Price Adjustment in Currency Unions: Another Dimension to the Endogeneity of the Optimum Currency Area Criteria?

MICHAEL BLEANEY* and LIN YIN#

*School of Economics, University of Nottingham, University Park, Nottingham NG7 2RD, UK
(e-mail: michael.bleaney@nottingham.ac.uk)
#Emerging Markets Institute, Beijing Normal University, People's Republic of China
(e-mail: 951298673@qq.com)

Abstract

In a rational expectations model, wages and prices should respond more to shocks in currency unions than under adjustable pegs because of the absence of exchange rate adjustment. This is an aspect of the endogeneity of the optimum currency area criteria that has been largely ignored. Empirical evidence from three currency unions tends to suggest some degree of endogeneity of price flexibility, but the rate of adjustment is slow. Self-selection into currency unions by countries with naturally greater price flexibility does not appear to be a significant factor.

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I. INTRODUCTION

Robert Mundell opens his seminal 1961 paper on optimum currency areas with the following statement: "[I]t is patently obvious that periodic balance of payments crises will remain an integral feature of the international economic system as long as fixed exchange rates and rigid wage and price levels prevent the terms of trade from fulfilling a natural role in the adjustment process." The literature has emphasised the importance of international linkages between regions through the extent of trade, symmetry of shocks, labour mobility and fiscal transfer mechanisms as criteria for a currency union. Frankel and Rose (1997) added a new twist to the debate by noting the endogeneity of some of these criteria, showing that the formation of a currency union itself tended to increase intra-union trade and the symmetry of shocks. Yet Mundell's paper, as the quote above makes clear, is not about fixed exchange rates as such, but about fixed exchange rates *combined with rigid wages and prices*. This second element has figured relatively little in subsequent discussion, no doubt because the existence of these nominal rigidities is taken for granted.

An important component of modern economic theory, the rational expectations assumption, implies that nominal rigidities will not be entirely determined by the institutional structure of labour and product markets; rather, they will be endogenous to macroeconomic policy, and in particular to the exchange rate regime in place. Price-setters are likely to behave differently when faced with a government firmly committed to a fixed exchange rate to how they would if the government were known to be willing to adjust the exchange rate after prices have been set. If currency unions were to induce significantly greater wage and price flexibility through the exchange rate commitment, that would reduce the employment effects of region-specific shocks and absorb some of the pressure that would otherwise fall on other adjustment mechanisms. In other words, the point about the endogeneity of the optimum currency area criteria may also apply to wage and price rigidity. There has been very little empirical work on this issue in general, although it has been an important element of the discussion and analysis of the crisis in the euro area.

Recent history does not support the view that currency unions are immune from shocks that require internal adjustment. In the euro area, for example, large capital flows from the centre to the periphery collapsed after the global financial crisis, leaving internal real exchange rates severely misaligned (Jaumotte and Sodsriwiboon, 2010; Shambaugh, 2012). If nominal rigidities obstruct the required internal price adjustment, the resulting output losses may precipitate a flight from a country's assets, particularly if the banking system is also exposed to significant losses, as in the euro area.[1] In second-generation models of currency crises (e.g. Obstfeld, 1996), a crisis can be precipitated if agents perceive that there is a limit to the output cost that the authorities are willing to bear in defence of the currency. The same can happen in a currency union, because a severe crisis is likely to put the possibility of leaving the union and devaluing back on the political agenda.

The general perception of the Eurozone crisis is that adjustment in the periphery has been far too slow to prevent large output losses (Eichengreen *et al.*, 2014; Gibson *et al*., 2014; Honkapohja, 2014). Ireland may be the poster boy of post-crisis adjustment, having achieved a substantial reduction in relative unit labour costs, but it is regarded as very much the exception that proves the rule (OECD, 2016; Whelan, 2014).

This paper addresses the issue of adjustment within a currency union. If an individual member country's wages and prices get too high relative to those of the other members, the situation can only be corrected by adjustment of relative wages and prices. This is the question that is addressed here: is there more internal wage and price adjustment in currency unions than

[1] For a model of the interaction between banking and currency crises, see Bleaney *et al*. (2008).

under other exchange rate regimes, because of the disciplinary effect of the fixed exchange rate? Perhaps surprisingly, there has been virtually no formal investigation of this issue.

In a rational expectations model, as mentioned above and shown below, wage- and price-setters should be more willing to adjust wages and prices under hard pegs, because the nominal exchange rate is known to be fixed. The results of our empirical analysis show that, under floating or soft pegs, adjustment works more or less exclusively through the nominal exchange rate, and price adjustment is small. In currency unions, as the model predicts, price adjustment is somewhat greater, but still slow: a ten percent difference in the level of the real effective exchange rate is estimated to be associated with a relative price movement of less than one percent per annum, using consumer prices, and somewhat faster using GDP deflators.

The structure of the paper is as follows. A theoretical model is presented in Section Two. The empirical model is laid out and data issues discussed in Section Three, and empirical results are presented in Section Four. Section Five concludes.

II. AN ILLUSTRATIVE MODEL

The aim of this section is to present a simple model that captures the idea that, under rational expectations, fixing the exchange rate alters the response of prices to a negative shock. In the model presented below, the economy is populated by a set of *n* monopolistically competitive individual producers of a single differentiated good, as in the sticky-price model of Obstfeld and Rogoff (1996, Ch. 10). Producers like higher output and higher prices, but demand is a declining function of the real exchange rate. The government likes higher output and also a higher nominal exchange rate (to keep inflation down). The demand curve is subject to a stochastic shock that is observed by all agents.

The main results are as follows. With a fixed exchange rate, a negative demand shock induces producers to reduce prices, but the government cannot adjust the exchange rate to further protect output. With an adjustable peg, under a negative shock the government sets the exchange rate lower than they otherwise would, and after producers have set prices, but producers anticipate this and consequently set prices higher than they would in the currency union case.

The model is in the tradition of Barro and Gordon (1983), in the sense that the government's preferences incorporate an ambitious output target that generates an inflation bias. The deviation of (the log of) output per producer (y) from its "natural" level ($\bar{y}$) is a decreasing function of (the log of) the real exchange rate ($p+e$), adjusted for a zero-mean stochastic demand shock (z), where p is the log of the price level, e is the log of the nominal exchange rate (foreign currency units per unit of domestic currency, so that an increase represents an appreciation of the domestic currency) and foreign prices are fixed at one (so their logarithm is zero):

$$y = \bar{y} - \theta(p + e) + z \qquad \theta > 0 \qquad (1)$$

The producers maximise profit (π) subject to increasing marginal costs:

$$\pi = (p - a)y - b(y - \bar{y})^2 \qquad a, b > 0 \qquad (2)$$

The government cares about output and price stability, and has a target level of output per producer of $\tilde{y}$. In order to maintain the one-period nature of the model, the desire for price stability is represented as the government's preference for a higher nominal exchange rate, so that imported inflation is lower. The government's loss function is:

$$L_g = \frac{1}{2}(\tilde{y} - y)^2 + \frac{1}{2}(\tilde{e} - e)^2 \qquad (3)$$

where $\tilde{e}$ represents the government's exchange rate target.

The order of events in each period is as follows. First the demand shock, *z*, is determined and observed by all agents. Then the producers set prices, taking the expected exchange rate into account. Finally the government sets the exchange rate, if it is free to do so. Substituting from (1) into (2) yields:

$$\pi = p\bar{y} + pz - \theta p(p+e) - a\bar{y} - az + a\theta p - bz^2 - b\theta^2(p+e)^2 + 2bz\theta(p+e) \quad (4)$$

A currency union

Consider first the case of a currency union. Since the exchange rate is fixed, the reaction of prices to the demand shock may be obtained by partially differentiating (4) with respect to *p*:

$$\partial\pi/\partial p = \bar{y} + z - 2\theta p - \theta e + a\theta - 2b\theta^2(p+e) + 2b\theta z \quad (5)$$

Since the second derivative is negative, profits are maximized when (5) is equal to zero, or:

$$(2\theta + 2b\theta^2)p = \bar{y} - \theta e + a\theta - 2b\theta e + (1 + 2b\theta)z \quad (6)$$

The reaction of prices to a demand shock is given by differentiating (6) with respect to z:

$$\partial p/\partial z = (\frac{1}{2\theta})(1 + (b\theta/(1 + b\theta))) \quad (7)$$

An adjustable peg

In the case of an adjustable peg, *e* can be adjusted after prices have been set. Since the producers have full information about the government's loss function, however, under rational expectations they can calculate the exchange rate that will be chosen. Writing $k = (\tilde{y} - \bar{y}) > 0$, the first-order condition for the government's problem is:

$$\frac{\partial L_g}{\partial e} = \theta[k + \theta(p + e) - z] - [\tilde{e} - e] = 0 \quad (8)$$

which yields the solution

$$(1 + \theta^2)e = \tilde{e} - \theta k - \theta^2 p + \theta z \quad (9)$$

And the real exchange rate is:

$$(1 + \theta^2)(p + e) = \tilde{e} - \theta k + p + \theta z \quad (10)$$

If producers set higher prices, the government chooses a lower nominal exchange rate, but the real exchange rate is higher. It is shown in Appendix 1 that substituting from (1) and (10) into (2) and solving for the maximum price as in the currency-union case yields:

$$\partial p/\partial z = (\frac{1}{2\theta})(1 + (b\theta/(1 + b\theta + \theta^2))) \quad (11)$$

which is smaller than in the currency union case because of the additional θ^2 term in the denominator.

Equation (11) implies that prices adjust less in response to a shock under an adjustable peg than in a currency union. The output response in the two cases depends on whether this difference in price response is more than offset by the exchange rate response. Differentiating (10) with respect to *z*, we find that under an adjustable peg the response of the real exchange rate is:

$$\partial(p + e)/\partial z = \partial p/\partial z + \theta/(1 + \theta^2) \quad (12)$$

It is shown in Appendix 1 that this is always greater than in the currency union case, which means that the output effects of a shock are smaller under an adjustable peg.

Summary

In a rational expectations model, prices exhibit more flexibility in response to shocks in a currency union than under an adjustable peg, but the real exchange rate adjusts less and output is more affected by the shock, because the nominal exchange rate cannot perform the role of a shock absorber.

III. THE EMPIRICAL MODEL AND DATA

Several predictions emerge from the model. One is that prices are more sensitive to shocks in currency unions than under adjustable pegs. A second prediction is that the real exchange rate is less sensitive to shocks in currency unions than under adjustable pegs, because in the latter case the adjustment in nominal exchange rates outweighs the lower sensitivity of prices. We concentrate on these two predictions; a third prediction – that output is more sensitive to shocks under a currency union – has been addressed elsewhere (e.g. Ghosh *et al*., 2015).

How should shocks be represented empirically? Since we want them to reflect an exchange rate disequilibrium, we use the lagged real effective exchange rate as a measure of this disequilibrium.

We initially estimate the following equation:

$$\Delta lnP_{it} - \Delta lnPA_{it} = a_i - blnR_{it-1} - c\Delta lnRA_{it} + w_t + v_{it} \qquad (13)$$

where P_{it} is the consumer price index in country *i* in year *t*, PA_{it} is the same thing for country *i*'s anchor currency, *R* is the real effective exchange rate index (an increase representing an appreciation), *RA* is the real effective exchange index of the anchor currency, Δ is the first-difference operator, *a* is a country fixed effect, *w* is a time fixed effect and *v* is a random error. Equation (13) expresses inflation relative to that in the anchor currency as a function of the lagged level of the real exchange rate of country *i*, and of the change in the real effective exchange rate of the anchor currency. If $b > 0$, then there is price adjustment relative to the anchor currency in response to the lagged level of the country's real effective exchange rate. In an alternative formulation we replace the consumer price index by the GDP deflator.

There is a possibility of endogeneity bias even though the real exchange rate regressor is lagged (Reed, 2015) that is not easily addressed, as we discuss below. To the extent that the focus of the analysis is more on a comparison of estimated coefficients across regimes than on the absolute value, bias is less of a problem provided that it is fairly consistent across countries, but that is a conjecture.

There are three currency unions in our analysis: the euro area, the African Financial Community (CFA) and the East Caribbean Currency Authority (ECCA). The identification of other pegs and floats is derived from the exchange rate flexibility index of Bleaney and Tian (2017).[2] Some assumptions have to be made about the anchor currency for countries outside a currency union. We assume it to be the euro for all countries in Europe, and also for the CFA zone, since the CFA franc is pegged to the euro. Since the euro is a floating currency, but area-wide price and real effective exchange rate indices are available, the euro area as a whole is treated as the anchor currency for individual member countries. In all other cases the US dollar is treated as the nominal anchor. The anchor currency prices are either US prices (if the US dollar is the anchor) or prices for the euro area.

Annual data for 186 countries (listed in Appendix 2) over the period 1980 to 2014 are used (1999 to 2014 for the euro area and the CFA zone), and are mostly drawn from IMF International Financial Statistics (IFS).[3] The GDP deflators are from the IMF World Economic Outlook (WEO) database, and price indices for the euro area from OECD Economic Outlook.

IV. EMPIRICAL RESULTS

After some preliminary data analysis, in this section some regression results are presented for price adjustment under different exchange rate regimes, based on equation (13) or variants

[2] This classification is chosen because of its data coverage. An index of less than 0.01 is treated as a peg, and an index of greater than 0.01 is treated as a float.

[3] Data before 1999 are not used for the CFA zone because of the large devaluation of the CFA franc in 1994.

thereof. Some tests of whether the results might be the effect of self-selection by countries with intrinsically lower price rigidity into currency unions are incorporated. This is followed by some analysis of exchange rate adjustment.

It is useful to disaggregate the volatility of the real effective exchange rate of a member of a currency union into separate elements. Let R be the log of the real effective exchange rate of the country, N the log of its nominal effective exchange rate, and P and PF respectively the log of domestic prices and of the trade-weighted average of foreign prices (PA and PFA respectively for the anchor currency). By the definition of R,

$$R = N + P - PF \tag{14}$$

and for the anchor currency (A),

$$RA = NA + PA - PFA \tag{15}$$

Subtracting (16) from (15) and taking first differences yields:

$$\Delta R = \Delta RA + (\Delta N - \Delta NA) + (\Delta P - \Delta PA) - (\Delta PF - \Delta PFA) \tag{16}$$

So real exchange rate movements (ΔR) can be decomposed into (1) real effective exchange rate changes of the anchor currency (ΔRA); (2) nominal effective exchange rate changes relative to the anchor currency ($\Delta N - \Delta NA$), which can only happen (in the absence of a currency union devaluation) because of differences in trade weights; (3) inflation relative to the anchor currency ($\Delta P - \Delta PA$); and (4) differences in trade-weighted foreign inflation, which again is a matter of weights. The second and last terms are the effect of different trading partner weights between the member of the currency union and the anchor currency.

Table 1 shows that real exchange rate volatility of the anchor currency (ΔRA) has tended to be more important than inflation differentials ($\Delta P - \Delta PA$) to the real exchange rate volatility of currency union members. This suggests that the exogenous shocks assumed in the model have been a significant component of real exchange rate volatility in currency unions.

TABLE 1

Real Effective Exchange Rate Volatility in Currency Unions

Standard deviation	ECCA 1980-2014	CFA 1999-2014	Euro Area 1999-2014
ΔR	0.0414	0.0461	0.0268
ΔRA	0.0571	0.0579	0.0540
ΔN – ΔNA	0.0495	0.0273	0.0312
ΔP – ΔPA	0.0182	0.0297	0.0108
ΔPF – ΔPFA	0.0383	0.0104	0.0055
Observations	204	192	226
Anchor currency	US dollar	euro	Euro

Notes: Data are annual. ΔR (ΔRA): change in log of real effective exchange rate of member countries (anchor currency). ΔN (ΔNA): change in log of nominal effective exchange rate of member countries (anchor currency). ΔP (ΔPA): change in log of consumer price index of member countries (anchor currency). ΔPF (ΔPFA): trade-weighted average of change in log of trading partners' consumer price indices of member countries (anchor currency).

In the remainder of this paper we investigate whether the price level of member countries responds to the level of the lagged real effective exchange rate. The model in Section II predicts that the response will be stronger in currency unions than in soft pegs.

Table 2 shows the results of estimating equation (13) separately for currency unions, other pegs and floats, and then for the three currency unions individually, using the price index and real effective exchange rate (REER) index of the euro area for the CFA and for individual euro-area countries, and of the US dollar for the ECCA. Standard errors are clustered by country. For currency unions the point estimate of the coefficient of the lagged REER is -0.0639, with a *t*-statistic of -2.23, whereas for other pegs the coefficient is only -0.0111, with a *t*-statistic of -1.59. Thus in currency unions there is a significant negative correlation between the lagged REER and consumer price inflation relative to the anchor currency. This is consistent with the predictions of the model, but it also implies that adjustment to real exchange rate shocks is slow: the effect on relative inflation rates of a 10 percent difference in the real exchange rate is estimated to be less than 0.7 percent p.a. However this compares with a relative inflation effect of only about 0.1% p.a. in other exchange rate regimes.

In the individual currency unions the picture varies quite considerably, with a lagged REER coefficient of -0.1283 for the euro area, -0.0829 for the CFA zone, and -0.0266 for the ECCA. Thus price adjustment seems to be fastest in the euro area.

In Table 3 we estimate a less parsimonious model of inflation as follows:

$$\Delta lnP_{it} = a_i + b\Delta lnPA_{it} - c\Delta lnRA_{it} - elnR_{it-1} + f\Delta lnP_{it-1} + g\Delta lnR_{it-1} + w_t + v_{it} \quad (17)$$

In equation (17) the coefficient of the anchor country's inflation rate is no longer constrained to be equal to one, and lagged inflation and lagged real exchange rate movements are added to the equation. There is a potential problem of bias because the equation contains both country fixed effects and a lagged dependent variable. Because the time series dimension (T) of the data is long (over thirty years in most cases), and the bias is less when the time span is long, the bias should be relatively small. Although instrumental variables techniques can be used to address this bias, they are likely to involve considerable loss of efficiency.

Table 3 shows the results of estimating equation (17). For currency unions, both as a whole and individually, anchor currency inflation is highly significant with a coefficient exceeding but not very far from one, which implies that the Table 2 model is not unreasonable. The lagged REER coefficients are similar to those in Table 2, with a point estimate of -0.0608 (and a *t*-statistic of -2.07) for currency unions, -0.0064 (-1.53) for other pegs and -0.0076 (-1.30) for floats. For individual currency unions the lagged REER coefficient is similar to that shown in Table 2, which is perhaps an indication that any bias is small.

The models estimated so far assume that, apart from the lagged dependent variable, the explanatory variables are exogenous. This seems reasonable: they are either predetermined, because they relate to the previous period, or if not they are anchor-currency variables, and therefore relate to a much larger economy (the United States or the Euro Area). Thus one form of endogeneity, a feedback effect from the dependent variable to the independent variables, should not be a major concern here. A different sort of endogeneity issue is that countries with lower price rigidity might self-select into currency unions, so that the estimated parameters overstate the effect of a given country joining a customs union. In this case it is not that the parameters are subject to simultaneous equation bias, but that their interpretation depends on how currency union (CU) membership is determined. If any difference between currency unions and other regimes is in fact the effect of self-selection, then there is no evidence that currency unions change agents' behaviour, as the model above predicts.

The question is how to test for self-selection. Prices of primary products tend to be more flexible than other prices, so countries where primary products are more important may have fewer nominal rigidities. It is also true that currency unions are geographically concentrated, and other countries in the same region are likely to be reasonably similar in income levels and economic structure. For example, taking figures for the year 2010, the share of agriculture in GDP in the CFA zone averaged 28.8 percent, similar to 28.0 per cent for the rest of West Africa. For the euro zone the figure was 1.9 percent, and for the rest of Europe 6.4 percent; for the ECCA and the rest of the Caribbean the figures were respectively 5.5 percent and 2.7 percent. If we assume that there are regional differences in price rigidity, then under the self-selection hypothesis non-CU members in the same region as a CU should have higher price rigidity than CU members in the same region (since they have chosen not to join), but lower price rigidity than non-CU countries in other regions (where the lack of a CU suggests greater price rigidity). This can be tested by separating out non-CU countries in the same region as a CU from other non-CU countries. If the self-selection argument is correct, the difference should be significant (although non-CU countries in the same region as a CU may still have greater price rigidity than CU members, which might explain why they have not joined the CU).

Accordingly, in Table 4, we pool the data and treat non-CU members in Europe, West Africa or the Caribbean as a separate group (defined as $Z = 1$). The regression reported in Table 4 is equivalent to Table 2 estimated across the full sample but with coefficients allowed to differ between CU members, non-CU members in the same regions (Z=1), pegs and floats. The omitted category is pegs for which Z=0, and the lagged real exchange rate coefficient for them is -0.0090. The lagged real exchange rate coefficient interacted with the float dummy has a coefficient of +0.0110, which is significant at the five percent level and measures the estimated difference relative to the omitted category. The lagged real exchange rate interacted with Z has a coefficient of -0.0114, indicating slightly more price flexibility than countries with the same regime in regions where there is no currency union, but it is not statistically significant. For currency unions, however, the difference in the lagged real exchange rate coefficient is about five times greater, at -0.0552, and is significant at the five percent level. This suggests that the estimated CU effect is not a self-selection effect.

Table 5 repeats Table 3 using relative GDP deflators rather than consumer prices; GDP deflators cover a wider range of goods and include exports rather than imports. Relative GDP deflators are substantially more volatile than relative consumer prices, and this is reflected in higher root mean square errors, particularly in the case of the CFA zone. For currency unions as a group (column 1), the point estimate of the lagged REER coefficient is in every case somewhat more negative than in Table 3, at -0.1017 compared with -0.0608 in Table 3, but is no longer significant at the five per cent level. Looking at currency unions individually (columns 4 to 6), the pattern is similar to Table 3, but for ECCA the point estimate of the lagged

REER coefficient is actually significantly positive, at +0.0669. For the CFA zone, this coefficient is more than 100 percent more negative than in Table 3 (-0.1867 compared with -0.0740), although it is still not significant at the five percent level. For the euro area, the lagged REER coefficient is 40 % larger than in Table 3 (-0.2124 compared with -0.1116) and highly statistically significant. This is consistent with Tressel and Wang's (2014) finding that different measures produce different estimates of the degree of REER adjustment in the euro area.

In Table 5 the lagged real exchange rate coefficients for other pegs (column 2) and floats (column 3) are still much less negative than those for currency unions, although somewhat more negative than in Table 2, and significant at the one percent level in the case of other pegs.

A common explanation for slow price adjustment is the existence of nominal rigidities, and particularly resistance to falls in prices and wages. If rigidities are particularly strong in a downward direction, then adjustment should be slower for negative shocks, which require price falls, than for positive ones. This suggests that nominal rigidities should be reflected in asymmetries in the adjustment process. Some tests of this are reported in the working paper version of this article (Bleaney and Yin, 2015); no significant asymmetries were found.

Exchange rate adjustment

The model suggests that in adjustable pegs the exchange rate will be used to cushion the effect of pegs on output. Table 6 looks at nominal and real exchange rate adjustment relative to the US dollar for soft pegs and floats, with the same explanatory variables as used for relative price adjustment in Table 2. The sample is confined to non-European countries, since European countries are more likely to be pegged to the euro, and also to observations with inflation in the range -10 % to +10 %. The estimated equation is:

$$\Delta lnEUS_{it} = a_i - blnR_{it-1} + w_t + v_{it} \quad (18)$$

where *EUS* is the bilateral exchange rate against the U.S. dollar (U.S. dollars per unit of country *i*'s currency).

The coefficient of the lagged REER in Table 6 is negative, as expected, and much more so for floats than for other pegs. For other pegs the point estimate of the lagged real exchange rate coefficient is -0.0264 with a *t*-statistic of -1.71 for nominal rates, and -0.0455 with a *t*-statistic of -2.52, for real rates. These numbers are quite low, suggesting only limited use of the exchange rate as a shock absorber.

Summary

Our results indicate some statistically significant relative price adjustment in response to real exchange shocks for the typical currency-union member country. Using consumer prices, the estimated price elasticity varies considerably across the three customs unions from –11.2% in the euro area to –7.4% in the CFA zone and –2.3% in ECCA. When GDP deflators are used rather than consumer prices, the estimated adjustment of prices to real exchange rate shocks is about twice as large in every case except that of the ECCA, for which the sign is unexpectedly positive. For adjustable pegs and floats the elasticity of relative prices with respect to the real exchange rate is very small (of the order of –1% for consumer prices and –2% for GDP deflators) and usually not statistically significant, which indicates a reliance on the adjustment of nominal exchange rates.

V. CONCLUSIONS

Our theoretical model predicts that agents change their behaviour because of the exchange-rate commitment of a currency union, so that price rigidity is endogenous to the exchange rate regime. Potentially this is an important, but neglected, aspect of the endogeneity of the optimum currency area criteria. Whether this effect is significant in practice is an empirical question.

Our results suggest some evidence for such an effect. Under adjustable pegs, relative price adjustment in response to real exchange rate shocks is negligible; in currency unions, where nominal exchange rate adjustment is ruled out, relative price adjustment is statistically significant but nevertheless still quite slow in economic terms, with a ten percent higher real exchange rate being associated with a consumer price differential of less than one percent in the subsequent year. Adjustment is faster in the euro area than in other currency unions. These figures suggest that the limited endogeneity of price rigidity to the exchange rate regime implied by our results does little to diminish the relevance of other criteria for an optimum currency area, such as the absence of asymmetric shocks.

An alternative explanation of our results is that only countries with low price rigidity join currency unions. It is difficult to rule out this possibility, but we have attempted to test it by assuming that there is significant regional variation in price rigidity. Then, if countries in regions with low price rigidity are more likely to join currency unions, other countries in the same region should have lower price rigidity than those in regions with no currency union. We find little evidence of such a pattern.

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Appendix 1

1) Derivation of equation (11).

Starting from equation (4):

$$\pi = p\bar{y} + pz - \theta p(p+e) - a\bar{y} - az + a\theta p - bz^2 - b\theta^2(p+e)^2 + 2bz\theta(p+e),$$

We can use equation (10) to make the following substitutions:

$$\theta p(p+e) = \frac{\theta(\tilde{e}-\theta k)+\theta p^2+\theta^2 pz}{(1+\theta^2)} \quad \text{(A1)}$$

$$2bz\theta(p+e) = \frac{2bz\theta(\tilde{e}-\theta k)+2bz\theta p+2b\theta^2 z^2}{(1+\theta^2)} \quad \text{(A2)}$$

$$-b\theta^2(p+e)^2 = \frac{-b\theta^2 p^2-2b\theta^3 zp}{(1+\theta^2)^2} + \text{irrelevant terms} \quad \text{(A3)}$$

Then differentiating with respect to p yields

$$(1+\theta^2)^2\left(\frac{\partial\pi}{\partial p}\right) = (1+\theta^2)^2 z - (2\theta p + \theta^2 z + 2b\theta z)(1+\theta^2) - 2b\theta^2 p - 2b\theta^3 z + \text{irrelevant terms} \quad \text{(A4)}$$

Setting (A4) equal to zero yields the solution:

$$2\theta(1+\theta^2+b\theta)p = (1+\theta^2+2b\theta)z + \text{irrelevant terms} \quad \text{(A5)}$$

From which equation (11) follows.

2) Proof of larger real exchange rate response to shocks under an adjustable peg. Substituting (11) into (12) for an adjustable peg (AP) yields:

$$AP = [\partial(p+e)/\partial z]_{AP} = (\tfrac{1}{2\theta})(1+(b\theta/(1+b\theta+\theta^2))) + \theta/(1+\theta^2) \quad \text{(A6)}$$

Whereas from (7) under a currency union (CU), it is:

$$CU = [\partial(p+e)/\partial z]_{CU} = [\partial p/\partial z]_{CU} = (\tfrac{1}{2\theta})(1+(b\theta/(1+b\theta))) \quad \text{(A7)}$$

Subtracting (A7) from (A6) yields

$$AP - CU = -\left(\frac{1}{2\theta}\right)[(b\theta^3/(1+b\theta)(1+b\theta+\theta^2)] + \theta/(1+\theta^2)$$

$$= \left(\frac{1}{2}\right)[(2\theta + 2b^2\theta^3 + 3b\theta^2 + 2\theta^3 + b\theta^4]/[(1+b\theta)(1+b\theta+\theta^2)(1+\theta^2)] > 0$$

Appendix 2. Countries in the Sample

Table A1. Sample of Countries and Groups (listed by 2012 exchange rate regime)	
Currency Unions (37)	
Euro area (17)	Austria, Belgium, France, Germany, Italy, Luxembourg, Netherlands, Finland, Greece (since 2001), Ireland, Malta (since 2008), Portugal, Spain, Cyprus (since 2008), Slovak Republic (since 2009), Estonia, Slovenia (since 2007);
CFA (14)	Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Côte d'Ivoire, Republic of Congo, Equatorial Guinea, Gabon, Guinea-Bissau, Mali, Niger, Senegal, Togo;
East Caribbean (6)	Antigua and Barbuda, Dominica, Grenada, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines;
Soft Pegs (92)	Albania, Angola, Anguilla, Argentina, Aruba, Republic of Azerbaijan, Bahamas, Bahrain, Barbados, Belize, Bhutan, Bolivia, Bosnia and Herzegovina, Botswana, Brunei Darussalam, Bulgaria, Burundi, Cabo Verde, Cambodia, P.R. China: Hong Kong, P.R. China: Macao, P.R. China: Mainland, Comoros, Democratic Republic of Congo, Costa Rica, Croatia, Curaçao and St Maarten, Denmark, Djibouti, Dominican Republic, Egypt, El Salvador, Eritrea, Ethiopia, Fiji, Georgia, Guinea, Guyana, Haiti, Honduras, Indonesia, Iran, Iraq, Jamaica, Jordan, Kazakhstan, Kiribati, Kuwait, Lao People's Democratic Republic, Latvia, Lebanon, Lesotho, Libya, Lithuania, Macedonia, Malawi, Maldives, Micronesia, Montenegro, Montserrat, Morocco, Myanmar, Namibia, Nicaragua, Nigeria, Oman, Pakistan, Panama, Papua New Guinea, Peru, Qatar, Rwanda, São Tomé and Príncipe, Samoa, Saudi Arabia, Sierra Leone, Solomon Islands, Sudan, Suriname, Swaziland, Tajikistan, Tanzania, Thailand, Tonga, Trinidad and Tobago, Tunisia, Ukraine, United Arab Emirates, Vanuatu, Venezuela, Vietnam, Republic of Yemen;
Floats (52)	Afghanistan, Algeria, Armenia, Australia, Bangladesh, Belarus, Brazil, Canada, Chile, Colombia, Czech Republic, Gambia, Ghana, Guatemala, Hungary, Iceland, India, Israel, Japan, Kenya, Republic of Korea, Kyrgyz Republic, Liberia, Madagascar, Malaysia, Mauritania, Mauritius, Mexico, Moldova, Mongolia, Mozambique, Nepal, New Zealand, Norway, Paraguay, Philippines, Poland, Romania, Russian Federation, Republic of Serbia, Seychelles, Singapore, South Africa, Sri Lanka, Sweden, Switzerland, Turkey, Uganda, United Kingdom, United States, Uruguay, Zambia.

TABLE 2

Consumer Price Inflation Relative to the Anchor Currency and Lagged Real Effective Exchange Rates

	Exchange rate regime			Individual currency union		
	Currency union	Other peg	Float	CFA	Euro area	ECCA
Estimation method:	Two-way FE	Two-way FE	Two-way FE	Two-way FE	Two-way FE	Two-way FE
ΔRA	-0.0649*** (-2.71)					
R(-1)	-0.0639** (-2.23)	-0.0111 (-1.59)	-0.0097** (-2.43)	-0.0829 (-1.28)	-0.1283*** (-3.24)	-0.0266 (-0.65)
Sample size	602	1630	897	190	226	186
No. countries	37	136	111	14	17	6
RMSE	0.0183	0.0222	0.0198	0.0238	0.0088	0.0160

Notes: Time and country fixed effects included throughout. Dependent variable is change in log of consumer price index of member country relative to the anchor currency (ΔP – ΔPA). ΔRA: change in log of real effective exchange rate of anchor currency. R: log of real effective exchange rate of member country. Figures in parentheses are heteroscedasticity-robust t-statistics, with standard errors clustered by country. *, **, ***: significantly different from zero at the 10, 5 and 1 % levels. Annual data 1980-2014 (1999-2014 for CFA and Euro area). For regimes other than currency unions, the sample excludes countries with consumer price inflation of more than 10 % or less than -10 %, and the anchor currency is the US dollar. Regime classifications: Bleaney and Tian (2017).

TABLE 3

A Less Restrictive Model

	Exchange rate regime			Individual currency union		
	Currency union	Other peg	Float	CFA	Euro area	ECCA
Estimation method:	Two-way FE	Two-way FE	Two-way FE	Two-way FE	Two-way FE	Two-way FE
ΔPA	1.045***	-0.552	0.147			
	(3.83)	(-1.48)	(0.46)			
ΔRA	-0.0633***	-0.0180	-0.0190			
	(-2.82)	(-1.01)	(-0.77)			
R(-1)	-0.0608**	-0.0064	-0.0076	-0.0740	-0.1116***	-0.0226
	(-2.07)	(-1.53)	(-1.30)	(-1.33)	(-3.58)	(-0.59)
ΔP(-1)	-0.0192	0.0795*	0.0361	-0.1937**	0.3660***	0.122**
	(-0.32)	(1.84)	(0.96)	(-2.15)	(6.38)	(2.42)
ΔR(-1)	-0.0059	-0.0330**	-0.0053	0.0307	-0.0334	0.0198
	(-0.20)	(-2.36)	(-0.63)	(0.27)	(-0.75)	(0.22)
Sample size	595	1417	786	189	226	180
No. countries	37	136	103	14	17	6
RMSE	0.0183	0.0219	0.0193	0.0234	0.0082	0.0156

Notes: Time and country fixed effects included throughout. Dependent variable is change in log of consumer price index of member country (ΔP). ΔRA: change in log of real effective exchange rate of anchor currency. R: log of real effective exchange rate of member country. ΔPA: change in log of consumer price index of anchor currency. Figures in parentheses are heteroscedasticity-robust t-statistics, with standard errors clustered by country. *, **, ***: significantly different from zero at the 10, 5 and 1 % levels. Annual data 1980-2014 (1999-2014 for CFA and Euro area). For regimes other than currency unions, the sample excludes countries with consumer price inflation of more than 10 % or less than -10 %, and the anchor currency is the euro for European countries, and otherwise the US dollar. Regime classifications: Bleaney and Tian (2017).

TABLE 4

Testing for endogenous self-selection into currency unions

Dependent variable:	Change in log of consumer price index of member country relative to the anchor currency
Estimation method:	Two-way FE
ΔRA	-0.0387** (-2.31)
R(-1)	-0.0090 (-1.56)
Currency union dummy (CU)	0.250** (2.43)
CU*ΔRA	-0.0080 (-0.34)
CU*R(-1)	-0.0552** (-2.48)
Float dummy (FL)	-0.0473* (-1.93)
FL*ΔRA	0.0265 (1.24)
FL*R(-1)	0.0110** (2.08)
Z*ΔRA	-0.0239 (-1.19)
Z*R(-1)	-0.0114 (-1.13)
Sample size	2840
No. countries	167
RMSE	0.0212

Notes: Time and country fixed effects included throughout. Dependent variable is change in log of consumer price index of member country (ΔP). ΔRA: change in log of real effective exchange rate of anchor currency. R: log of real effective exchange rate of member country. ΔPA: change in log of consumer price index of anchor currency. Z: dummy =1 for non-CU countries in Europe, West Africa and the Caribbean, and =0 otherwise. Figures in parentheses are heteroscedasticity-robust t-statistics, with standard errors clustered by country. *, **, ***: significantly different from zero at the 10, 5 and 1 % levels. Annual data 1980-2014 (1999-2014 for CFA and Euro area). For regimes other than currency unions, the sample excludescountries with consumer price inflation of more than 10 % or less than -10 %, and the anchor currency is the US dollar. Regime classifications: Bleaney and Tian (2017).

TABLE 5

Using GDP Deflators Instead of Consumer Prices

	Exchange rate regime			Individual currency union		
	Currency union	Other peg	Float	CFA	Euro area	ECCA
Estimation method:	Two-way FE	Two-way FE	Two-way FE	Two-way FE	Two-way FE	Two-way FE
ΔPA	-1.349 (-0.96)	-0.178 (-0.63)	0.105 (0.21)			
ΔRA	-0.0632 (-1.21)	0.0226 (0.97)	-0.0189 (-0.68)			
R(-1)	-0.1017* (-1.92)	-0.0254*** (-2.76)	-0.0188* (-1.85)	-0.1867* (-1.97)	-0.2124*** (-5.20)	0.0669*** (3.07)
ΔP(-1)	-0.1820*** (-6.62)	0.0573** (2.33)	0.0087 (0.15)	-0.1772*** (-6.67)	0.3423** (2.75)	-0.1608* (-2.36)
ΔR(-1)	0.0140 (0.22)	-0.0114 (-0.67)	-0.0015 (-0.16)	0.5800* (2.12)	-0.1012* (-1.97)	-0.1869* (-2.04)
Sample size	616	1578	820	192	226	198
No. countries	37	146	109	14	17	6
RMSE	0.0525	0.0300	0.0233	0.0831	0.0110	0.0275

*Notes:*Time and country fixed effects included throughout. Dependent variable is change in log of the GDP deflator of member country (ΔP). ΔRA: change in log of real effective exchange rate of anchor currency. R: log of real effective exchange rate of member country. ΔPA: change in log of consumer price index of anchor currency. Figures in parentheses are heteroscedasticity-robust t-statistics, with standard errors clustered by country. *, **, ***: significantly different from zero at the 10, 5 and 1 % levels. Annual data 1980-2014 (1999-2014 for CFA and Euro area). For regimes other than currency unions, the sample excludes countries with rate of change of the GDP deflator of more than 10 % or less than -10 %, and the anchor currency is the euro for European countries, and otherwise the US dollar. Regime classifications: Bleaney and Tian (2017).

TABLE6

Nominal and Real Exchange Rate Adjustment in Other Pegs and Floats

Regime	Other pegs		Floats	
Dependent variable = change in log exchange rate against US dollar	Nominal	Real	Nominal	Real
R(-1)	-0.264* (-1.71)	-0.0455** (-2.52)	-0.1362*** (-3.05)	-0.3839** (-2.09)
Sample size	1234	1234	601	601
No. countries	97	97	75	75
RMSE	0.600	0.593	0.0893	0.1351

Notes: Time and country fixed effects included throughout. Dependent variable is change in the log of either the nominal or the real (CPI-based) bilateral nominal exchange rate relative to the US dollar (rise = appreciation of domestic currency), as specified. R: log of real effective exchange rate of member country. Figures in parentheses are heteroscedasticity-robust t-statistics, with standard errors clustered by country. *, **, ***: significantly different from zero at the 10, 5 and 1 % levels. Annual data 1980-2014. The sample excludes European countries and countries with consumer price inflation of more than 10 % or less than -10 %. Regime classifications: Bleaney and Tian (2017).