; see Table C; ECM=MARGIN-b1*CAPU-b2*LCOM)

Table B. Weak exogeneity; PM, M6ULC and COM

Vector autoregression estimates
Sample: 1975:4 2001:1
Standard errors in ( ) & t-statistics in [ ]

	DLPM	DLM6ULC	DLCOM
DLPM(-1)	0.141088	-0.034029	0.043807
	(0.12149)	(0.22047)	(0.11096)
	[1.16130]	[-0.15435]	[0.39478]
DLPM(-2)	0.280362	0.077547	0.108063
	(0.11795)	(0.21404)	(0.10773)
	[2.37697]	[0.36230]	[1.00309]
DLM6ULC(-1)	0.074291	0.240980	-0.070867
	(0.09360)	(0.16986)	(0.08549)
	[0.79369]	[1.41871]	[-0.82893]
DLM6ULC(-2)	-0.050457	0.010930	0.066439
	(0.09116)	(0.16543)	(0.08326)
	[-0.55348]	[0.06607]	[0.79793]
DLCOM(-1)	-0.107628	0.178512	0.263068
	(0.17834)	(0.32363)	(0.16289)
	[-0.60350]	[0.55160]	[1.61502]
DLCOM(-2)	0.068984	0.066675	0.099986
	(0.17132)	(0.31089)	(0.15648)
	[0.40266]	[0.21446]	[0.63898]
Constant	0.004985	0.005902	-0.001888
	(0.00243)	(0.00441)	(0.00222)
	[2.05067]	[1.33806]	[-0.85031]
ECM(-1)	**-0.094767**	**-0.051639**	**0.035787**
	(0.03017)	**(0.05474)**	**(0.02755)**
	[-3.14150]	**[-0.94332]**	**[1.29887]**
R-squared	0.303103	0.063859	0.141397
Adj. R-squared	0.251206	-0.005853	0.077459
Sum sq. resids	0.040690	0.133995	0.033945
S.E. equation	0.020806	0.037756	0.019003
F-statistic	5.840510	0.916039	2.211460

6   Identification

As remarked above, the results suggest that there is strong evidence for incomplete pass-through. However, there may be unresolved identification problems.[27] First, suppose PPP held. Then

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[27] We ignore the issue of identification of underlying shocks, in contrast to the Structural VAR (SVAR) approach. Contemporaneous shocks are not explicitly modelled or identified in this methodology. For example, a structural shock might hit both import and producer prices. As we are not modelling those shocks there are issues about

prices continue to be determined as a mark-up on costs, but where the mark-up is now constant. Thus **(7)** loses the term in *(p-p*-e)*. Nevertheless, there is also a law of one price condition, so that **(7)** is replaced by two equations.

$$p*+e = \mu_0 + (w*+l*-q*+e) \qquad\qquad (6)$$

$$p*+e = p \qquad\qquad (7)$$

If both of these are cointegrating relationships then any linear combination also cointegrates. Thus single-equation estimates may be profoundly misleading and may understate the true (100%) level of pass-through, as an estimated version of **(7)** may simply be an arbitrary combination of **(10)** and **(11)**. However, there is a simple test we can carry out. If PPP holds then there should be two cointegrating relationships in the set *{p, p*+e, w*+l*-q*+e}* (**(6)** and **(7)**), whereas under PTM there is one (**(2)**). As reported above, the trace and maximum eigenvalue tests agree that there is a unique relationship, and this holds for a variety of lag lengths. However, also as reported above, when we test the restrictions implied by static homogeneity (required under both PPP and PTM), they are rejected. But we have argued the Johansen test may have low power relative to our single-equation estimates conditional on a unique relationship, where static homogeneity is always accepted. Moreover, the ADF test reported above rejecting stationarity of COM is strong evidence against PPP. While the Johansen results rejecting homogeneity weaken the case for our interpretation, it is clear that there is no reason to suppose that our estimated relationship is corrupted with a second PPP cointegrating relationship.

But as mentioned above, if there are two types of good, 'PPP'[28] and 'PTM' goods, then our equation becomes a weighted average of the price effects from PPP and PTM, which differ in their economic implications. One way to examine this is to look at the weak exogeneity results again. The issue is about the direction of causality. Under PPP, domestic and import prices are related, and the direction of causality is from world prices to domestic. Under PTM, causality is from domestic to import prices. Table B showed that M6ULC and COM were weakly exogenous and that all the adjustment is via import prices. This is consistent with the PTM model, and inconsistent with full PPP.

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causality that cannot be resolved. But it remains true that the cointegrating relationships we identify still stand as long-run structural relationships, and non-identification of structural shocks does not change the interpretation of those long-run relationships.

[28] PPP is interpreted as a competitive model here. But note that if there were 'complete' pricing to market (say because there is complete market segmentation and foreign producers are small, and therefore price takers in the domestic market) then again *p = p* + e.*

Table C. Weak exogeneity; PM, M6ULC and PDOM

Vector autoregression estimates
Sample: 1975:4 2001:1
Standard errors in ( ) & t-statistics in [ ]

	DLPM	DLM6ULC	DLPDOM
DLPM(-1)	0.248716	-0.212541	0.029455
	(0.19150)	(0.34751)	(0.16508)
	[1.29876]	[-0.61160]	[0.17842]
DLPM(-2)	0.211379	0.010872	0.219456
	(0.18388)	(0.33369)	(0.15851)
	[1.14952]	[0.03258]	[1.38445]
DLM6ULC(-1)	0.074291	0.240980	0.003424
	(0.09360)	(0.16986)	(0.08069)
	[0.79369]	[1.41871]	[0.04244]
DLM6ULC(-2)	-0.050457	0.010930	0.015982
	(0.09116)	(0.16543)	(0.07859)
	[-0.55348]	[0.06607]	[0.20338]
DLPDOM(-1)	-0.107628	0.178512	0.155440
	(0.17834)	(0.32363)	(0.15373)
	[-0.60350]	[0.55160]	[1.01110]
DLPDOM(-2)	0.068984	0.066675	0.168969
	(0.17132)	(0.31089)	(0.14768)
	[0.40266]	[0.21446]	[1.14413]
Constant	0.004985	0.005902	0.003097
	(0.00243)	(0.00441)	(0.00210)
	[2.05067]	[1.33806]	[1.47793]
ECM(-1)	**-0.094767**	**-0.051639**	**-0.058980**
	(0.03017)	**(0.05474)**	**(0.02600)**
	[-3.14150]	**[-0.94332]**	**[-2.26809]**
Adj. R-squared	0.251206	-0.005853	0.294138
Sum sq. resids	0.040690	0.133995	0.030237
S.E. equation	0.020806	0.037756	0.017935
F-statistic	5.840510	0.916039	7.012508
Mean dependent	0.009280	0.008258	0.008670
S.D. dependent	0.024044	0.037646	0.021347

Table C reports the same exercise replacing the equation for competitiveness with the implicit domestic price level, PDOM. Domestic prices are apparently endogenous. The size of the ECM needs to be interpreted in terms of the level of the relevant variable. The 'effective' coefficient for imports is about –0.26, while the corresponding coefficient for the domestic price is 0.11. Note that the latter is positive, in single-equation terms error exaggerating. The system still allows equilibration as the import price feeds back through the long-run relationship, and the

import price loading is absolutely larger than the domestic loading.[29] Nevertheless, we can conclude that as the equilibration is occurring via import prices, there is still no evidence for PPP.

7 Non-linearity in the margins equation

7.1 Theory

It is regularly argued that apparent persistence can be modelled by thresholds, where no adjustment takes place within a range of inaction, but that when this threshold is breached, adjustment occurs.[30] Note that neither of the mechanisms discussed above will generate this. What might induce it, however, are menu costs, transport costs or other fixed costs of entering the market. Some variations on these are necessary for the pricing to market models to exist (as PTM cannot hold in fully contestable markets). However, this does not mean that pricing to market automatically implies threshold behaviour. Note that these arguments can apply to integrated markets, though in general there ought to be less scope for inaction. The specific mechanism is rarely spelt out. In addition, how individual firm' behaviour translates into aggregate behaviour is unclear. Standard '*Ss*' models of state-dependent pricing (seminally, Barro (1972)) predict that firms will change prices only when demand (or cost) shifters breach upper or lower bounds: the *S* and *s* refer to the bounds. This is indeed threshold behaviour. But in aggregate, firms may be distributed over the range of their price-setting cycle, some well within the threshold and others close to a bound.[31] The question is whether we will find threshold behaviour in aggregate. In Caplin and Spulber (1987), for relatively high inflation rates, when there is a nominal shock it will not cause all firms to change their prices; but those that do adjust by a large amount, and aggregate prices display no persistence.[32] Subsequent research has attempted to reintroduce price-setting persistence into macroeconomic models, preferably in a tractable manner. For example, Dotsey, King and Wolman (1999) introduce stochastic cost changes, that determine the probability that a firm will be able to endogenously change its price, and this effectively puts back time-contingent pricing. But we are interested in other aspects of the aggregate time series, namely non-linear responses to shocks.

Caballero and Engel (1993) construct a microeconomic model with asymmetric price adjustment at firm level and examine the resulting aggregate time series. They report that '[a]t the aggregate level we find that the aggregate price level responds less to negative shocks than to positive shocks, that the size of this asymmetry increases with the size of the shock, and that the number

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[29] A further test would be to include domestic labour costs in the set of potential cointegrating relationships and identify a domestic price equation as well. But when the set is extended in this way there is no evidence for cointegration, despite the fact that there is such evidence when we exclude it. Finally, for completeness we note that if importers set prices equal to domestic producers', perhaps following from importers being very small in relation to large UK producers, PPP holds but there is no 'pass-through'. This is observationally equivalent to the perfectly competitive PPP case.

[30] Thresholds may induce bias in econometric estimates of persistence in linear models: see Taylor (2000). Threshold models are commonly estimated for exchange rates, often in a smooth-transition framework. See Balke and Fomby (1997), Kilian and Taylor (2001), Michael, Nobay and Peel (1997), Taylor and Peel (2000), Taylor, Peel and Sarno (2001) and Chowdhury, Sarno and Taylor (2002).

[31] This does not always follow. For example, after a large shock all firms may change prices and be at the same point on the boundary.

[32] By contrast, in a low-inflation environment, where prices might fall, the optimal change is smaller and persistence emerges.

of firms changing their prices ─ and therefore the flexibility of the price level to aggregate shocks ─ varies endogenously over time in response to changes in economic conditions'. The step reaction at firm level is smoothed into a form of adjustment that will not be well modelled by simple threshold models. It may be, however, that there is some smooth non-linear process at work, and we explore such effects below, in a model that nests the extreme threshold case.

There is also relevant research in other areas. Caballero (1992) has a paper on factor (labour) adjustment in which he concludes that firm level asymmetric responses need not imply aggregate asymmetry. But a more relevant example might be investment, often modelled in a manner similar to *Ss* models. One example is spelt out by Caballero (1999), who uses an asymmetric linear adjustment cost function: irreversibility results in similar effects (Dixit and Pindyck (1994)). In this model the 'desired' level of capital *K** varies continuously, but actual investment only occurs when the capital stock *K* falls below a critical lower value *L*, at which point it rises to a level *l*. Similarly, disinvestment occurs only when *K* is above a critical upper value *U*, then falling until it reaches *u* (hence *LluU* model; also known as two-sided *Ss*). In Caballero and Engel (1999) a related model is estimated on aggregate data. Aggregation does not remove the non-linearities, which surface in the form of positive skewness and high kurtosis. This suggests that if non-linearities exist in aggregate data, they are unlikely to be simple on-off threshold effects.[33]

7.2 Methodology

We argued above there is scope for non-linear adjustment. In this section we discuss the econometric techniques available to test this hypothesis. The starting point is the linear error correction model.

$$\Delta y_t = \beta_1(L)\Delta y_{t-1} + \beta_2(L)\Delta x_{t-1} - \lambda(y_{t-1} - \alpha x_{t-1}) + \varepsilon_t \qquad \textbf{(8)}$$

Here the dependent variable is *y*, the explanatory variables *x*, and ε the stochastic error term. Define the long-run equilibrium error (or error correction (ECM) term) as $z = y - \alpha x$. Standard practice (Rothman, van Dijk and Franses (2000), van Dijk, Teräsvirta and Franses (2001) is to estimate the long-run relationship with linear methods before examining non-linear dynamics.[34]

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[33] Beyond thresholds, there may be two other types of effect at work. As discussed above, the effects of market entry lead to permanent shifts in market power. This is not non-linear adjustment, but a discrete shift to a new equilibrium, and would require some form of regime-shifting methodology. The second aspect concerns expectations, rather than an inherent non-linearity. Firms will react less to shocks that are expected to be short-lived. At some point after a persistent shock wrongly perceived as transitory, perceptions change and behaviour abruptly adjusts. This calls for explicit modelling of expectations and adjustment. Had we good measures of expectations, we could model this explicitly. Cuthbertson (1990) models UK export prices in this way: Price (1992) uses a generalisation (Pesaran (1991)) of Cuthbertson's model to model UK producer prices. Adjustment depends on the future expected path of the exchange rate (and other variables), with testable restrictions on the leads derived from a quadratic loss function.

[34] Escribano and Mira (2001) have recently extended the Engle-Granger representation theorem to some non-linear cases.

7.3   General tests of non-linearity

We begin by first investigating the general issue of whether non-linearity of any form is present in the data. Our tests are designed to be general, in the sense that they detect any form of non-linearity in the data. But it is an obvious consequence that the power (ability to reject the null of linearity) is bound to be lower than in tests explicitly designed to investigate a particular form of non-linearity. Consequently we also test for specific forms.

We use two tests. The first is the neural network test by Lee, White and Granger (1993). This test considers the relationship of a dependent variable, p, and a set of explanatory variables, q. The null hypothesis is that the relationship between p and q is linear, $p = a'q$; the alternative is that $p = f(q)$. White uses neural networks as they offer a good approximation to any $f(.)$. The second test is similar to the well-known RESET test. It is again motivated by neural networks, but uses a Taylor expansion to the non-linear function. So it tests for the significance of q^2, q^3 and cross products of variables in q and q^2. This has the great advantage of being based on a linear regression, and LM tests can be used (Teräsvirta, Lin and Granger (1993)).[35]

The question then is what q to use. We consider a number of alternatives. We begin with the univariate linearity properties of each variable involved, so that q is taken to be lagged values of each variable. Next, we consider the linearity properties of each equation where p is the change in the import price, and q is the set of regressors used for each equation, including the ECM term itself, z. The main variable of interest is in fact the latter. The implication is then that the adjustment to the long-run equilibrium takes place in a non-linear manner.

7.4   Three specific non-linear models

In this paper we model three explicit forms of non-linearity. First, a threshold model.

$$\Delta y_t = \beta_1(L)\Delta y_{t-1} + \beta_2(L)\Delta x_{t-1} - \lambda_1(d_1 = 1; z_{t-1} > c_1)z_{t-1} - \lambda_2(d_2 = 1; z_{t-1} < c_2)z_{t-1} + \varepsilon_t \qquad \textbf{(9)}$$

where d_i are indicator variables taking the values 1 where the condition is satisfied and 0 else. If $c_1 \neq c_2$ then there is a zone where no adjustment occurs; error correction only occurs outside the thresholds. This model can be estimated conditional on values of c_1 and c_2, and the estimates determined by a simple grid search. Critical values are non-standard but can be determined by simulation (Hansen (1996)). In this example we restrict the other dynamics to be the same across regimes. There is asymmetry in this model as the adjustment parameters are allowed to vary either side of the thresholds.

A simple spline model, equation **(10)**, can also allow asymmetry, but no threshold. In this specification, an indicator variable separates positive and negative and negative disequilibria, and allows the adjustment coefficient to differ between these two cases. Note that **(10)** is encompassed by **(9),** for $c_1 = c_2, = 0$. However, there is still a case for estimating the spline

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[35] See also the closely related tests by Luukkonen, Saikkonen and Teräsvirta (1988).

model as under this null **(10)** will offer a more powerful test of asymmetry.

$$\Delta y_t = \beta_1(L)\Delta y_{t-1} + \beta_2(L)\Delta x_{t-1} - \lambda_1(d_1 = 1; z_{t-1} > 0)z_{t-1} - \lambda_2(d_2 = 1; z_{t-1} < 0)z_{t-1} + \varepsilon_t \quad \textbf{(10)}$$

A third model offers enough flexibility to allow either on-off thresholds or a smooth transition, with linearity as a special case, the quadratic-logistic STAR, but with symmetry.

$$\Delta y_t = \beta_1(L)\Delta y_{t-1} + \beta_2(L)\Delta x_{t-1} - \lambda_1 z_{t-1}(1 - G(s_t)) - \lambda_2 z_{t-1}G(s_t) + \varepsilon_t \quad \textbf{(11)}$$

Here s_t is a trigger variable, z_{t-1} in this case, and

$$G(s_t) = \{1 + \exp[-\gamma(s_t - c_1)(s_t - c_2)/\sigma_s^2]\}^{-1}, \gamma > 0 \quad \textbf{(12)}$$

The $G(.)$ function is normalised on the variance of the trigger s to aid computation. If $\gamma = 0$ the model is linear, and as γ tends to infinity the model tends to the threshold (defined by c_1 and $c_{2)}$. For intermediate values there is a zone in which less adjustment occurs. Thus linearity and the threshold model are nested in this specification, which can be estimated by non-linear least squares. Although at first sight it may not appear to be so, the model is symmetric: the adjustment speed is (approximately) the same for $s_t \gg c_1$ and $s_t \ll c_2$. The model is asymmetric in the sense that local deviations from equilibrium ($z_{t-1} = 0$) lead to different speeds of adjustment for positive and negative values if $c_1 \neq -c_2$. Note that it does not strictly nest **(9)** due to the smoothness, but it may approximate it very closely.

7.5 Results

The general non-linearity tests reveal that there is marginal evidence of non-linearity (at the 10% significance level) in the ECM term, and also in the relationship between the ECM and PM. In particular, we find that both general non-linearity tests do not reject the null hypothesis of linearity when a univariate AR model is fitted to the differenced import price and unit labour cost series. When a similar model is applied to the ECM term the approximate neural network test finds marginal evidence for non-linearity. When looking at whether the linear relationship of the model should be augmented with non-linear terms we again find only marginal evidence for non-linearity and only with the approximate neural network test. Moving on to the specific threshold test using the simulation methodology of Hansen (1996), we test for threshold effects in the ECM term. No evidence for threshold non-linearity is found, as the probability values of the test are close to or equal to 1 (depending on the summary test statistic used, ie supremum, average or exponential average). Of course this does not necessarily mean that there is no non-linearity in the relation since the tests are not very powerful in samples of the size we consider.

We then estimated the STAR specification set out in **(11)**, allowing threshold non-linearities in the ECM. We were unable to estimate the model over the full sample (as parameters caused a numeric overflow), but were successful over a sample starting in 1980. However, linearity cannot be rejected, as γ is insignificantly different from zero with a p-value of 0.96. This conclusion is not necessarily as strong as it seems, as the precision with which this 'smoothing'

parameter can be estimated depends upon there being a reasonable number of observations in the region of the threshold. However, it has a negative point estimate and the threshold parameters are not meaningful in this case. A more general STAR model can be estimated over the entire sample when the dynamics are also allowed to vary between regimes, but again linearity cannot be rejected as γ is again negative (and poorly determined). Thus there is absolutely no evidence in favour of thresholds. Furthermore, linearity cannot be rejected against the spline model (p-value = 0.464). Yet another test is to include polynomial terms in the long-run error, which can be interpreted as a general test for asymmetric adjustment.[36] When this is done for a quadratic and quartic, linearity cannot be rejected (p-value = 0.44 in the latter case). So adjustment is not asymmetric. The clear conclusion here is that there is no real evidence of non-linear effects at work.

8   Conclusions and further work

The appreciation of sterling that began in 1996 has still not fully passed through into import prices. This could simply be due to slow adjustment; or, more profoundly, it could be that long-run equilibrium has changed. We began the study with two aims in mind. First, to consider pass-through in a systematic way; and, second, to explore non-linearities. We link partial pass-through to new theories that suggest that pricing to market may emerge where there is 'market segmentation'. This can have important macroeconomic consequences. The implication for firms' import (and domestic) price setting is that competitors' prices affect the mark-up. There may also be non-linearity, although this is not necessary. Small changes in the exchange rate may leave the prices of imported goods unchanged in sterling terms, but large changes that cross a 'threshold' may trigger an adjustment. Unlike the pricing to market theory, the reasons for this are much less certain. In our work so far, we find evidence that pricing to market exists in two distinct specifications, but no real evidence of non-linearity. The pricing to market effects in our preferred specification (driven by 'world' (major six) unit labour costs) appear to be substantial, but there is an identification problem that lead us to qualify this. However, the results imply that there is some pricing to market; the questions are about how large this is, and how to interpret it. So our first aim has proved fruitful, and we appear able to discount the second.

Finally, we note that there are two issues unexplored in our work. One of the motivations for threshold phenomena is that, as mentioned above, agents will react less to shocks that are expected to be short-lived. The argument is that at some point after a persistent shock wrongly perceived as transitory, perceptions change and behavior abruptly adjusts. But this calls for the proper modelling of expectations and adjustment, rather than an arbitrary threshold model that just happens to fit the data. Given that we are focusing on the strategic pricing behaviour of firms, this was not the paper in which to pursue this argument. The other issue is that, again as mentioned above, exchange rate changes may allow a trade 'beachhead' to be established which permanently affects the competitive structure. This mechanism would be better modelled with switching regime or models of multiple equilbria, rather than the threshold and smooth transition adjustment models considered here.

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[36] All these tests maintain the linear long run. This is defined to include the effect of capacity utilisation. Arguably it should be confined to the short run of the equation. When we do this, the linear results are unchanged as it involves a linear transformation of the equation, and the non-linear results turn out to be virtually identical.

Annex A

Price mark-ups

Monopolistically competitive firms face a demand curve for output of the following form:

$$Y^d = D(Z, P/EP^*) \qquad\qquad\qquad \textbf{(A1)}$$

where P/EP^* is the price relative to competitors' and Z is any other demand shifter. Production is determined by a constant returns to scale (CRS) production function

$$Y^s = F(NA, K) \qquad\qquad\qquad \textbf{(A2)}$$

where A is labour augmenting technical progress. The first-order condition can be written as

$$P = \frac{W/AF_1}{1 - 1/\theta(Z, P/EP^*)}. \qquad\qquad\qquad \textbf{(A3)}$$

W/AF_1 is marginal cost and $1-1/\theta(Z, P/EP^*)$ determines the mark-up. With constant elasticity of substitution (CES) technology,

$$Q = \gamma[\delta K^{-\theta} + (1-\delta)(Ne^{at})^{-\theta}]^{-1/\theta} \qquad\qquad\qquad \textbf{(A4)}$$

where the elasticity of substitution σ is given by $1/(1+\theta)$ and a_t indicates technical progress. In this case, one version of **(A3)** is

$$p = \alpha_0 + w - (1/\sigma)(y-n) - (\sigma-1)/\sigma a_t + \alpha_1(p - p^*) + \alpha_2(y - y') \qquad\qquad \textbf{(A5)}$$

The coefficient on technical progress a_t may be positive or negative, depending on whether σ is less than or greater than one. The unrestricted version of this equation is

$$p = \beta_0 + \beta_1 w + \beta_2(y-n) + \beta_3 t + \beta_4(p - p^*) + \beta_5(y - y') \qquad\qquad \textbf{(A6)}$$

where a_t is usually modelled as a time trend, so that $\beta_3 = -(1+\beta_2)\varphi$ where φ is a positive scale factor. Thus the CES specification implies that $\beta_3 > (<)0$ if $\beta_2 < (>)-1$. With Cobb-Douglas technology σ is unity so $w - (1/\sigma)(y-n)$ may be replaced by unit labour costs. In that case

$$p = \beta_0 + \beta_1(w - y + n) + \beta_4(p - p^*) + \beta_5(y - y') \qquad\qquad \textbf{(A7)}$$

where static homogeneity implies $\beta_1 = 1$. Hence in the Cobb-Douglas specification unit labour costs can be used in the pricing equation and there is no exogenous trend productivity term.

Annex B
A simple oligopoly model

Suppose that the demand curve for a domestic firm is given by:

$$D_h(p_h, p_m, Z)$$

where p_h is the price of home goods (in domestic currency), p_m is the price of imported goods (in home currency) and Z is a scale variable. If the domestic firm has (exogenous) unit costs of production, c, then the profit maximisation problem is:

$$\max D_h(p_h, p_m, Z)[p_h - c]$$

The first-order condition can be written as:

$$p_h = \frac{\eta_h(p_h, p_m, Z)}{\eta_h(p_h, p_m, Z) - 1} c \qquad \textbf{(B1)}$$

In this case the (absolute) elasticity of demand is represented as $\eta_h = -\dfrac{\partial D_h}{\partial p_h} \dfrac{p_h}{D_h}$ which will be positive if the demand curve is downward sloping.

A similar analysis applies to producers of imported goods. They wish to maximise profits evaluated in foreign currency so they set p_m to solve:

$$\max D_m(p_m, p_h, Z)[p_m e - c^*]$$

where e is the nominal exchange rate and c^* are foreign unit costs. Here we can see that the first-order condition can be written as:

$$p_m = \frac{\eta_m(p_m, p_h, Z)}{\eta_m(p_m, p_h, Z) - 1} \frac{c^*}{e} \qquad \textbf{(B2)}$$

where η_m is the elasticity of demand for imports. This means that importers set prices as a mark-up over (exchange rate adjusted) unit costs. The mark-up depends on the elasticity of demand which in turn (generally) depends on the pricing decisions of both import producers and domestic producers.

This simple algebra illustrates the analysis in Section 2 of the paper. In particular, if preferences are such that importers face isoelastic demand, the demand elasticity η_m will be constant and so there are no direct effects of domestic prices on import prices.

This analysis also makes it clear that solving for import prices conditional on costs, the exchange rate and the level of total demand (Z) requires us to solve **(B1)** and **(B2)** simultaneously. The

analysis in the paper only considers **(B2)** which is conditional on domestic producer behaviour. This is econometrically valid, but gives only a partial estimate of the dynamic propagation of shocks.

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