The Evolution of Forward-looking Agent Behavior in Inflation Dynamics

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Abstract

In the wake of the rational expectations revolution, empirical measures of inflation have increasingly focused on models incorporating forward-looking behavior. Prior to the 1990's, most empirical measures of the Phillips curve were decidedly backward-looking.

As such, there has been a clear shift in thought and practice between the backward-looking inflation dynamic 20-plus years ago, and the more forward-looking inflation dynamic in practice today. This paper estimates the evolution of the degree of backward versus forward-looking behavior in the inflation specification over time. Results for the U.S. indicate a clear but gradual deterioration of predominantly forward-looking behavior starting in the early 1960's, reversing course sometime between 1985 and 1989. The timing of this trend seems to coincide closely with variation in Fed credibility.

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1 Introduction

In the wake of the rational expectations revolution, empirical measures of inflation have increasingly focused on models incorporating forward-looking behavior. In particular, the New Keynesian Phillips curve (NKPC) assumes agents are completely forward-looking, and provides an inflation dynamic that depends on expected future inflation. The theoretical implication is that inflation is a jump variable, and that monetary policymakers can engineer costless disinflations. Gali and Gertler (1999) augment the standard forward-looking NKPC by introducing a fraction of agents who use rule-of-thumb behavior in pricing decisions. The implied theoretical persistence is designed to better match empirical measures of inflation persistence, and hence costs to disinflation policies. More recent research has challenged the robustness of the NKPC, and has incorporated various mechanisms of inertia, such as Mankiw and Reis' (2002) sticky information Phillips curve. Yet prior to the 1990's, most empirical measures of the Phillips curve were decidedly backward-looking, incorporating lags of inflation to varying degrees.

As such, there has been a clear shift in thought and practice between the backward-looking inflation dynamic 20-plus years ago, and the more forward-looking inflation dynamic in practice today. This paper aims at estimating the evolution of the degree of backward versus forward looking behavior in the inflation specification over time, primarily to identify when and how quickly the wholesale shift took place, and explore some of the key reasons for the shift.

This paper proceeds as follows. The next section briefly outlines some of the previous findings on inflation dynamics. Section 3 examines the dynamic estimates of the hybrid New Keynesian Phillips curve outlined by Gali and Gertler (1999) and the related partial indexation model in the same context. Section 4 explores some explanations for the evolution of forward-looking behavior in the

inflation specification. Concluding remarks then follow.

2 Previous Literature

Early work on structural changes in inflation dynamics by Barsky (1987) and Klein (1978) illustrate the evolving nature of inflation persistence. In particular, Barsky shows that inflation exhibited very little persistence until the postwar period. Indeed, from the late 1960s through the mid-1980s, inflation exhibited highly persistent behavior, which gave rise to empirical models of inflation behavior using lagged inflation as the predominant characterization.

Recently there has been a resurgence in research on the behavior of inflation dynamics, and several papers specifically investigating inflation persistence. For instance, Lansing (2006), Cogley and Sargent (2002), and Levin and Piger (2006), using various alternative metrics, show persistence is relatively high throughout most of the 1960's through the 1980's, after which at some point in the 1990's inflation persistence begins to deteriorate. Pivetta and Reis (2007), using a similar methodology to Cogley and Sargent, show that when framed by confidence intervals over various measures of persistence, statistically one cannot reject the null of stable inflation persistence from the 1960s forward.

Shown in Figure 1 below is the first-order autocorrelation statistic of GDP deflator inflation, calculated over a centered rolling window of data. Using a 20 year window of data shows that this simple measure of persistence follows a story similar to Lansing, Cogley et al., and Levin et al. Expanding the data window to 30 years shows that inflation persistence appears to be a bit more stable, with no perceptible decline in the late 1980's or early 1990's.[1]

[1] Given another year or two of data, it seems likely that the autocorrelation indicator for the 30 year window would begin to decline, as is indicated by the main estimation results below.

[figure 1 about here]

Our concern in this paper is not inflation persistence per se, rather we investigate the related issue of the structural form of the Phillips curve as it relates to inflation persistence. Historically, autoregressive forms of the Phillips curve have had good success at fitting post-war inflation data. The recent emergence of the NKPC, with forward-looking optimizing agents seems to have roughly coincided with the degradation of inflation persistence measures. Figure 2 shows the 20 year centered rolling window estimation results for a standard autoregressive Phillips curve, using the OLS specification of Rudebusch (2001):

$$\pi_t = a + \sum_{i=1}^{4} b_i \pi_{t-i} + c y_{t-1}, \tag{1}$$

where π is the inflation rate of the GDP deflator, and y is the output gap as measured by CBO estimates. Clearly, the simple autoregressive Phillips curve is remarkably stable from the late 1960's through the 1980's. However, in the early 1990's the structural stability and predictive power begins to break down. Both the R-squared, and the coefficient on the first lag of inflation fall substantially. Moreover, the sum of the lagged inflation coefficients decreases well below one, suggesting a violation of the natural rate hypothesis.

[figure 2 here]

At the other extreme is the purely forward-looking NKPC, where inflation depends on *expected future* inflation, and some driving aggregate variable such as the output gap, as is commonly formulated in equation (2) below.

$$\pi_t = b E_t \pi_{t+1} + c y_t \tag{2}$$

This specification has received much criticism, primarily because the theoretical

construction does not imply very much inflation persistence, which is at odds with the data. Using microfoundations, Gali and Gertler (1999) modify the NKPC by assuming a fraction of agents who utilize rule-of-thumb behavior in price setting. The result is the 'hybrid' NKPC which contains both lagged inflation, and a forward-looking inflation component which Gali and Gertler assert matches the data quite well, with around one-third of agents using rule-of-thumb behavior. Mankiw and Reis (2002) modify the purely forward-looking NKPC by assuming that, although agents are rational, they consciously choose to ignore some amount of information, and therefore some price setting behavior is based on outdated information; this introduces some form of structural inertia in the inflation process that can be accounted for by the data.

Given there appears to be a breakdown in the stability of inflation persistence, this suggests that structural estimates of inflation dynamics would be better suited to be estimated dynamically, similar to Branch (2004) and (2007). Branch (2004) estimates dynamically the proportion of agents who use less-than-rational predictors in survey measures of inflation expectations. He finds that those proportions for the most part vary little over time, with the exception of the period of the early 1980's. Branch (2007) measures a time varying distribution of how often agents update their information sets in the sticky information model of Mankiw and Reis (2002) and finds considerable variation over time in the proportion of agents who update at certain frequencies.

A similar approach to ours is by Cogley and Sbordone (2006), who develop a NKPC which allows for drift in trend inflation over time. The Cogley and Sbordone model has several key features which set it apart from Gali et al. First, the allowance for variation in trend inflation implies several key coefficient parameters vary over time. Second, rather than a rule-of-thumb, Cogley and Sbordone assume some agents update prices through indexation. In addition, an infinite

stream of expected future inflation terms enters the inflation specification. The key result of Cogley and Sbordone is that accounting for changes in trend inflation dramatically reduces the implied persistence in inflation, and that the resulting primarily forward-looking inflation specification is well suited to the data.

Sbordone (2007) asserts that the model incorporating trend inflation is the appropriate structural model, and that the statistical significance of lagged inflation in 'ad hoc' models such as Gali and Gertler's rule-of-thumb pricing model is actually a proxy for the stream of expected future inflation in the (true) trend inflation model. However, there are two key reasons to be cautious of this conclusion. First, they present no formal model of trend inflation, thus the trend inflation specification could be considered ad hoc in the sense that it doesn't explain *why* trend inflation varies over time, particularly in the 1970's and early 1980's (for instance, by reflecting variation in trend inflation as a function of central bank preferences). And, given the difficulty of accurately forecasting inflation more than one or two quarters ahead, the prospect of forecasting a stream of expected inflation far into the future would seem to be exceedingly difficult.[2] In this respect, if the lagged inflation term is proxying for the stream of expected future inflation, then it would seem it is proxying *precisely because* some agents are unable to accurately assess these complex computations, and therefore rely on much simpler methods of price-setting. From this perspective, the hybrid NKPC seems appropriate to assess the evolution of forward-looking behavior, and consequent inflation persistence over time.

With this motivation, we dynamically estimate Gali and Gertler's (1999) hybrid NKPC to assess the stability of the forward- versus backward-looking

[2] For some mixed evidence of this, see Mankiw, Reis, and Wolfers (2003). They suggest that inflation expectations are "relatively accurate," however the horizon over which expectations are measured is generally a year or less, and dispersion among the different measures is substantial. In addition, a visual comparison of expected and actual inflation shows substantial divergence, especially during the 1970's and early 1980's.

composition of agents. In addition, the structural estimates allow for recovering the coefficient on expected future and lagged inflation, which is designed to give some insight into the breakdown in inflation persistence experienced in the 1990's, but with the added advantage that the source can be isolated from structural parameters. We focus our analysis to the Gali and Gertler (1999) and Gali, Gertler, and Lopez-Salido (2001, 2005) model for reasons of comparison and tractability, and extend this analysis to a similar model using partial indexation as in Smets and Wouters (2007). Results between the two models are reinforcing: forward-looking behavior gradually declines beginning in the 1960's before reversing trend sometime in the late 1980's. These results are consistent with reductions in inflation persistence found by Lansing (2006), Cogley and Sargent (2002), Levin and Piger (2006), and many others.

3 Specification and Results

3.1 Model

The hybrid version of the NKPC developed in Gali and Gertler (1999) and extended in Gali et al. (2001, 2005) assumes monopolistically competitive firms with price setting determined by a Calvo (1983) style random price setting mechanism, where each period firms have probability $1-\theta$ of resetting prices. It is assumed that, among all price setting agents, a fraction ω reset prices using a *rule-of-thumb*, where the representative firm sets its price according to $p_t^* = \overline{p}_{t-1}^* + \pi_{t-1}$, and $\overline{p}_{t-1}^*$ is the average of all reset prices in period $t-1$. The remaining fraction of agents, $1-\omega$ are assumed to behave in a fully rational manner, setting prices based on a rational expectations mechanism. Given a discount factor β, it can be shown that the microfoundations imply an inflation dynamic which evolves according to

$$\pi_t = \gamma_f E_t \pi_{t+1} + \gamma_b \pi_{t-1} + \lambda x_t, \tag{3}$$

where

$$\lambda \equiv (1-\omega)(1-\theta)(1-\beta\theta)\phi^{-1},$$
$$\gamma_f \equiv \beta\theta\phi^{-1},$$
$$\gamma_b \equiv \omega\phi^{-1},$$
$$\phi \equiv \theta + \omega[1-\theta(1-\beta)].$$

and x is the driving aggregate variable.

This hybrid NKPC has the feature that it nests the purely forward-looking NKPC when $\omega = 0$. Note also that the restriction that $\gamma_f + \gamma_b = 1$ is equivalent to the restriction that $\beta = 1$, an imposition of the natural rate hypothesis.

3.2 Estimation

For estimation, we use quarterly data obtained from the Federal Reserve database FRED, from 1947:1 to 2006:3. Gali and Gertler, in their original estimation use DRI/Citibase data for their results. We use the matching Federal Reserve counterparts to those specified variables (see Appendix A for a description). For the aggregate driving variable, x, we use a measure of real marginal cost, labor's share of total income.[3] Inflation is measured by the GDP implicit price deflator.

Due to the nonlinear nature of the inflation specification, we replicate Gali and Gertler's estimation approach, using GMM estimation, but on a 20 year rolling window as our initial procedure. Following Gali et al. (2005), we specify instruments as 4 lags of inflation, and two lags each of quadratically detrended

[3] Gali and Gertler (1999), Sbordone (2002), and others show that using measures of marginal cost more consistently produce the appropriate sign and magnitude for the driving variable, as opposed to traditional measures such as the output gap, which can rely on arbitrary measures of potential output.

output, real marginal cost, and wage inflation. For comparison purposes, a summary of the static estimates of Gali et al. (2005) are below in Table 1.

[Table 1 about here]

The first column group replicates the estimates using the same data obtained from Gali et al. The second column group shows the same estimation and sample period, using the comparable Fed data series. Generally, the estimates for the different data series for comparable samples are quite close: rule-of-thumb behavior is on the order of about 40% of agents, and the forward-looking component in the inflation dynamic is about two-thirds, while the lagged inflation component contributes about one-third. The third column group shows the same estimation procedure, but for a wider sample spanning 1947:1 to 2006:3. These estimates are quite different than the previous two column groups, and in light of the results from Figures 1 and 2, appear to be heavily influenced by the particularly forward-looking nature of inflation pre-1970, and from the 1990's onward.

Indeed, the apparent instability of the coefficient estimates over the different samples indicates that the coefficients themselves have evolved over time, from a mostly forward-looking dynamic pre-1970, to a much more inertial, backward-looking dynamic from about 1970 to the 1990's, and beyond that, appears to egress again to a more forward-looking dynamic to the present. Gali and Gertler (1999) examine the issue of subsample stability in their estimations, however they parse the benchmark sample from 1960 - 1997 into smaller samples. Given that their benchmark sample predominantly spans the 'relatively stable' period from the 1970's to the 1990's, Gali and Gertler's conclusion of subsample stability seems appropriate. However, their data set clearly excludes apparent structural changes in the wider sample used here.

For the initial estimation, we use a 20 year centered rolling estimation pro-

cedure to dynamically estimate (3). Rolling forward, at each estimation point one observation is dropped from the back of the sample, and one added at the front. The centered nature of the estimation is such that, at the estimation point, there is 10 years of data ahead, and 10 years behind. The purpose of using the centered window is such that the 'turning points,' if any, of the structural coefficients underlying the inflation generating process can be reasonably identified.

3.3 Results

Results for the 20 year rolling window are presented below in Figure 3(a). In the periods where ω is particularly low (less than about 10%), in some cases these estimates for ω were not statistically significant, or weakly significant at best. If ω (and hence γ_b) was estimated to be negative, a theoretical impossibility, the proportion of rule-of thumb agents was constrained to be zero. At a few estimation points, the GMM procedure did not converge. When this occurred, one extra observation was added to the front and back of the sample. The process was successively repeated until convergence occurred.[4] The vast majority of estimation points produced strongly statistically significant and reasonable coefficient estimates.

Clearly, forward-looking behavior is predominant through the late 1950's to mid-1960's, also corresponding to a low proportion of rule-of-thumb agents. By the mid-1960's, there is a relatively rapid fall in the forward-looking component of inflation, and consequent rise in ω to well over 60%. From this point, until about the mid 1980's, the forward-looking and lagged components of inflation remain relatively stable, fluctuating around two-thirds and one-third, respectively. At some point in the mid 1980's, forward-looking behavior begins to

[4] This process was utilized at 6 points along the 20 year window estimation, and only one added observation was needed in these cases. For the 25 year window estimation below, this procedure was used only once.

deteriorate further: ω increases again to well over 60%, implying $\gamma_f = 0.31$ and $\gamma_b = 0.54$ by 1989:2. Beyond this point, forward-looking behavior begins to increase again, to levels characterized by $\omega = 0.25$, $\gamma_f = 0.75$ and $\gamma_b = 0.20$.

[Figure 3(a) about here]

As shown in Figure 3(b), constraining the coefficient sum on inflation to one, i.e. $\gamma_f + \gamma_b = 1$ yields similar results to above. The peak of backward-looking behavior occurs around 1967:4 ($\omega = 0.68$) and again around 1989:2 ($\omega = 0.66$). Moving ahead, forward-looking behavior again begins to predominate, implying $\gamma_f \approx 0.80$ and $\gamma_b \approx 0.20$ by the early 1990's.

[Figure 3(b) about here]

A common concern with GMM is the reliability of the estimates in small samples. In the results of Figures 3(a) and 3(b) there appears to be quite a bit of variation in the estimates over relatively short time periods, especially in the mid-1960's and late 1980's, which could be due to the small sample properties of GMM. Staiger and Stock (1997) suggest that $10 - 20$ observations per instrument is a good guideline for sampling distributions to reasonably approximate asymptotic distributions. Under the baseline data window of 20 years, quarterly data implies 80 observations; with 9 instruments used, this is a bit below the range recommended by Staiger and Stock.

As a consequence, we expand the size of the data window to check the robustness of the results. Figure 4(a) shows the estimates using a 25 year centered rolling window. The expanded data window reveals a more consistent trend in the estimates: forward-looking behavior predominates in the early 1960's, but appears to gradually decline over time, until about 1984:4, where $\omega = 0.58$, $\gamma_f = 0.49$ and $\gamma_b = 0.44$. After 1985, forward-looking behavior rises again to where γ_f is a bit above 0.80 and γ_b slightly less than 0.20. Apparently, the ad-

dition of the extra 20 observations mutes some of the high-frequency variation in the previous estimates, revealing a clear downward trend in γ_f which reverses in the mid-1980's.

[Figure 4(a) about here]

Constraining $\gamma_f + \gamma_b = 1$ in Figure 4(b) again gives a similar picture, although the clarity of the downward trend is not quite as stark as in Figure 4(a). However, the main characteristics do hold: overwhelmingly forward-looking behavior in the early 1960's deteriorates until 1984:4, then begins to rise after that.

[Figure 4(b) about here]

As a final check, we expand the data window to 30 years. These results for the standard estimation, and the restricted estimation ($\gamma_f + \gamma_b = 1$) are shown below in Figures 5(a) and 5(b). In similar fashion to the 25 year data window, forward-looking behavior gradually declines from its early 1960's peak, bottoming out around 1987:3 for the standard estimation, and 1987:1 for the restricted estimation, before recovering to around $\gamma_f \approx 0.80$ and $\gamma_b \approx 0.20$ by the early 1990's.

[Figure 5(a) about here]

[Figure 5(b) about here]

3.4 Partial Indexation Model

An alternative but similar model to generating inflation persistence through the presence of lagged inflation is the partial indexation model, originating from Christiano, Eichenbaum, and Evans (2005) and outlined in Woodford (2003), and Smets and Wouters (2007), among others. There are two key distinctions

of this model from the hybrid NKPC proposed by Gali and Gertler. In the partial indexation model, *all* price-setters are allowed to adjust prices every period, and the mechanism by which prices are updated is slightly different. In the partial indexation model, the fraction of firms θ who do not get chosen to optimally update prices are allowed to reset prices through contract indexation. Letting τ denote the degree of indexation, the representative firms who reset prices through indexation are allowed to set its price to $p_t^* = p_{t-1}^* + \tau\pi_{t-1}$. When $\tau = 1$, contracts are fully indexed to inflation, and when $\tau = 0$, the model reverts to the typical forward-looking NKPC. Under these assumptions, the inflation specification is again

$$\pi_t = \gamma_f E_t \pi_{t+1} + \gamma_b \pi_{t-1} + \lambda x_t, \tag{4}$$

but now the coefficients are defined as

$$\begin{aligned}
&\lambda \equiv (1-\theta)(1-\beta\theta)\left(\theta\phi\right)^{-1}, \\
&\gamma_f \equiv \beta\phi^{-1}, \\
&\gamma_b \equiv \tau\phi^{-1}, \\
&\phi \equiv 1 + \beta\tau.
\end{aligned}$$

In this model, the degree of indexation τ plays a similar role to that of the proportion of rule-of-thumb agents ω, as in the Gali and Gertler model, in generating inflation persistence through the lagged inflation coefficient γ_b. Using the same GMM procedures, Table 2 shows static estimates for the narrow sample from 1960:1 to 1997:4, and the larger sample from 1947:1 to 2006:3. A similar pattern emerges to that of the counterpart Table 1. The degree of indexation is higher in the narrow sample than that encompassed by the larger sample, and as a result, the lagged inflation coefficient is much smaller in the larger sample. It is worth noting that the estimated coefficients γ_f, γ_b, and λ are identical across the two specifications in Tables 1 and 2, thus the slightly differing roles

of the structural coefficients result in similar, but not identical values.

[Table 2 about here]

The last columns in Table 2 provide coefficient estimates from Smets and Wouters (2007). The degree of indexation varies substantially across samples: the high inflation period of the late 1960's and 1970's shows a relatively higher degree of indexation and a larger coefficient on lagged inflation, while the period from the mid-1980's onward shows a much smaller degree of indexation and consequent γ_b.

Figure 6 presenting the 25 year centered rolling window estimates of the partial indexation model shows a nearly identical picture to the counterpart in Figure 4(a) using rule-of-thumb pricing. Predominantly forward-looking behavior deteriorates throughout the 1960's to early 1980's, reaching the low point in 1985:1 where $\gamma_b = 0.44$, $\gamma_f = 0.48$, and $\tau = 0.64$. Forward-looking behavior begins to recover before briefly dropping around 1991 at which point the degree of indexation briefly spikes to $\tau = 0.68$ by 1992:1 before quickly falling.

[Figure 6 about here]

4 Analysis

The results bring into clear focus the notion that the reduced-form coefficients of the hybrid NKPC have evolved from a highly forward-looking, low persistence regime in the early 1960's to a more backward-looking, inertial process that peaked sometime between 1985 and 1989, before reversing fairly quickly again to a predominantly forward-looking regime by the early 1990's. In both the 25 and 30 year windows, it takes approximately 20 years for γ_f to *decrease* from about 0.80 to its low point, but less than 10 years to increase from the low point back to $\gamma_f \approx 0.80$. In addition, the timing of the dynamic GMM

estimates roughly coincide with the autocorrelation results and autoregressive Phillips curve estimates provided in Figures 1 and 2.

Given the evolution story indicated above, the more important question then becomes what is the cause of the evolution? The degradation of forward-looking behavior in the 1960's seems to coincide with the gradual increase in inflation throughout the decade and continuing through the 1970's into the early 1980's. The timing of the peak backward-looking behavior around the mid-1980's does roughly coincide with the peak behavior of the inflation rate: as inflation declines from its high point in the early 1980's, so does the lagged inflation component γ_b. This proposition seems to be confirmed in Figure 7 below, which shows ω, τ, and γ_b for the benchmark 25 year estimations superimposed with the inflation rate, and the 5 year trailing moving average of the inflation rate. Though by no means conclusive, generally as the lagged average inflation rate rises through the 1960's to early 1980's, so does ω, τ, and γ_b.

[Figure 7 about here]

We speculate two plausible and somewhat related concepts are driving this result: central bank credibility and the costly acquisition of information. The primary justification for the presence of less-than-rational agents is often motivated by agents' abilities to access or process accurate information. In an environment when inflation increases or becomes more variable, one would expect that the ability to get timely, accurate pricing information would be diminished, thus the acquisition costs (in monetary, time, or other dimensions) presumably rise. In addition, as the inflation rate rose substantially in the 1970's, the belief in the central bank's ability to maintain stable inflation became increasingly dire. In such an environment, relying on announcements about future policy from a non-credible central bank becomes increasingly futile, thus agents may switch to a rule-of-thumb, or adaptive type expectations formation mechanism.

The results of Beechey and Osterholm (2007) indicate some validity to this hypothesis. They confirm the drop in inflation persistence that others have found in the data, and attribute much of the evolving inflation persistence to changes in Fed preferences on the output-inflation tradeoff. In particular, they show that preferences for output stabilization increased through the 1970's, allowing inflation to slide farther from desired levels, thereby enhancing inflation persistence and reducing the Fed's implied credibility in managing inflation.[5] Benati (2006) also provides some evidence of this, asserting that "...under stable monetary regimes with clearly defined nominal anchors, inflation appears to be (nearly) purely forward-looking, so that no mechanism introducing backward-looking components is necessary to fit the data." The Federal Reserve clearly lacked any credible nominal anchor in the 1970's and early 1980's, however in the last decade or so as the Fed has moved closer to more formal targeting strategies, transparency has substantially improved as the forward-looking component has become dominant.

Paul Volcker is famously credited for reducing the inflation rate from its early 1980's peak through a series of austerity measures. However, those strong policies didn't have an immediately appreciable impact on credibility. Hardouvelis and Barnhart (1989) analyze the evolution of Fed credibility over the period from 1978 to 1984, finding that there was a somewhat delayed, gradual response to major policy innovations in October 1979 and October 1982. In particular, the response of commodity prices "...began a downward trend after mid-1980..." indicating that markets were still unsure as to the effectiveness of Fed policy in reducing inflationary pressure.

The timing of the relatively quick recovery and increase in γ_f somewhere between 1985 - 1989 then seems not to be coincidental: once the Fed regained

[5] However, they also assume stability in γ_b and γ_f over time. This is clearly at odds with the results presented here, thus it would be beneficial to see how Beechey and Osterholm's results differ on this level.

some measure of credibility through low, stable inflation, it became increasingly feasible to rely on forward-looking measures of prices. Interestingly, when inflation perks up again in the early 1990's, we again see a jump in ω, τ, and consequently γ_b around the same time, perhaps representing a collective worry that the economy will repeat the high-inflation period of the 70's and 80's. Presumably, once it became clear that inflation was under control by the Fed, γ_b dropped precipitously.

5 Conclusions

The hallmark of modern monetary policy is to maintain low, stable inflation, which is generally achieved through prudent, credible monetary policy and managing inflation expectations. As long as a stable relationship exists between expected inflation and actual inflation in the inflation specification, executing policy is relatively straightforward.

However, as is clear from the results of this paper, that relationship has not been all that stable in the U.S., complicating policymakers' ability to conduct policy. Since the 1960's, the magnitude of the forward-looking inflation component gradually declined, while lagged (and hence persistent) inflation appears to increase in importance. The trend reverses sometime between 1985 and 1989, which appears to coincide with a resurgence in Fed credibility and lower inflation by the mid-1980's.

Though by no means definitive, our results suggest that the evolution of the expected future and lagged inflation components may be linked to the credibility of the monetary authority. Intuitively, declines in Fed credibility would suggest that announcements of future policies can no longer be believed, thus price setting agents utilize less costly methods of price setting, such as an adaptive mechanism. Establishing a direct connection between policy credibility (such as

through the central bank's preference parameters in the output-inflation trade-off) and choice of expectations formation mechanism (as in endogenizing the choice of ω or τ) would then seem to be worthy of further investigation.

Sbordone (2007) shows the consequences of mis-specifying the degree of inflation persistence when constructing policy, thus having an accurate assessment of the sources of persistence and behavior over time is crucial to constructing prudent policy prescriptions. This point is even more salient when considering influential policy recommendations, such as those of Giannoni and Woodford (2003) who construct optimal policy rules from an estimated structural model, comparing the optimal responses to actual policy behavior. In particular, they estimate the degree of indexation (for data from 1980 to 2002) to be essentially one, and thus base the optimal responses and comparisons to actual policy under this assumption. Our results suggest that the degree of indexation, and hence persistence, is much lower and has varied quite substantially over this time frame, raising concerns about the sensitivity of such recommendations to variation in contract indexation or rule-of-thumb behavior.[6]

It isn't clear that the upward resurgence of the forward-looking inflation component for the U.S. is transitory or permanent. Given a few more years of data, it would seem a more definitive assessment of this question can be made. In any event, if the proposed connection between credibility and expectations formation mechanisms is real, then the Fed's long-term commitment to transparent monetary policy via an implicit or explicit inflation targeting regime would suggest that the forward-looking inflation coefficient will be permanently higher for some time.

[6] In the discussion summary of Giannoni and Woodford's (2003) paper, Olivier Blanchard (p. 171) raised a similar concern about the empirical properties of the estimated model, and warned that the welfare analysis would be misleading if these features were wrongly represented.

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7 Appendix: Data Definitions and GMM Estimation Procedures

7.1 Data

The list below shows the variables used, along with the appropriate Citibase/DRI and Federal Reserve variable equivalents.

Source:	Citi/DRI	FRED
Nominal GDP	*gdp*	*gdp*
Real GDP	*gdpq*	*gdpc*96
Nonfarm Business Compensation Per Hour	*lbcpu*	*compnfb*
Nonfarm Business Implicit Price Deflator	*lbgdpu*	*ipdnbs*
Nonfarm Business Unit Labor Costs	*lblcpu*	*ulcnfb*

From the above definitions, the appropriate variables are constructed as follows:

Potential output $\overline{y}$: Calculated by fitting an OLS quadratic time trend to real GDP

Output gap y: 100*log($gdpc96$ / $\overline{y}$).

GDP deflator = 100*log(gdp / $gdpc96$).

Inflation rate π = GDP deflator - GDP deflator(-1).

Wage compensation = 100*log($compnfb$).

Wage inflation = Wage compensation - Wage compensation(-1).

Labor's share of total income (real marginal cost): 100*log($ulcnfb$ / $ipdnbs$).

7.2 GMM Estimation Details

Following Gali et al. (2005), the orthogonality condition used as a basis for estimation is

$$E_t\{[\pi_t - \beta\theta\phi^{-1}\pi_{t+1} - \omega\phi^{-1}\pi_{t-1} - (1-\omega)(1-\theta)(1-\beta\theta)\phi^{-1}x_t]Z_t\} = 0,$$

where all variables are previously defined, and Z_t is a vector of orthogonal instrumental variables known at time t. As instruments, we use four lags of inflation, two lags of wage inflation, two lags of detrended output, two lags of real marginal cost. A Newey-West correction for heteroskedasticity and autocorrelation is used, assuming 12 lags.

Table 1: Static estimates, hybrid NKPC

Source:	Citi/DRI data/GG		Fed data		Fed data	
Sample:	1960:1 - 1997:4		1960:1 - 1997:4		1947:1 - 2006:3	
	Baseline	$\gamma_f + \gamma_b = 1$	Baseline	$\gamma_f + \gamma_b = 1$	Baseline	$\gamma_f + \gamma_b = 1$
ω	0.4456	0.4539	0.3848	0.3822	0.1419	0.2582
	(0.0648)	(0.0683)	(0.0896)	(0.0921)	(0.1020)	(0.0908)
θ	0.8464	0.8542	0.8810	0.8912	0.9004	0.9430
	(0.0324)	(0.0376)	(0.0384)	(0.0452)	(0.0613)	(0.0551)
β	0.9569	1.0000	0.9611	1.0000	1.0928	1.0000
	(0.0352)	(n/a)	(0.0377)	(n/a)	(0.0634)	(n/a)
γ_f	0.6349	0.6530	0.6760	0.6998	0.9334	0.7850
	(0.0353)	(0.0354)	(0.0514)	(0.0533)	(0.1225)	(0.0581)
γ_b	0.3493	0.3470	0.3072	0.3002	0.1346	0.2150
	(0.0350)	(0.0354)	(0.0527)	(0.0533)	(0.0802)	(0.0581)
λ	0.0127	0.0089	0.0090	0.0058	0.0013	0.0020
	(0.0062)	(0.0051)	(0.0062)	(0.0050)	(0.0058)	(0.0041)

standard error in parentheses below coefficient estimates

Table 2: Static estimates, partial indexation NKPC

Source:	Fed data		Fed data		Smets and Wouters		
Sample:	1960:1-1997:4		1947:1-2006:3		1966:1-2004:4	1966:1-1979:2	1984:1-2004:4
	Baseline	$\gamma_f + \gamma_b = 1$	Baseline	$\gamma_f + \gamma_b = 1$			
τ	0.4352 (0.1060)	0.4289 (0.1088)	0.1579 (0.1096)	0.2738 (0.0942)	0.2200	0.4500	0.2100
θ	0.9100 (0.0291)	0.9134 (0.0361)	0.9008 (0.0588)	0.9507 (0.0486)	0.6500	0.5500	0.7300
β	0.9578 (0.0408)	1.0000 (n/a)	1.0947 (0.0647)	1.0000 (n/a)	0.9984	0.9986	0.9988
γ_f	0.6760 (0.0514)	0.6998 (0.0533)	0.9334 (0.1225)	0.7850 (0.0581)	0.8186	0.6890	0.8256
γ_b	0.3072 (0.0527)	0.3002 (0.0533)	0.1346 (0.0802)	0.2150 (0.0581)	0.1804	0.3105	0.1736
λ	0.0090 (0.0062)	0.0058 (0.0050)	0.0013 (0.0058)	0.0020 (0.0041)	0.1550	0.2545	0.0828

standard error in parentheses below coefficient estimates

Figure 1

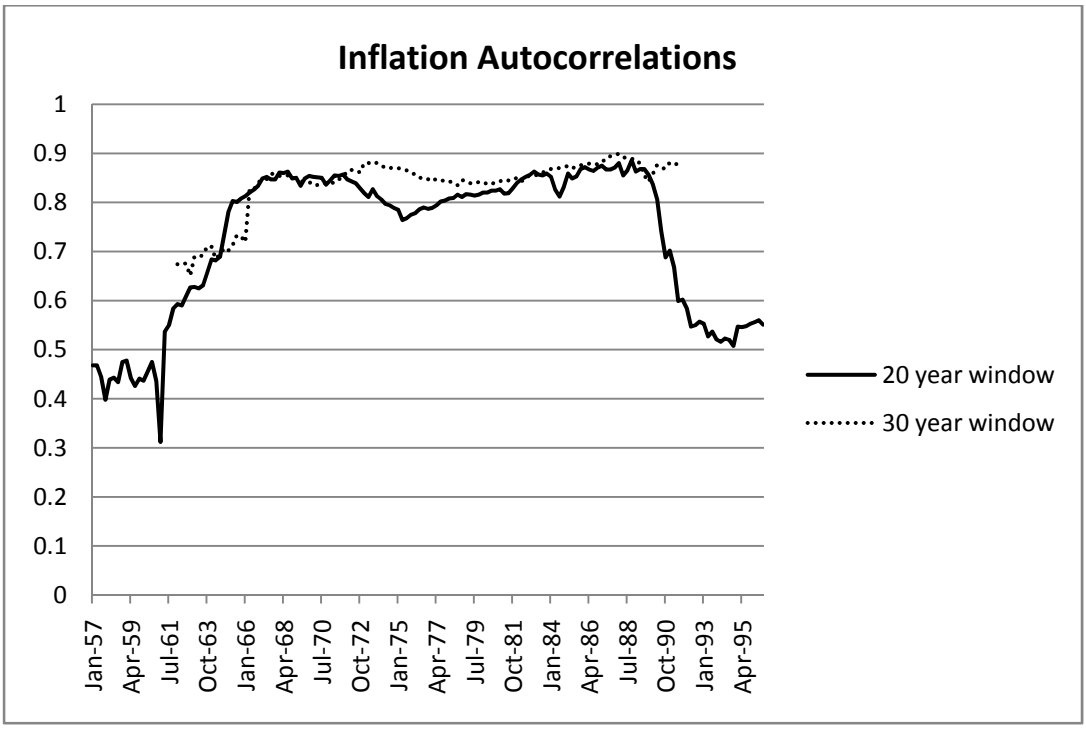

Inflation Autocorrelations
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Jan-57
Apr-59
Jul-61
Oct-63
Jan-66
Apr-68
Jul-70
Oct-72
Jan-75
Apr-77
Jul-79
Oct-81
Jan-84
Apr-86
Jul-88
Oct-90
Jan-93
Apr-95
20 year window
30 year window

Figure 2

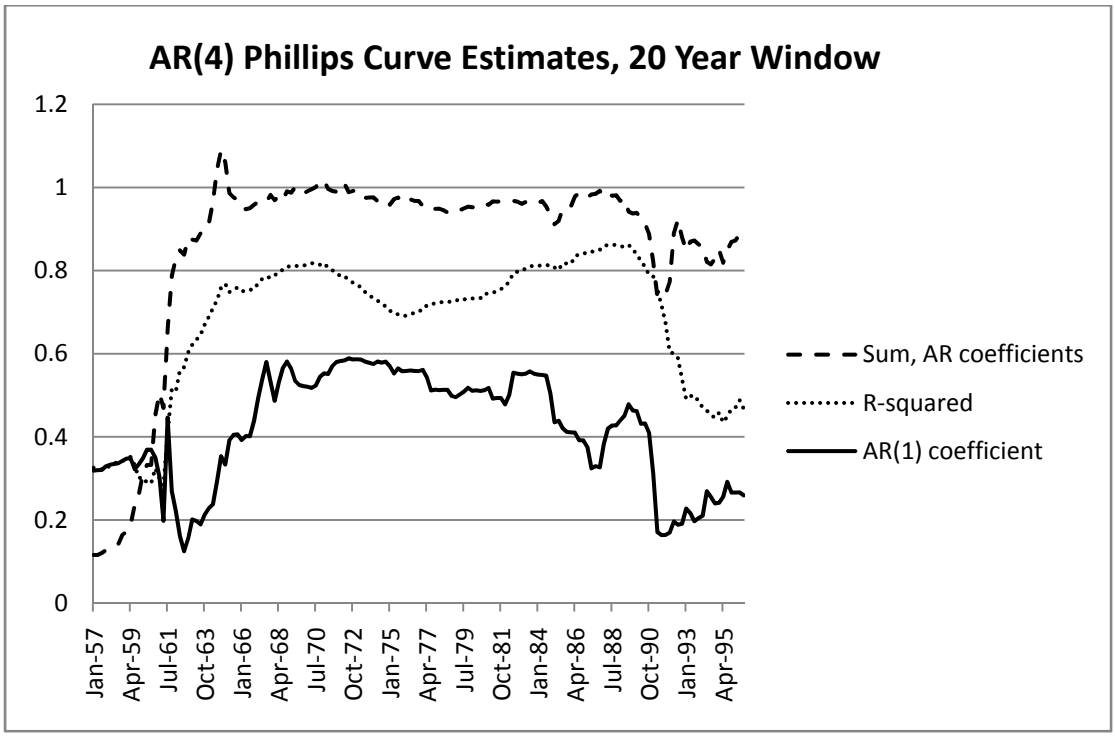

AR(4) Phillips Curve Estimates, 20 Year Window
1.2
1
0.8
0.6
0.4
0.2
0
Jan-57
Apr-59
Jul-61
Oct-63
Jan-66
Apr-68
Jul-70
Oct-72
Jan-75
Apr-77
Jul-79
Oct-81
Jan-84
Apr-86
Jul-88
Oct-90
Jan-93
Apr-95
Sum, AR coefficients
R-squared
AR(1) coefficient

Figure 3(a)

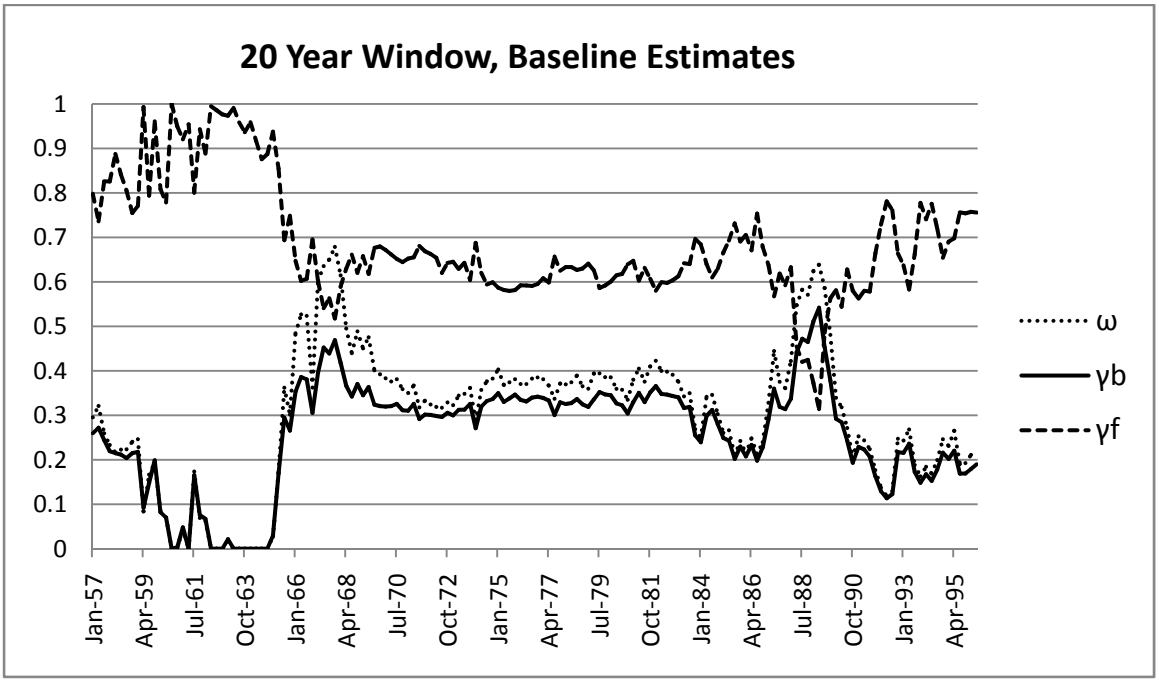

20 Year Window, Baseline Estimates
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Jan-57
Apr-59
Jul-61
Oct-63
Jan-66
Apr-68
Jul-70
Oct-72
Jan-75
Apr-77
Jul-79
Oct-81
Jan-84
Apr-86
Jul-88
Oct-90
Jan-93
Apr-95
ω
γb
γf

Figure 3(b)

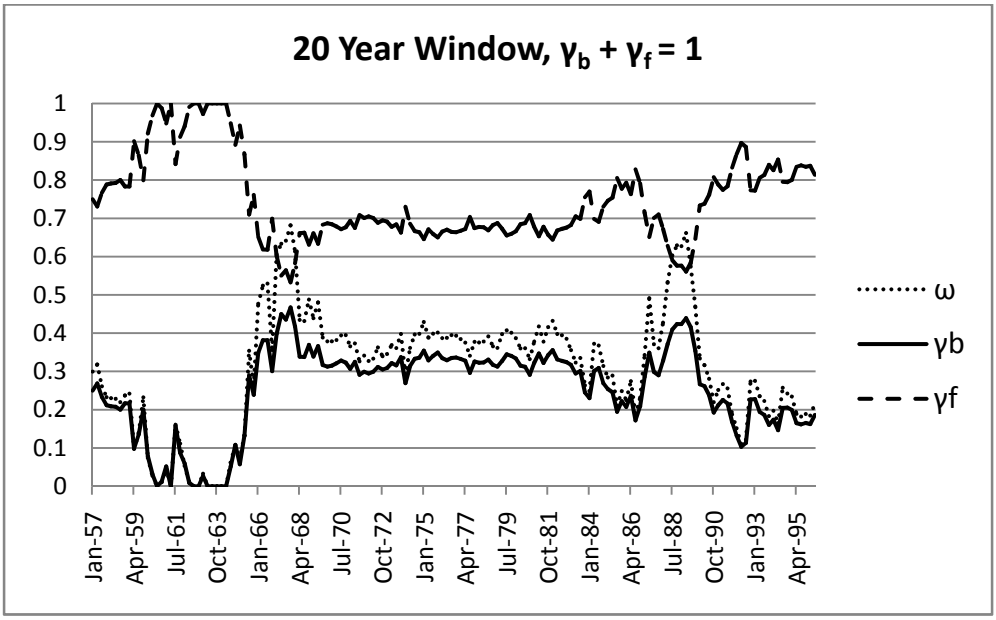

20 Year Window, $\gamma_b + \gamma_f = 1$
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Jan-57
Apr-59
Jul-61
Oct-63
Jan-66
Apr-68
Jul-70
Oct-72
Jan-75
Apr-77
Jul-79
Oct-81
Jan-84
Apr-86
Jul-88
Oct-90
Jan-93
Apr-95
ω
γb
γf

Figure 4(a)

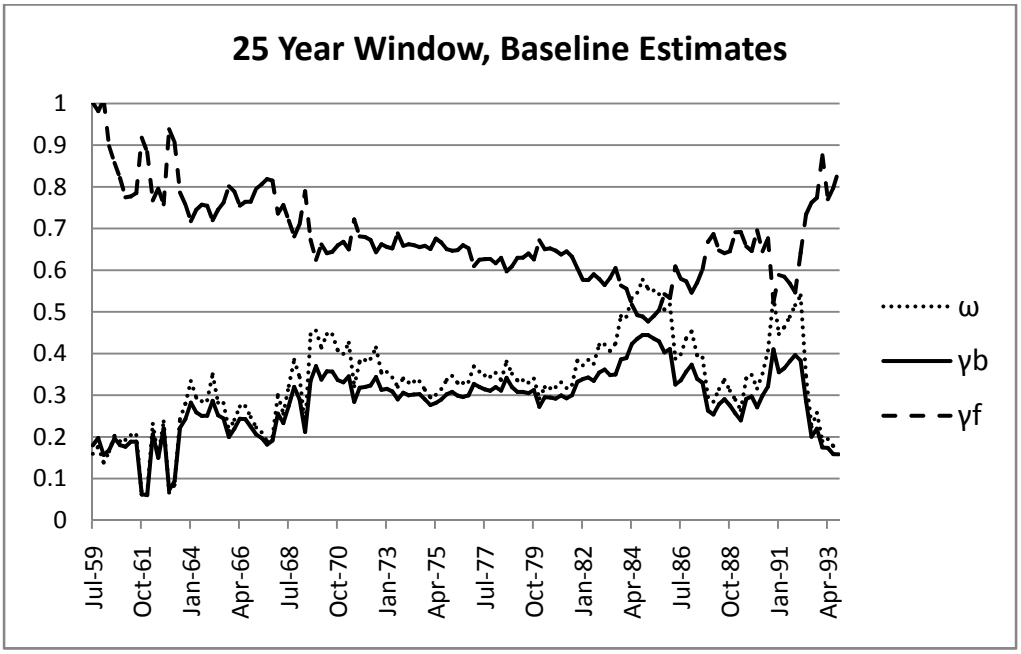

25 Year Window, Baseline Estimates
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Jul-59
Oct-61
Jan-64
Apr-66
Jul-68
Oct-70
Jan-73
Apr-75
Jul-77
Oct-79
Jan-82
Apr-84
Jul-86
Oct-88
Jan-91
Apr-93
ω
γb
γf

Figure 4(b)

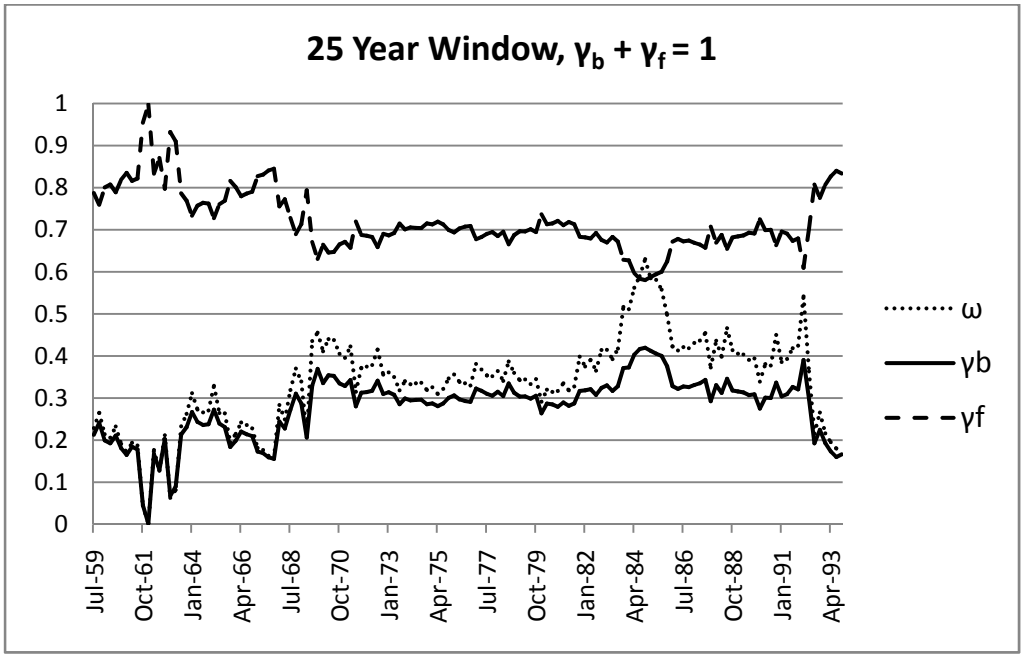

25 Year Window, $\gamma_b + \gamma_f = 1$
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Jul-59
Oct-61
Jan-64
Apr-66
Jul-68
Oct-70
Jan-73
Apr-75
Jul-77
Oct-79
Jan-82
Apr-84
Jul-86
Oct-88
Jan-91
Apr-93
ω
γb
γf

Figure 5(a)

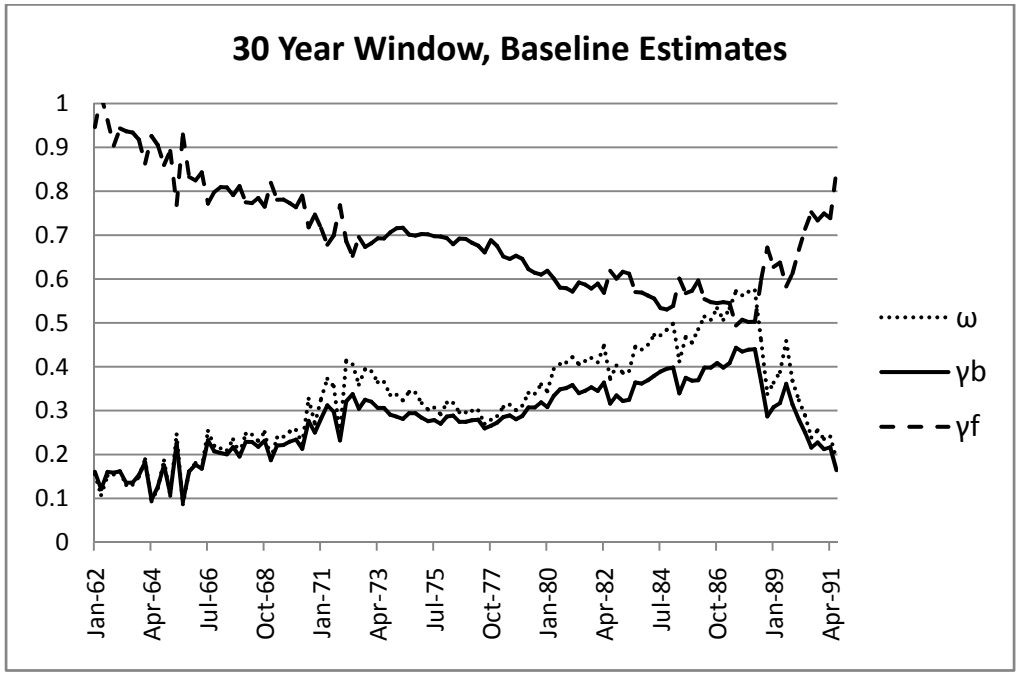

30 Year Window, Baseline Estimates
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Jan-62
Apr-64
Jul-66
Oct-68
Jan-71
Apr-73
Jul-75
Oct-77
Jan-80
Apr-82
Jul-84
Oct-86
Jan-89
Apr-91
ω
γb
γf

Figure 5(b)

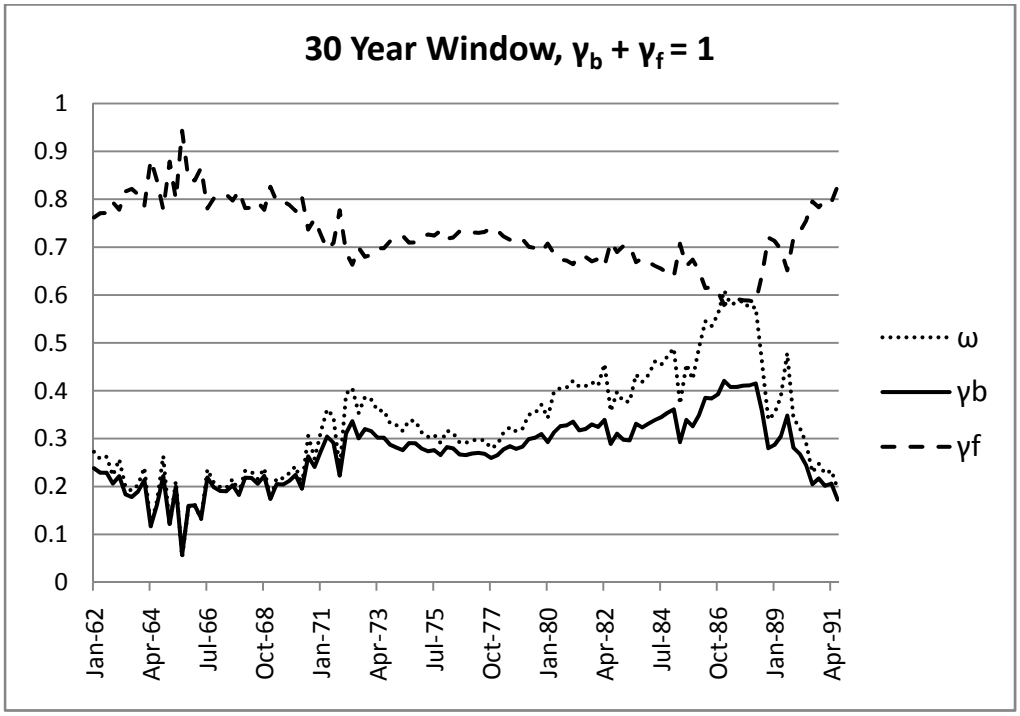

30 Year Window, $\gamma_b + \gamma_f = 1$
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Jan-62
Apr-64
Jul-66
Oct-68
Jan-71
Apr-73
Jul-75
Oct-77
Jan-80
Apr-82
Jul-84
Oct-86
Jan-89
Apr-91
ω
γb
γf

Figure 6

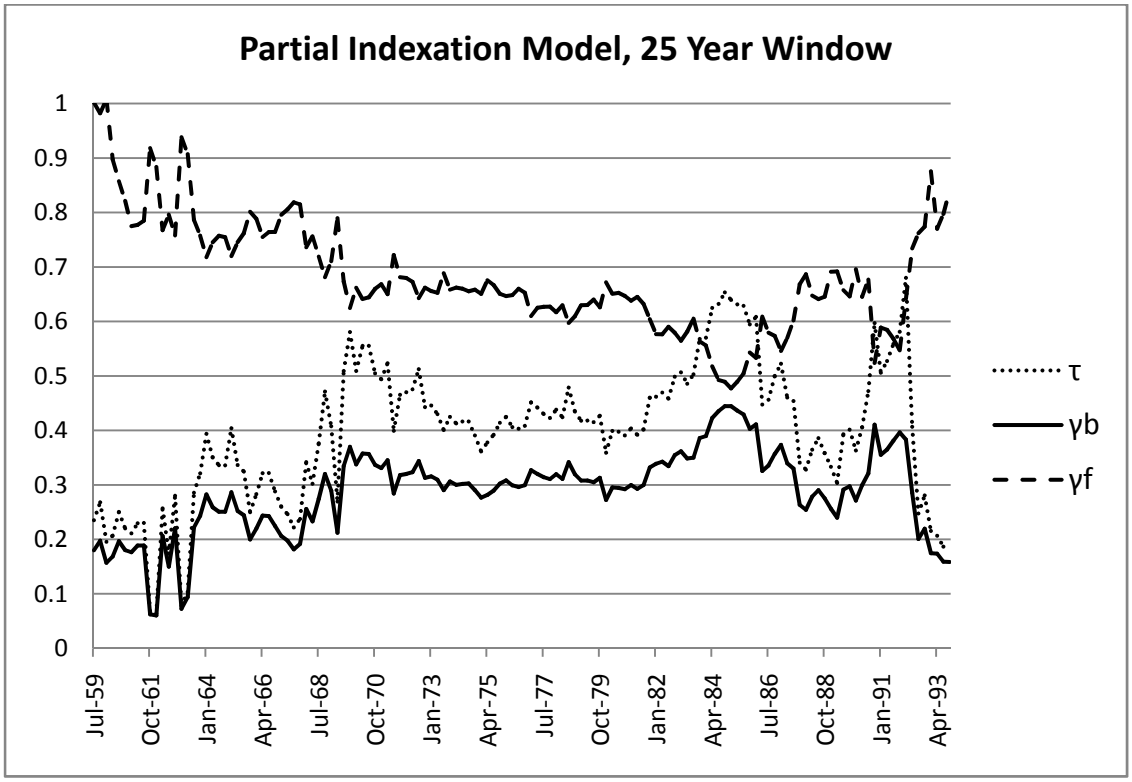
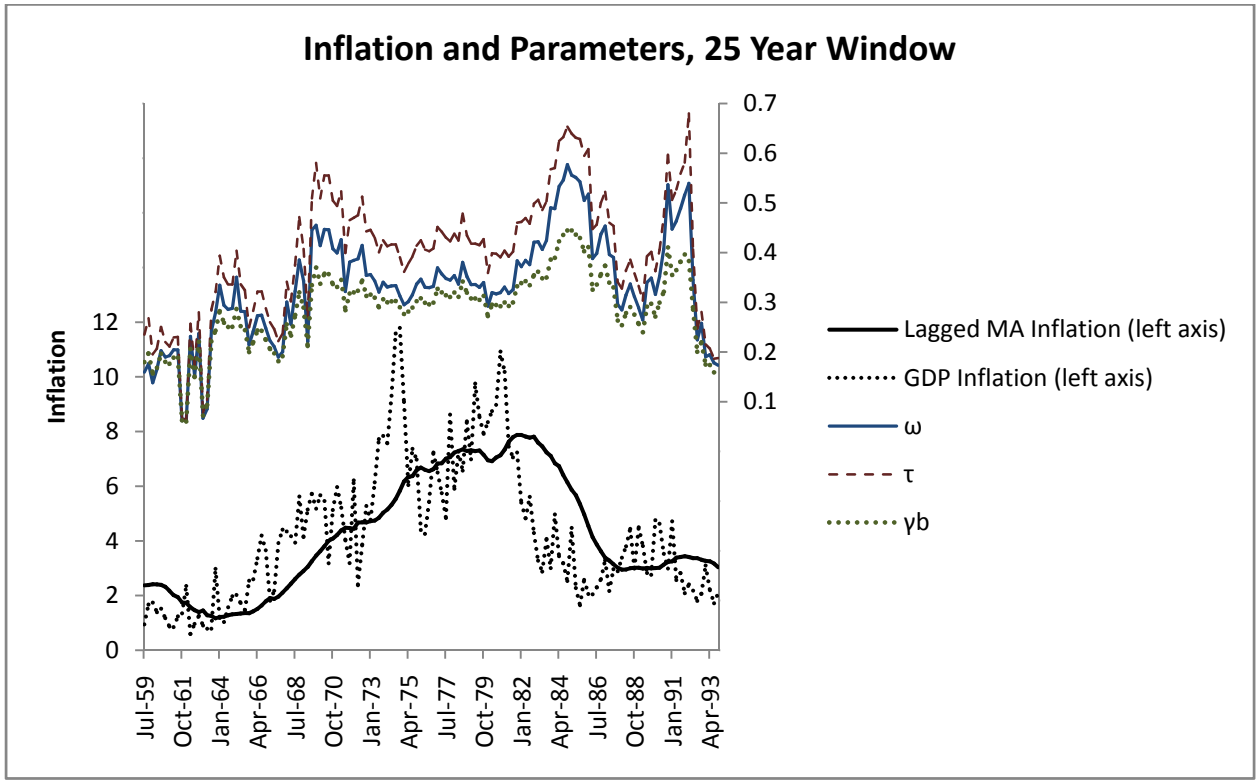

Partial Indexation Model, 25 Year Window
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Jul-59
Oct-61
Jan-64
Apr-66
Jul-68
Oct-70
Jan-73
Apr-75
Jul-77
Oct-79
Jan-82
Apr-84
Jul-86
Oct-88
Jan-91
Apr-93
τ
γb
γf

Figure 7


Inflation and Parameters, 25 Year Window
Inflation
0
2
4
6
8
10
12
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Jul-59
Oct-61
Jan-64
Apr-66
Jul-68
Oct-70
Jan-73
Apr-75
Jul-77
Oct-79
Jan-82
Apr-84
Jul-86
Oct-88
Jan-91
Apr-93
Lagged MA Inflation (left axis)
GDP Inflation (left axis)
ω
τ
γb