PRELIMINARY DRAFT

Simple Pricing Rules, the Phillips Curve and the Microfoundations of Inflation Persistence

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Abstract

We analyse the microfoundations of the Phillips curve, a key relationship in general macroeconomics and models of monetary policy in particular. The form in current widespread use includes both forward looking expected inflation and lagged inflation. The presence of lagged inflation is necessary to generate predicted inflation persistence to match actual persistence in real world data but it has proved very difficult to microfound. Recent contributions from Christiano, Eichenbaum and Evans (2005) and Gali and Gertler (1999) have attempted to provide such microfoundations through the assumption of indexing or rule of thumb behaviour. We question the nature of the indexing rules or rules of thumb assumed and re-derive these models for the case where firms choose constrained optimal simple pricing rules. We find that the models no longer convincingly predict inflation persistence.

JEL E52, E58, E22

Key Words: Monetary policy, Phillips curve, Inflation persistence, Microfoundations

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Introduction

This paper is concerned with the plausibility of the indexing/rule of thumb microfoundations which underpin the form of the Phillips curve in current widespread use shown by (1).[2] The Phillips curve relationship is a key component of macroeconomic and monetary policy models since it strongly influences macroeconomic dynamics and is the key constraint faced by monetary policy makers. The relationship has a long and controversial history, of course, but we focus on (1) given its prominence in current practice within the New Keynesian approach.

$$\pi_t = F\, E_t[\pi_{t+1}] + B\, \pi_{t-1} + \kappa y_t + \epsilon_t \tag{1}$$

In (1), the coefficients F and B index the relative importance of forward looking expectations of inflation and lagged inflation respectively. B>0 is generally accepted as necessary to match observed inflation persistence, though empirical dispute continues about the size of B and the degree of autocorrelation in inflation that a model should be able to reproduce.

This paper addresses the plausibility of the microfoundations which have been suggested for the presence of lagged inflation. In particular, with the well-microfounded Calvo (1983) pricing mechanism, B is zero and F is close to unity. Finding microfoundations for B>0 has proved difficult with fully optimising pricing behaviour. The two key contributions of Christiano, Eichenbaum and Evans (2005) and Gali and Gertler (1999) rely on indexing or rule of thumb behaviour by some or all firms. These contributions assume particular forms for the indexing rules or rules of thumb used without much discussion of their nature. We seek to extend their analysis by taking the existence of indexing/rule of thumb behaviour as given but analyse the consequences of firms adopting indexing rules or rules of thumb which give rise to price choices that are as close to optimal as possible subject to the adoption of these simple rules. We argue that these rules amount to reduced form forecasting rules and ask what the optimal coefficients in those rules would be rather than simply assuming that they take arbitrary values. In both cases we find, unsurprisingly, that the

[2] The notation is standard; π, y, ϵ are inflation, the output gap and the cost push or inflation shock respectively. Some formulations replace the output gap with marginal cost.

optimal reduced form coefficients depend on firms' perceptions of the degree of inflation persistence. Given that firms behaviour influences actual inflation persistence, through determining the value of B in (1), we may analyse the value of B that would result from such near-optimal behaviour. Our conclusion is striking. We show that in both models the only long run outcome in which firms' beliefs have adjusted to observed inflation behaviour is one without inflation persistence and a zero value for B. Hence we conclude that the indexing/rule of thumb approaches proposed do not constitute plausible microfoundations for sustained inflation persistence, even if one is happy to accept the existence of such behaviour. The remainder of the paper considers each of the two models in turn.

1. The Christiano, Eichenbaum and Evans (2005) Model

In the core Christiano, Eichenbaum and Evans (CEE) model all firms may change their prices each period though in any given period they face a constant probability, q, of fully re-optimising their price and a probability (1-q) of applying a simple indexing rule to their price of the previous period. If a firm may re-optimise it chooses its new price x^I at time t to minimise the loss function (2) where β is the standard discount factor and p* the ideal log single period flexible price given by (3) such that (2) is a quadratic approximation to the loss from the firm's price differing from its preferred price in each period due to the frictions assumed in re-optimisation. The quadratic term is discounted and survival probability weighted for each period j in the future. In a standard Calvo model the firm's price on the right hand side is constant over time whereas in CEE the new price set at time t is indexed by an updating rule of the form (4) each period until a new optimisation occurs.

$$L_t^I = E_t \Sigma_{j=0}^{\infty} \beta^j (1-q)^j (x_{t+j}^I - p_{t+j}^*)^2 \tag{2}$$

$$p_t^* = p_t + \phi y_t + \epsilon_t \tag{3}$$

$$x_{t+j}^I = x_{t+j-1}^I + \gamma \pi_{t+j-1} \tag{4}$$

In CEE the parameter γ in (4) was not considered and thus implicitly fixed at unity though it was included as a free parameter by Woodford (2003) in his extension of the CEE model.

Prior to considering the possibility of firms optimizing the value of gamma in (4), we note that in the CEE model all firms change price every period, even though they re-optimize infrequently. This property is difficult to reconcile with the microeconomic data available from survey evidence (Apel et. al., 2005, Blinder et. al. 1998, Hall et. al., 2000) which strongly points towards many prices remaining fixed for more than one period. To address this we combine the CEE firms modelled above with standard Calvo firms. A simplifying assumption is that the constant probability of (always optimally) changing prices for the Calvo firms is the same as the probability of re-optimisation for the CEE firms. Given this, Calvo firms who may change their price at time t set the new price x^c to minimise (5) where that price is now fixed until the next price change opportunity.

$$L_t^c = E_t \Sigma_{j=0}^{\infty} \beta^j (1-q)^j (x_t^c - p_{t+j}^*)^2 \tag{5}$$

We use the notation, I, for the proportion of indexing CEE firms in the overall price level, the remainder being standard Calvo firms. Combining the first order conditions for minimising (2) and (5) with the appropriate expression for the aggregate price level gives (6), the Phillips curve for this model.

$$\pi_t = \frac{\beta}{1+\beta\gamma I} E_t[\pi_{t+1}] + \frac{\gamma I}{1+\beta\gamma I}\pi_{t-1} + \frac{q[1-\beta(1-q)]}{(1+\beta\gamma I)(1-q)}(\phi y_t + \epsilon_t) \tag{6}$$

From (6) the CEE Phillips curve is derived from setting γ and I to unity, the Woodford extension corresponds to I at unity with γ free, and allowing for I<1 is new. These two parameters always appear as their product and an increase in that raises the coefficient on lagged inflation while lowering that on the forward looking term.

With (6) in place we first examine the effect of changing γ on the properties of the model with I set to unity, then we allow for I<1 and discuss how γ might be determined..

With I=1 so as to remain within the scope of the CEE/Woodford model, Figure 1 shows the effect of reducing γ below unity on the lagged inflation coefficient in (6). Figure 2 reports a policy simulation exercise whereby (6) is imposed as the constraint on a standard discretionary monetary policy maker minimising the quadratic (7). What is of interest is the degree of inflation persistence predicted by the model which is informative over and above simply inspecting the coefficients in (6). Given the structure of (6) and (7), inflation follows an AR(1) reduced form process and we report the autoregressive parameter on the vertical axis of Figure 2 as a function of γ. While the empirical evidence is not wholly clearcut a lagged inflation coefficient in the Phillips curve, B in (1), above perhaps 0.3 and an AR(1) parameter for inflation above say 0.4 might be used as reference values.[3] From Figures 1 and 2 a value of γ around 0.5 is necessary to predict these values. It is clear that γ may be calibrated to achieve these or higher figures in the CEE model but equally it is desirable to explore further the implications of introducing some Calvo firms and the value of the indexing parameter that CEE firms might choose or learn over time.

$$L_t = E_t \Sigma_{s=0}^{\infty} \beta^s (\pi_{t+s}^2 + \lambda y_{t+s}^2) \tag{7}$$

We first show the implications of extending the model to allow for some standard Calvo firms such that I<1 in (6). Figures 3 and 4 repeat the information for I=1 from Figures 1 and 2 while also showing the cases for I=0.5 and I=0.25. From the microeconomic evidence, the proportion of prices which are changed each quarter or more frequently is unlikely to be much above 0.25 and a proportion of those would be Calvo firms who happened to receive consecutive price change opportunities in the sample period. If correct, that would imply a proportion of CEE firms significantly less than unity and probably less than 0.25. It is clear that reducing the proportion of CEE firms has very strong implications for the properties of the model. Firstly, Figure 3 shows that with I=0.5 the lagged inflation coefficient reaches 0.3 only with γ very close to unity while I=0.25 implies a coefficient of around 0.2 when γ=1. Equally, Figure 4 shows that the model cannot reproduce an AR parameter above approximately 0.4 when I is a half or less.

[3]On the empirical evidence see Batini (2002), Boileau and Letendre (2003), Dotsey (2002), Fuhrer and Moore (1995), Gali, Gertler and Lopez-Salido (2001), Levin and Piger (2003), Nelson (1998), Roberts (1997, 2001), Rudd and Whelan (2001), Soderstrom, Soderlind and Vredin (2003).

From these simulations we conclude that the CEE model is much less successful at reproducing inflation persistence once we take the microeconomic evidence into account and calibrate the proportion of CEE firms accordingly. Nevertheless, the likely value of γ is of interest. It is possible that firms may simply choose an arbitrary value but equally they may wish to choose γ optimally so as to minimise their loss function (2) while retaining their updating rule (4). This would be consistent with these firms being rational optimisers in a general sense while high decision costs prevent them re-optimising in each period.

To explore this possibility we assume that firms choose a value of γ to use each time they re-optimize their price before possible updating later, thus combining the first order conditions for each from the minimisation of (2) given (3) and (4). From these it is straightforward to show that the optimal γ is the firm's estimate of the AR parameter for actual inflation. This is intuitive from (2) and (4) since in expectation the firm can do no better than plan to update its price each period by the amount suggested by an AR(1) forecast for the increase in the price level[4].

Firms' optimal γ being given by their estimate of inflation's AR(1) parameter opens up potentially rich dynamics in the model since the latter is endogenous. If we ignore that feedback effect for a moment we could form a view on firms' beliefs about inflation persistence and calibrate the model accordingly. However, in terms of assessing the model's ability to reproduce persistence it is clear from Figure 4 that perceived persistence would need to be very high, in tandem with I well above 0.25, to generate an AR(1) coefficient in the likely range.

Turning to the dynamics, the lines relating actual to perceived inflation persistence are all below th 45 degree line. In other words actual persistence is always lower than perceived persistence

[4]This is subject to the caveat that lagged inflation will contain information about future values of the output gap in this model. This is ignored here but strictly speaking it matters for the firm's choice of price via (3). In addition, (4) imposes the constraint that future indexed prices are based on the firm's earlier choice of price. In practice it seems possible that firms would index based on previous aggregate prices rather than their own lagged price. This takes the analysis outside the scope of the CEE model and we leave it to future research.

except in the limiting case where both are zero. It is possible that firms would know the model and jump direct to that case as the only symmetric equilibrium. Alternatively, firms might start with a prior that inflation is a persistent process and set their indexing parameters accordingly. Over time, however, firms would observe actual persistence below that prior and revise downwards their belief of the inflation AR(1) parameter and thus their indexing parameter. This has the striking implication that learning behaviour may give rise to lower and lower persistence over time with zero the stable long run value for both actual and perceived persistence. We do not model this learning process formally, and it may of course be gradual, but we conjecture that any reasonable model of learning behaviour would tend to reduce persistence over time.[5]

To summarise this section, we have argued that:

1) Given the microeconomic evidence on price changing behaviour we should be uncomfortable assuming that all firms change their prices each period which is what the CEE model assumes. Hence the combined CEE/Woodford-Calvo model, with Phillips curve (6), is appealing and plausible calibrations for the share of CEE firms may be around or less than 0.25.

2) Once that share is reduced even to 0.5, the model's ability to match macroeconomic evidence on inflation persistence is severely compromised, even with very high values of the indexing parameter in (4).

3) If firms choose their degree of indexation optimally, they will choose a value that corresponds to their belief about actual inflation persistence. At a minimum this would mean that they are likely to choose a value somewhere below unity, thus reinforcing point (2).

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[5]Strictly speaking this depends on the behaviour of the policy maker. Figure 4 implicitly assumes that they simply optimise given the current Phillips curve (which they are assumed to know). This is myopic since if they returned inflation to target more quickly they would benefit from lower perceived and thus actual persistence in the future. This would strengthen the argument above. A contrary possibility would be where the policymaker has imperfect information about the Phillips curve and perhaps overestimates the degree of persistence in private sector behaviour. We leave these interactions to future research.

4) If firms learn and adjust their indexing behaviour over time they are likely to reduce the amount of persistence that they inject into the model. This would further reduce the amount of persistence they observe and so on. In the simple model here, subject to the details of the learning process, it is possible that the outcome over time is zero persistence.

2. The Gali and Gertler (1999) Model

The Gali and Gertler (GG) model combines standard Calvo firms with rule-of-thumb/indexing firms with respective shares (1-w) and w. The indexing firms face the same probability of price change as the Calvo firms but differ from them by applying a rule of thumb formula rather than optimising when they have the opportunity to change price. In particular they apply (8) where the left hand side is the new price they set assuming that they can and a particular feature is that they index on last period's new prices, p', rather than simply last period's aggregate price level. In GG, γ is not considered (implicitly unity) but here we include it as a free parameter, in parallel with Woodford's extension of the CEE model above. It also allows us to assess its most plausible range of values but for the time being we simply treat it as given.

$$x_t^b = p_{t-1}^{/} + \gamma\pi_{t-1} \tag{8}$$

Given (8) we may re-work GG's Phillips curve derivation to give (9) where a value for γ falling below unity reduces the coefficient on lagged inflation while raising that on the forward looking term.

$$\pi_t = \frac{\beta(1-q)E_t[\pi_{t+1}] + (1-q+\gamma q)w\pi_{t-1} + q[1-\beta(1-q)](1-w)[\phi y_t + \epsilon_t]}{1-q+w[q+\beta(1-q)(1-q+\gamma q)]} \tag{9}$$

As a baseline, however, we first impose GG's value for γ of unity and show the persistence properties of their model in Figures 5 and 6 as a function of the share of rule-of-thumb (RoT) firms, w. Clearly w may be calibrated to match any desired degree of persistence, the debate at this point being the plausibility or otherwise of the required share of non-optimising firms.

However, the value of γ clearly matters for the properties of the model via (9) and hence we explore its plausible value further. To address this we initially assume the different indexing formula (10), which differs from (8) by using last period's aggregate price level rather than only new prices as a base, and analyse the optimal value of its indexing parameter before relating that result back to the GG indexing formula (8). Substituting (10) into the firm's loss function (5) with x^c replaced by x^r, the optimal price for a firm using (10), and minimising with respect to γ^r gives its optimal value by (11) where rho is the perceived AR(1) coefficient for inflation.

$$x^r_{t+j} = p_{t+j-1} + \gamma^r \pi_{t-1} \tag{10}$$

$$\gamma^r = \frac{\rho}{1-\beta(1-q)\rho} \tag{11}$$

We now use (11) to derive the optimal γ in (8) and thus the possible value to use when simulating (9). As a first step, the standard expression for the aggregate price level given the Calvo constant hazard assumption is shown by (12). Lagging (12) one period and rearranging gives (13) which may be substituted into (8) to give (14) which has the same structure as (10). From (14) it is apparent that the pricing rule (8) implies a significant degree of indexing to last period's aggregate price level even if γ is zero via the term (1-q)/q.

$$p_t = qp^{/}_t + (1-q)p_{t-1} \tag{12}$$

$$p^{/}_{t-1} = p_{t-1} + \left(\frac{1-q}{q}\right)\pi_{t-1} \tag{13}$$

$$x^b_t = p_{t-1} + \left[\frac{1-q}{q} + \gamma\right]\pi_{t-1} \tag{14}$$

The optimal value for the indexing parameter in (8) may be derived from equating the square bracketed coefficient in (14) with (11). This implies that a value of γ of unity is very high and that it may often be negative. For example, with a standard calibration of q=0.25, (1-q)/q is 3 and hence the square bracketed term in (14) would be 4 which is much higher than the right hand side of (11) if rho is less than unity. Hence it appears that the GG model with γ=1 has much too high a degree of indexing built in. This arises from indexing to last period's new prices rather than last period's aggregate price level. From (13) it may be seen that simply setting the new rule of thumb price equal to last period's new prices already implies indexing by (1-q)/q and the second term in (8) adds to that if γ is positive.

In Figure 7 we show the implication of setting γ in (8) to the optimal value derived above, typically much less than unity and often negative. From the figure both a high share of rule-of-thumb firms (w) and a high degree of perceived persistence is required to generate plausible actual persistence. The possibility of learning dynamics is clearly present here also with actual persistence consistently much lower than perceived persistence.

To summarise, we have argued that the GG model has an implausibly high degree of persistence built into it, generated by assuming that rule-of-thumb firms index much more vigorously to past inflation than optimal indexing behaviour would imply. If the degree of indexing is endogenised the model can only generate high levels of persistence with a very high share of rule-of-thumb firms with very high priors on the degree of actual persistence. Even then, learning behaviour would tend to weaken the degree of actual and perceived persistence over time with zero persistence a stable outcome of that process in common with the CEE model.

3. Conclusion

This paper has addressed the plausibility of the microfoundations for a lagged inflation term in the Phillips curve put forward by Christiano, Eichenbaum and Evans (2005) and Gali and Gertler (1999). This term is usually considered necessary for data consistency. In the models, lagged inflation matters for current inflation due to indexing or rule of thumb behaviour by at least some firms. The paper has pursued this general modelling approach but strongly questioned its application in the two models. In the first instance, the coefficient on lagged inflation drops significantly in Christiano, Eichenbaum and Evans (2005) if we follow microeconomic evidence and allow for not all firms to change their price each period. Secondly, in both models we showed that indexing/rule of thumb behaviour implicitly rests on simple AR(1) forecasting rules and that the existing models implicitly assumed beliefs that inflation was a very persistent process. If indexing or rule of thumb firms are near rational, in the sense that they follow simple rules but periodically update the coefficients in those rules in line with the observed behaviour of inflation, we found that when private sector behaviour is combined with a standard policy maker the only long run stable degree of inflation persistence is zero. Given that result, we conclude that the existing indexing/rule of thumb models do not provide convincing microfoundations for inflation persistence unless firms initially believe that inflation is highly persistent and do not subsequently revise their beliefs in the light of actual inflation behaviour.

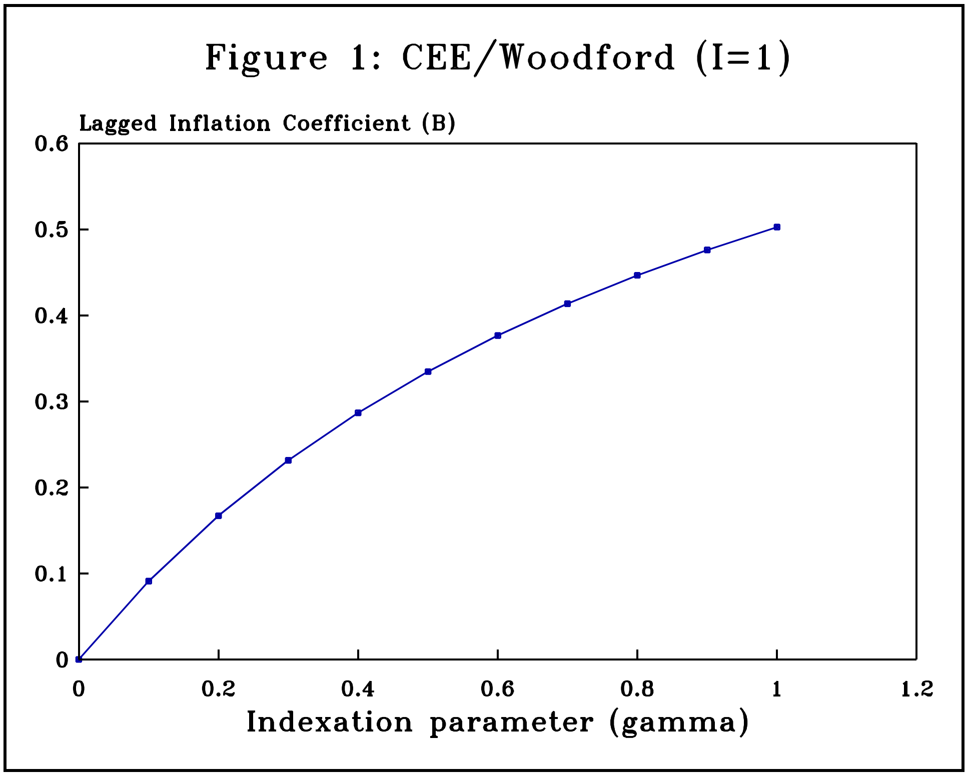


Figure 1: CEE/Woodford (I=1)
Lagged Inflation Coefficient (B)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
0.8
1
1.2
Indexation parameter (gamma)

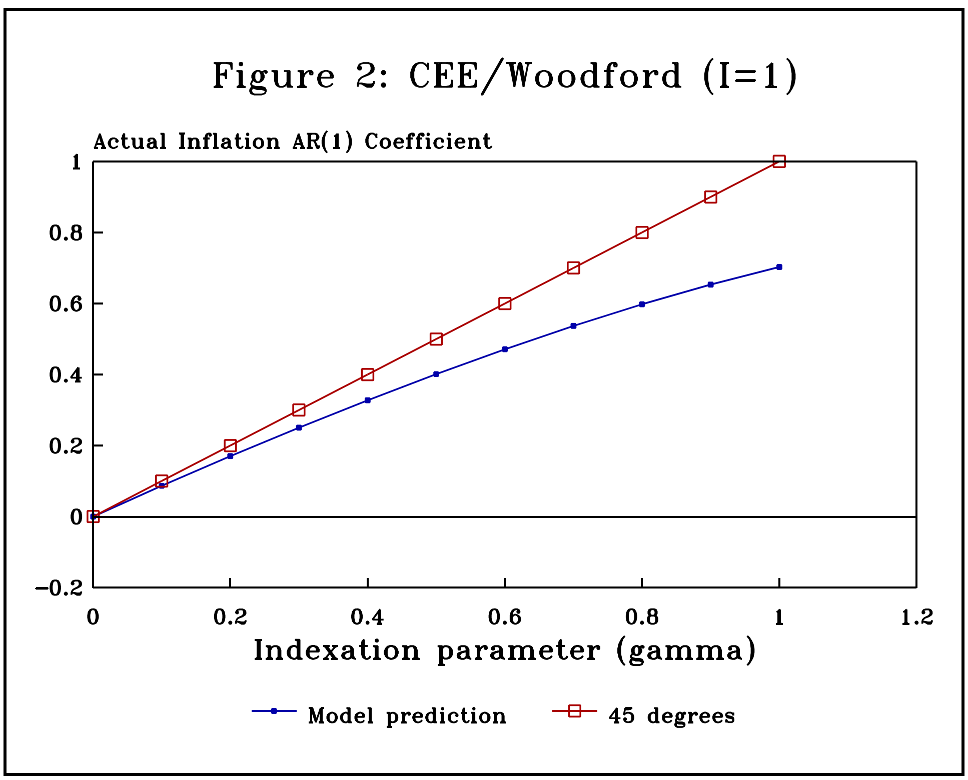


Figure 2: CEE/Woodford (I=1)
Actual Inflation AR(1) Coefficient
1
0.8
0.6
0.4
0.2
0
−0.2
0
0.2
0.4
0.6
0.8
1
1.2
Indexation parameter (gamma)
Model prediction
45 degrees

Figure 3: Hybrid CEE/Woodford and Calvo

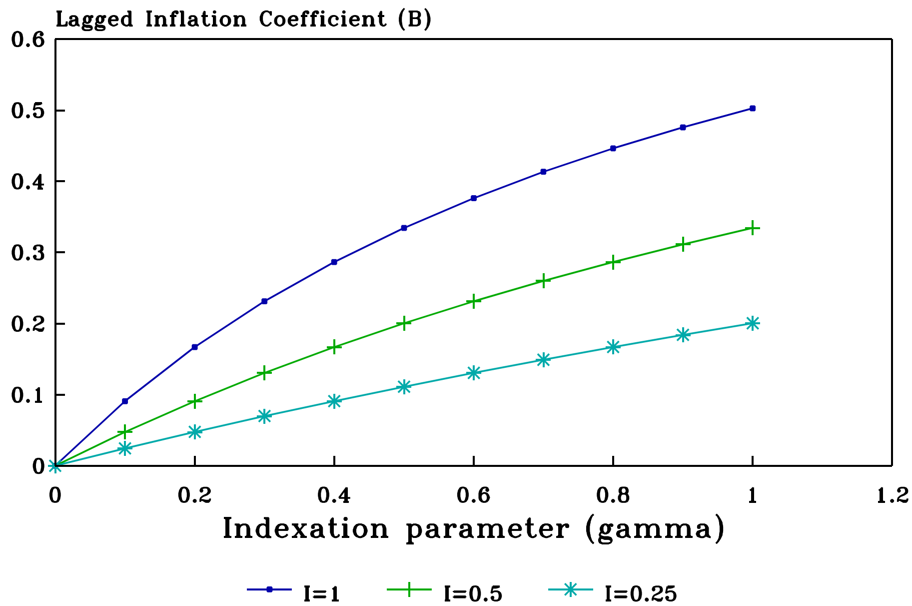
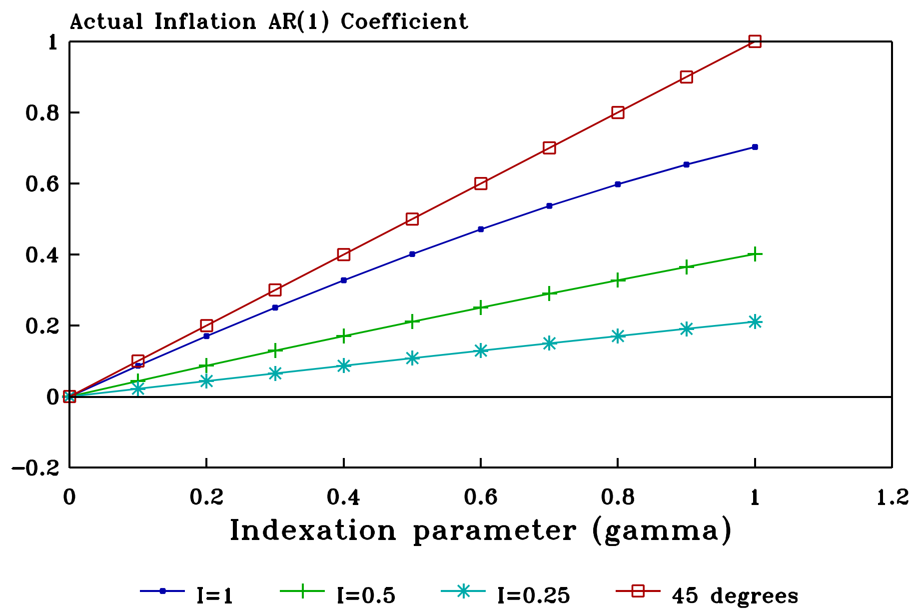


Figure 4: Hybrid CEE/Woodford and Calvo



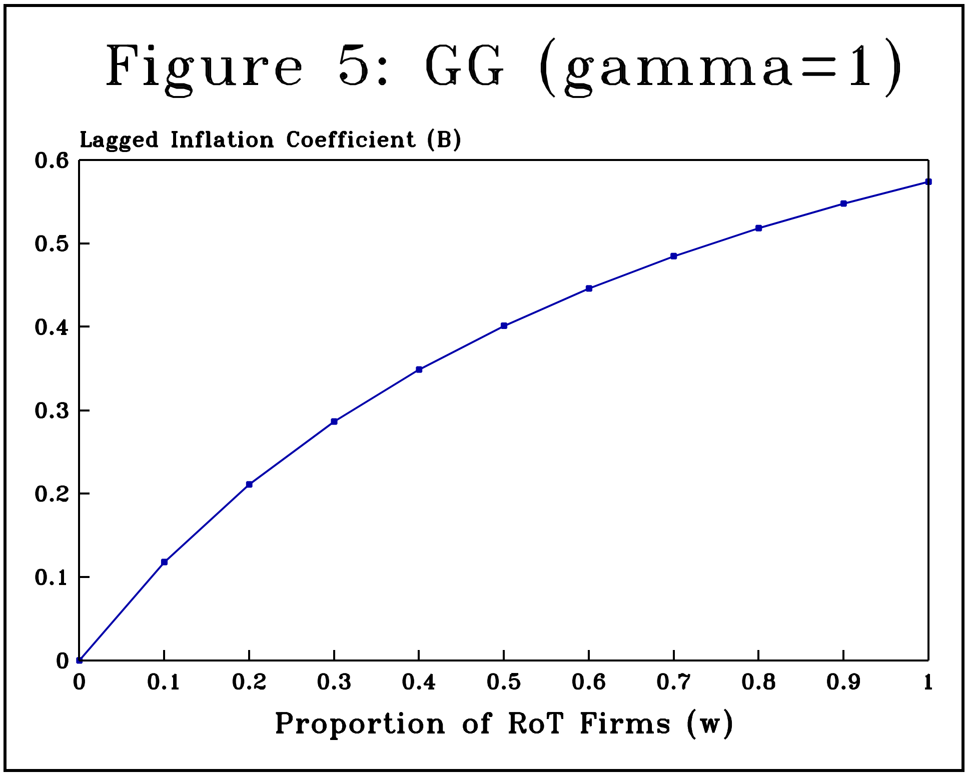


Figure 5: GG (gamma=1)
Lagged Inflation Coefficient (B)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Proportion of RoT Firms (w)

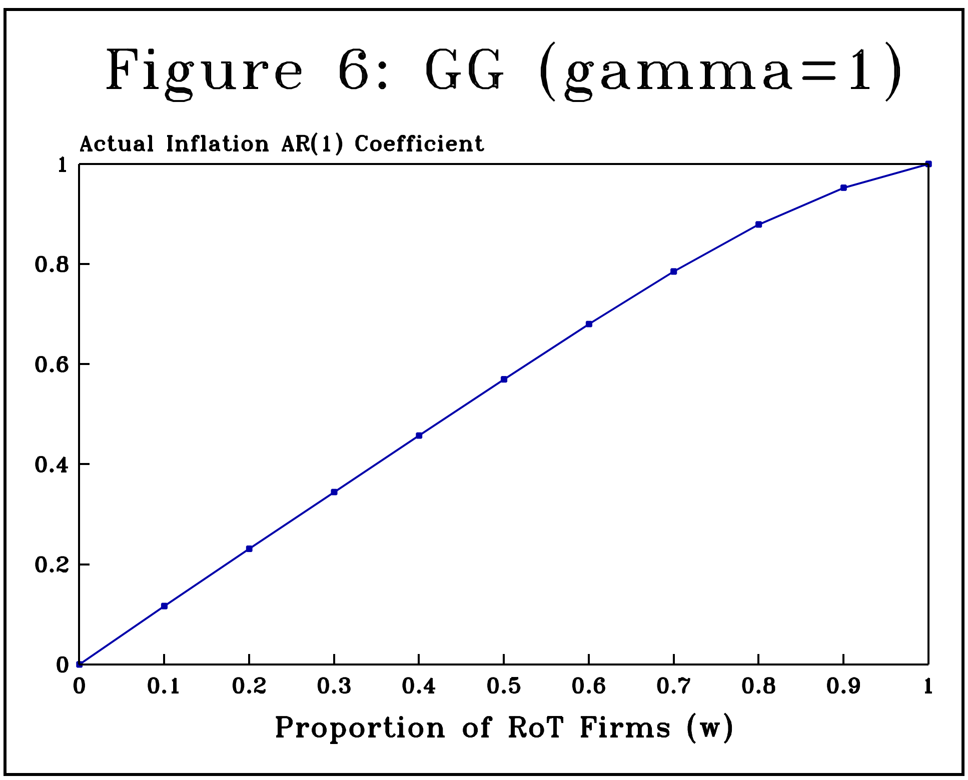


Figure 6: GG (gamma=1)
Actual Inflation AR(1) Coefficient
1
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Proportion of RoT Firms (w)

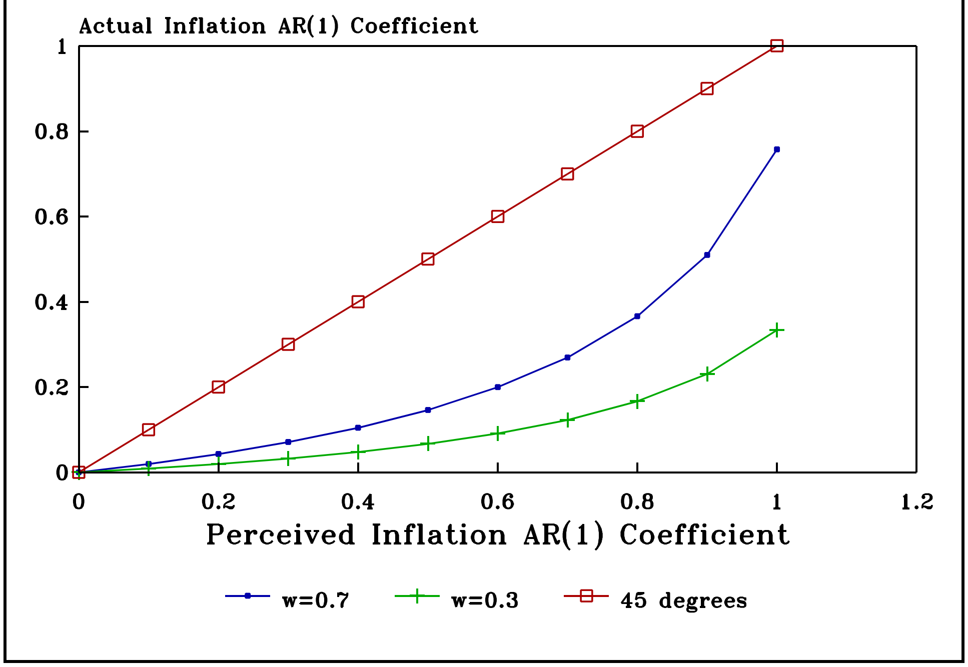


Figure 7: GG With Optimal Indexing

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