Implications of the permanent-transitory confusion for New-Keynesian modeling, inflation forecasts and the post-crisis era

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1 Introduction

During the end of the seventies through the first half of the eighties Brunner and Meltzer devoted a non-negligible part of their research energies to the implications of the permanent-transitory confusion (PTC) for monetary policy and economic behavior. The PTC is a short title for the fact that even when all current and past information about the economy is available there still is uncertainty about the extent to which current and past states will persist into the future. This led to a number of publications in part of which I participated as a coauthor.

The PTC constitutes an important limitation on the accurate forecasting of future economic variables even under rational expectations. Since current decisions are based on expectations about the future their importance for understanding economic behavior cannot be overemphasized. This fact has been recognized by modern central banks (CBs) as well as by the NK model in the particular area of inflationary expectations by acknowledging explicitly that a first order determinant of actual inflation are inflationary expectations. The PTC refers to situations in which a stochastic shock is composed of a nonstationary random walk and a transitory white noise process none of which are ever directly observed. However the public gradually learns about the evolution of the permanent-random walk component by using observations about the stochastic shock. A closely related confusion is the persistent-transitory confusion (PsTC) in which the random walk component is replaced by a stationary stochastic process.

During the early days of the rational expectations revolution substantial research energy was devoted to the implications of such expec-

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tations for the short and medium term effectiveness of monetary policy in a world characterized by long run nominal neutrality and flexible prices. One of the early difficulties with the strong version of rational expectations, according to which unexpected inflation may differ from its subsequent realization only by an uncorrelated forecast error, implied that the impact of monetary policy on the economy should be very short. This flew in the face of most empirical evidence which suggested that the impact of monetary policy is persistent and led to a search for conceptual mechanisms that would reconcile theory and evidence. Among the proposed mechanisms were adjustments costs of long term and short term investment such as inventories as well as the PTC and the PsTC.

About twenty years later the nascent New-Keynesian (NK) literature proposed to resolve this tension by injecting price stickiness due to costs of price adjustments into imperfectly competitive real business cycle models and by recognizing explicitly the impact of forward looking inflationary expectations on price setting firms. Two attractive features of early NK models were that they were fully microfounded and could be solved analytically. This was achieved at the price of assuming that endogenous variables were mainly or even purely forward looking creating a gap between theory and the bulk of empirical evidence which suggested that output and inflation are affected by both backward and forward looking factors.

Subsequent versions of the NK model attempted to resolve this tension by means of partial deviations (like backward looking price setters and general indexation of prices) from fully rational expectations. One contribution of this paper is to show that, in the presence of either the PsTC or the PTC, past information will affect all the endogenous variables of the system including monetary policy even in rational expectations purely forward looking models. Another contribution is to show empirically, using inflation forecasts from the US Survey of Professional Forecasters (SPF), that those expectations utilize information on past inflation to forecast the future and that the implied speed of learning is relatively low.

The paper is organized as follows: Section 2 contains a brief methodological history of the PTC and the PsTC and of their applications. Section 3 demonstrates that in the presence of the PsTC rational expectations imply that all endogenous variables depend on past realizations of relevant shocks even in purely forward looking models. Section 4 demonstrates empirically that a stochastic process that features the PsTC supports the view that SPF inflationary expectation rely on past inflation to forecast the future. Section 5 briefly discusses the relevance of the past in learning about the future following the structural and pol-

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icy changes induced by the global financial crisis. This is followed by concluding remarks.

2 A brief methodological history of the permanent-transitory confusion

The section briefly surveys past modeling and applications of the PTC and the PsTC in various areas of monetary and macroeconomics since the early sixties to the present. Friedman (1957) was perhaps the first to highlight the importance of the difference between permanent and transitory expected changes in income for consumption decisions and used adaptive expectations to model empirically expected permanent income.[1] Muth (JASA, 1960) provided a rational statistical foundation for adaptive expectations by showing that, when each shock is composed of a (permanent) random walk and a (transitory) white noise, optimal expectations are adaptive. Two important consequences of Muth's model are: 1. Current expectations about the future utilize all past observations about the variable that is being forecasted implying that permanent changes are detected only gradually, 2. The speed of learning about permanent changes is systematically related to the relative sizes of the variance of the first difference in the permanent component and the variance of the transitory component.

Brunner et. al. (1980) embed Muth's process into an extended IS-LM model to explain the stagflation of the seventies. Their model features the PTC about shocks to productivity, aggregate demand, the real wage and (permanent) income. As stressed by Lucas and Rapping (1969) the distinction between permanent and transitory changes in the real wage is important for employment decisions. If a worker believes his wage is temporarily low he might become voluntarily unemployed for a while in order to devote his time to other activities. But, if he believes the change is permanent, he is likely to continue working and the impact on unemployment will be lower. Due to slow learning under rationally adaptive expectations permanent changes in productivity, and therefore potential output and the permanent real wage, are recognized only slowly. Brunner et.al. use this feature of the Lucas-Rapping (1969) framework to highlight one reason for the persistence of unemployment during the great inflation of the seventies.

In their Nobel winning paper on time to build and aggregate fluctuations Kydland and Prescott (1982) introduce a PsTC by positing that the aggregate productivity shock is composed of a stationary first

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[1]In a classic study on seven hyperinflations during the first half of the twentieth century Cagan (1956) used the adaptive structure to model inflationary expectations.

order Markov process and a white noise term none of which are ever observed separately. Although the persistent component is stationary it is assumed to be close to non stationarity. They then apply the Kalman (1960) filter to model the firms' learning process about productivity.

Brunner et. al. (1983) propose two mechanisms to explain the persistence of the business cycle in a model with sluggish adjustments of inventories. The first is based on the Lucas-Rapping (1969) framework: Following the realization of an unexpectedly high demand shock in the presence of temporarily sticky prices and output, aggregate inventories are subsequently rebuilt in order to avoid stockouts. This temporarily raises employment and real wages. Since the increase in real wages is expected to be temporary firms spread this process over time in order to economize on labor costs. The second mechanism is due to the slow detection of permanent shifts in monetary policy and their impact on aggregate demand by economic agents: Due to this PTC firms underestimate the permanence of the increase in aggregate demand and rebuild inventories more slowly than in the absence of this confusion. As they subsequently realize that the increase in aggregate demand is more permanent than what they had thought initially, they compensate for this later. As a consequence the rebuilding of inventories is spread out over time.[2]

Once excessively high inflation has been allowed to develop slow recognition of serious efforts to stabilize it is a major impediment to the success of stabilization. The reason is that slow recognition of such efforts leads to recessions by inducing persistent periods of negative unexpected inflation. This is the (by now) well known credibility problem of monetary policy during stabilization episodes. Using an extension of Muth (1960) process Cukierman and Meltzer (1986a) develop a model of imperfect transparency and credibility on the part of the CB. They use it to explain why, prior to the introduction of CB independence (CBI) and inflation targeting (IT), CBs had an incentive to maintain some ambiguity about their policy preferences in spite of the fact that the long run Phillips curve is vertical.

Cukierman (1982) presents a theory of the relationship between aggregate and relative price variability based on the inability of people, even in a rational world, to identify permanent changes in relative demands (whether caused by real or by monetary variability) and relative productivities as soon as they occur. The theory implies that the variance of the rate of inflation and the variance of relative price change are

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[2]Note that this mechanism operates whenever firms detect the permanence of shifts in aggregate demand independently of whether this is due to monetary shocks or to other reasons.

positively related. Although expectations are rational and markets always clear, production decisions respond sluggishly to changes in relative prices and to temporary shocks to relative demands.

In the midst of the early rational expectations revolution Ben Friedman (1979) was one of the first to point out that, excluding some over-simplified cases like that of Sargent and Wallace (1975) in which all the parameters of the model are assumed to be known and the only uncertainty concerns future shocks, optimal expectations formation is normally characterized by slow learning. Friedman demonstrates this by applying least square learning to potentially changing parameters of a linear system with either a rolling window or gradual discounting of past observations. In both cases the resulting optimal predictor is characterized by slow learning injecting past observations into forecasts of the future thereby restoring the short run effectiveness of monetary policy in monetary models with long run classical properties.[3] Although the emerging optimal predictors are generally not quite adaptive they have a structure similar to that of the canonical Friedman-Muth-Cagan adaptive expectations in the sense that future forecasts are adjusted in line with past forecast errors.[4]

Evans and Honkapohja (2001) introduce a general approach to least square learning in a world with changing parameters and apply it to a variety of well known economic models. They consider two alternative assumptions about the past data utilized by economic agents. One is a fixed rolling window and the other is a constant gain. An intriguing question is the following: If the parameters of the system eventually stabilize under what conditions will those learning processes converge to a rational expectations equilibrium in which individuals know the true parameters? Using the concept of 'expectational stability' Evans and Honkapohja derive conditions under which the answer to this question is affirmative.

More recently Coibion and Gorodnichenko (2015) propose a new empirical test of the hypothesis that seeming departures from full information rational expectations are due to informational rigidities rather than to failure of the rational expectations concept. Using forecasts on a number of macro variables from the Survey of Professional Forecasters for the US and on other countries from the Consensus Economics

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[3]When there are substantial deviations between an estimated equation of an econometric model practitioners often apply constant adjustments. Note that this procedure is consistent with optimal least square learning about changes in the constant parameter of the linear system described in the text.

[4]Taylor (1975) shows that during the learning period following a change in the monetary policy rule the effectiveness of monetary policy is restored even in natural rate models.

dataset they find substantial support for the information rigidity hypothesis.[5] Two closely related versions of this hypothesis are nested under the same empirical test. One, is that individuals do not update their information sets continuously (Mankiw and Reis (2002) and Sims (2003)). In this version the speed of learning is directly related to the probability that an individuals will update their information sets. The other is that professional continuously monitor relevant macro variables but since they only receive noisy signals they can never fully observe the true state. Hence they form and update beliefs about the underlying fundamentals via a signal extraction problem as is the case with early modeling of the PTC and of the PsTC.[6]

3 The past is a guide for the future even in purely forward looking rational expectations models in the presence of the persistent-transitory confusion

Early New Keynesian (NK) models like that of Clarida, Gali and Gertler (1999, CGG in the sequel) were purely forward looking implying that inflation should not be persistent. However empirical studies of the Phillips curve reveal that the inflation process is persistent (Fuhrer and Moore (1995), Fuhrer (1997)). Roberts (2001) finds that the NK purely forward looking Phillips curve does not fit the US data well. In particular, this equation requires additional lags of inflation not implied by the model under rational expectations. Gali and Gertler (2000) and Steinsson (2003) propose hybrid modifications of the purely forward looking Phillips curve that is consistent with inflation persistence. In those specifications a certain fraction of backward looking producers are assumed to set their prices as a function of past inflation. This assumption implies that the inflationary expectations of the backward looking firms are not rational.

This section shows that, in the presence of the persistent-transitory confusion (PsTC) and under rational expectations, inflation the output gap, expected inflation and interest rate policy all depend on past observations of relevant shocks even in purely forward looking models. One implication of this result is that it is not necessary to introduce adhoc assumptions about the backward looking behavior of price setters in order to justify the empirical appearance of past variables in hybrid NK

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[5]Andrade and Le Bihan (2013) provide evidence for both sticky and noisy information in the European Survey of Professional forecasters.

[6]A recent theoretical application of this approach appears in Ma´ckowiak and Wiederholt (2009).

models. This is demonstrated within a modified compact form of CCG model for the case of optimal monetary policy under discretion in the absence of endogenous state variables.[7] The main novelty of this variant of the model is that it acknowledges explicitly the existence of a PsTC concerning a basic shock of the model. The structure of the modified model is given by

$$x_t = -\varphi\left[i_t - E_t\pi_{t+1}\right] + E_t x_{t+1}, \tag{1}$$

$$\pi_t = \lambda x_t + \beta E_t \pi_{t+1} + u_t, \tag{2}$$

$$u_t = p_t + \psi_t, \tag{3}$$

$$p_t = \rho p_{t-1} + v_t, \ \rho \le 1. \tag{4}$$

Equation (1) is the familiar NK dynamic IS relation. It states that the output gap, x_t, is a decreasing function of the real interest rate and an increasing function of next period's output gap. The real rate is given by the difference between the nominal policy rate, i_t, and the expected rate of inflation, $E_t\pi_{t+1}$. Equation (2) is the standard NK Phillips curve. It states that inflation depends positively on the output gap, on expected inflation, and on a markup or cost push shock, u_t. The shock is the sum of a persistent Markovian component, p_t, and a transitory white noise process, ψ_t, none of which are ever observed separately. v_t and ψ_t are serially uncorrelated mutually independent normal variates with zero means and respective variances σ_v^2 and σ_ψ^2. In the particular case in which σ_ψ^2 tends to zero the shock u_t reduces to the specification of the cost shock in CCG.[8] As in CCG the objective function of the monetary authority is to maximize

$$-\frac{1}{2}E_t\left\{\sum_{i=0}^{\infty}\beta^i\left[\alpha x_t^2 + \pi_t^2\right]\right\}. \tag{5}$$

where α is the weight on deviations of output from potential output relatively to the deviation of inflation from a zero inflation target and β is a discount factor. Since it cannot credibly affect beliefs under discretion the central bank (CB) takes private sector expectations as given in solving the maximization in equation (5). The outcome of this optimization is a discretionary policy rule. In parallel, conditional on this rule the private sector forms beliefs rationally. Because there are no endogenous

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[7]Although this is illustrated within the framework of CCG (1999) this result is substantially more general applying to any model in which at least some of the exogenous shocks are subject to either the PTC or the PsTC.

[8]The demand shock featured in CCG has been dropped for simplicity and focus. All the results of this section extend to the case in which such a (perfectly observed) shock is present since the policymaker always manages to fully neutralizes its impact.

state variables the first stage of the policy problem reduces to the following sequence of static optimization problems: Each period choose x_t and π_t to maximize

$$-\frac{1}{2}\left[\alpha x_t^2 + \pi_t^2\right] + F_t \tag{6}$$

subject to

$$\pi_t = \lambda x_t + f_t \tag{7}$$

where

$$F_t \equiv -\frac{1}{2}E_t\left\{\sum_{i=1}^{\infty}\beta^i\left[\alpha x_t^2 + \pi_t^2\right]\right\} \tag{8}$$

$$f_t \equiv \beta E_t \pi_{t+1} + u_t. \tag{9}$$

Since it cannot affect expectations under discretion the CB takes F_t and f_t as given. The solution to to the first stage optimization problem takes the familiar form

$$x_t = -\frac{\lambda}{\alpha}\pi_t. \tag{10}$$

In the background this condition implies that when a positive cost shock raises (lowers) inflation the CB raises (lowers) the interest rate. This results in a negative (positive) output gap which leads to a trade-off between the inflation and output objectives. How aggressively the CB should lean against inflation depends positively on the gain in reduced inflation per unit of output loss, λ, and inversely on the CB relative concern for deviations of output from potential.

To this point the model and its interim solution are identical to those in the basic NK model of CCG. But a full characterization of the solutions for actual and expected inflation, the output gap and the policy rate, i_t, in terms of the distribution of the shock, u_t, require the application of rational expectations to the formation of public expectations about the persistent component of the shock. In the presence of the PsTC the rational expectation of future values of u_t is no longer Markovian as in CCG. As shown in the following subsection it depends on the entire past history of the shock.

3.1 The optimal predictor of future values of u_t

Since the shock is a mixture of persistent and transitory components a first step in deriving rational expectations for future values of the shock is to obtain an optimal predictor of the current persistent value of the shock conditioned on the current information set $I_t \equiv \{u_t, u_{t-1}, u_{t-2}, ...\}$. This predictor is given by

$$E_t p_t \equiv E_t\left[p_t \mid I_t\right] = (\rho - \theta)\sum_{j=0}^{\infty}\theta^j u_{t-j} \tag{11}$$

where

$$\theta = \frac{1}{2}\left[\frac{1+r}{\rho} + \rho\right] - \sqrt{\frac{1}{4}\left(\frac{1+r}{\rho} + \rho\right)^2 - 1} \qquad (12)$$

$$r \equiv \frac{\sigma_v^2}{\sigma_\psi^2}. \qquad (13)$$

The stochastic structure in equations (3) and (4) is a particular case of equations (4), (5) and (8) in Cukierman and Meltzer (1986a, CM in the sequel) when the constant, A, is equal to zero and the optimal predictor is considered in isolation rather than within a Nash interaction between the public's expectations and the policy rule of the CB.[9] The optimal predictor in the general case is given by equations (10a) and (10b) in CM. The optimal predictor in equation (11) is obtained from equation (10a) in CM by noting that, when considered in isolation, the parameter B in that equation is equal to 1.[10]

The optimal predictor of the current persistent component in equation (11) is an essential input into the production of efficient predictions of future values of the shock. Since CCG, as well as much of the NK literature assume that the persistent components of the shocks are known in each period they do not need to utilize the past in order to forecast the future. But as implied by the optimal predictor in equation (11), in the presence of the PsTC, all the past becomes relevant for predicting future values of the shock. Before deriving the consequences of this fundamental difference for equilibrium values of endogenous variables it is instructive to note some characteristics of the optimal predictor.

Lagging equation (11) by one period

$$E_{t-1}p_{t-1} = (\rho - \theta)\sum_{j=0}^{\infty}\theta^j u_{t-1-j}. \qquad (14)$$

Using this expression in equation (11) yields

$$E_t p_t = (\rho - \theta)u_t + \theta E_{t-1}p_{t-1}. \qquad (15)$$

Rearranging

$$E_t p_t - E_{t-1}p_{t-1} = (1-\theta)\left[u_t - E_{t-1}p_{t-1}\right] - (1-\rho)u_t. \qquad (16)$$

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[9]CM show that $\rho - \theta$ is non-negative.

[10]Note that since the information set, I_t, includes the current value of the shock the distributed lag in (11) starts from the signal u_t rather than from u_{t-1} as is the case in CM. Note also that the symbol λ in CM has been replaced by θ since here the first symbol designates the impact of the output gap on inflation.

Equation (16) is a modified version of adaptive expectations. For the particular case $\rho = 1$ it reduces to

$$E_t p_t - E_{t-1} p_{t-1} = (1 - \theta) [u_t - E_{t-1} p_{t-1}] \tag{17}$$

which is the familiar Muth (1960) adaptive-rational expectations. In both the general and the particular case individuals adjust their forecast of the persistent (or permanent) component in period t in direct proportion to the difference between period's t signal and period's $t-1$ forecast. But in the stationary case $(\rho < 1)$ the adjustment is lower the lower is ρ since the lower is ρ, the smaller the likelihood that the forecast error is persistent. As persistence increases this moderating effect diminishes and vanishes eventually when the persistent component of u_t becomes non-stationary.

The coefficient $1 - \theta$ is a measure of the speed of learning and is higher the larger is the variability of the innovation to the persistent component relatively to that of the transitory white noise (the larger is $r \equiv \frac{\sigma_v^2}{\sigma_\psi^2}$).[11] I shall refer to it in the sequel as the learning parameter. The sum of lag coefficients in equation (11) is smaller than one and is increasing in the learning parameter and $\frac{\sigma_v^2}{\sigma_\psi^2}$. The intuition is that, as the signal to noise ratio increases, the past becomes more relevant for predicting the future and is therefore given more weight.

Equations (4) and (11) imply that the optimal forecasts of future values of the shock are given by

$$E_t u_{t+j} = \rho^j E_t p_t, \ j \geq 1. \tag{18}$$

3.2 Derivation of equilibrium values of endogenous variables

Substituting equation (10) into the NK Phillips curve in equation (2) and rearranging

$$\pi_t = \frac{\alpha}{\alpha + \lambda^2} [\beta E_t \pi_{t+1} + u_t] \tag{19}$$

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[11] This can be seen by noting that the sign of the partial derivative of θ with respect to r is the same as that of

$$1 - \frac{\frac{1+r}{\rho} + \rho}{2\sqrt{\frac{1}{4} \left(\frac{1+r}{\rho} + \rho \right)^2 - 1}}$$

which is negative, implying that the learning parameter is increasing in $\frac{\sigma_v^2}{\sigma_\psi^2}$.

Leading by one period and applying period's t conditional expected value operator to the resulting expression yields

$$E_t \pi_{t+1} = \frac{\alpha}{\alpha + \lambda^2} \left[\beta E_t \pi_{t+2} + E_t u_{t+1} \right] = \frac{\alpha}{\alpha + \lambda^2} \left[\beta E_t \pi_{t+2} + \rho E_t p_t \right]$$

where the second equality follows from equation (18). Leading this equation by one period, substituting the resulting expression back into it and repeating this procedure j times yields

$$E_t \pi_{t+1} = \delta \rho \left[1 + \delta \rho \beta + ... (\delta \rho \beta)^{j-1} \right] E_t p_t + (\delta \beta)^j E_t u_{t+j+1} \qquad (20)$$

where

$$\delta \equiv \frac{\alpha}{\alpha + \lambda^2} < 1$$

Since β is a discount factor the product $(\delta \beta)^j$ tends to zero as j goes to infinity implying that the expression in equation (20) reduces to an infinite converging geometric series. Hence this equation can be rewritten

$$E_t \pi_{t+1} = \frac{\alpha \rho}{\lambda^2 + \alpha(1 - \beta \rho)} E_t p_t \equiv \rho \alpha q E_t p_t. \qquad (21)$$

The main novel message of this expression along with the optimal predictor in equation (11) is that, although individuals are purely forward looking, their best predictor of next period's inflation relies on past observations of the shock, u_t. The equilibrium reduced form expression for π_t can be obtained now by substituting equation (21) into equation (19)

$$\pi_t = \frac{\alpha}{\alpha + \lambda^2} \left[\beta \rho \alpha q E_t p_t + u_t \right] = \alpha q E_t p_t + \frac{\alpha}{\alpha + \lambda^2} (u_t - E_t p_t) \qquad (22)$$

implying that actual inflation is also a distributed lag of past values of the shock, u_t.[12] The same remark applies to the output gap. This follows from the reduced form expression for x_t which is obtained by combining equations (10) and (22), and by rearranging

$$x_t = -\frac{\lambda}{\alpha + \lambda^2} \left[\beta \rho \alpha q E_t p_t + u_t \right] = -\lambda q E_t p_t - \frac{\lambda}{\alpha + \lambda^2} (u_t - E_t p_t). \qquad (23)$$

The reduced form expressions for inflation and the output gap differ from their counterparts in CCG by a term that depends on $u_t - E_t p_t$.

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[12]In the case in which the variablity of the transitory component is zero $E_t p_t = u_t$, the PsTC vanishes, and the expression for equilibrium inflation reduces to that in CCG;

$$\pi_t = \alpha q u_t$$

The reduced form expressions for inflation and the output gap are larger and smaller respectively than their CCG counterparts when $u_t - E_t p_t$ is positive. The converse holds when $u_t - E_t p_t$ is negative. It is shown in the first part of the appendix that the reduced form expression for the rate of interest chosen by the CB is

$$i_t = \left(1 + \frac{(1-\rho)\lambda}{\varphi\rho\alpha}\right) E_t\pi_{t+1} + \frac{\lambda}{\varphi(\alpha+\lambda^2)}(u_t - E_t p_t) \qquad (24)$$

where $E_t\pi_{t+1}$ is given by equation (21). As in CCG the response coefficient of the policy rate to expected inflation is larger than one in order to dampen the inflationary consequences of an increase in expectations. This raises the real rate and dampens inflation by reducing the output gap. The presence of the PsTC leads to the appearance of the additional term, $u_t - E_t p_t$,.[13] This term may add a further incentive to tighten or to ease monetary policy depending on whether $u_t - E_t p_t$ is positive or negative. In turn, $u_t - E_t p_t$ is positive or negative depending on whether the current realization of the shock is larger or smaller than its recent past realizations.

The general conclusion that emerges from this analysis is that in the presence of the PsTC all equilibrium values of endogenous variables including the policy decision are influenced by the past history of the shock, u_t. This occurs in spite of the fact that all individuals and the CB are assumed to be purely forward looking since, in the presence of either the PsTC or the PTC, rationality of expectations implies that the best guide for the future is the past. In CGG purely forward looking model policy mistakes are recognized expost only because predictions of future innovations to the persistent component of the shock are imperfect. In the more general case presented here policy mistakes are recognized expost as such **also** because the persistent or permanent component of the shock is mixed with a transitory component.

The additional term $u_t - E_t p_t$ that appears in the equilibrium expressions of all the endogenous variables becomes particularly important when a relatively large persistent or permanent shock occurs. In such a case the error in forecasting the persistent component may persist on one side of zero for some time leading to a string of forecast and policy errors that are biased in the same direction. This is more likely to occur when the speed of learning is low. Further details on this appear in section 4 of Cukierman, Lustenberger and Meltzer (2018). Evidence presented in the penultimate section of Cukierman (2010) suggests that during the great US inflation of the seventies policymakers at the Fed, as well as

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[13]For the particular case, handled by CGG, $E_t p_t = u_t$ and this term is zero.

professional forecasters, systematically underestimated inflation leading to overly expansionary monetary policy. In terms of the modified NK model presented in this section this supports the view that during that period the US economy was hit by cost shocks whose persistence was not fully appreciated for a substantial number of years.

4   An empirical application of the persistent- transitory confusion to professional forecasts of inflation

Previous sections imply that in stochastic processes that feature the PsTC or the PTC rational expectations are backward looking. This section utilizes data on professional inflation forecasts in order to examine whether those directly measured expectation rely on data from the past or not. The data comes from the US Survey of Professional Forecasters (SPF) that is collected and maintained by the Federal Reserve Bank of Philadelphia. It features both one and ten year ahead expected inflation. The data is based on a sample of professional forecasts collected over each quarter and then averaged over all the forecasts to produce a single representative figure for each quarter. This section utilizes quarterly data on one year ahead average forecasts between 1981 and 2017.

Figure 1 shows actual (in red) and expected (in blue) inflation as well as unexpected inflation (in black). The main regularity that emerges from the figure is that, more often than not, during periods of sufficiently sustained decreases in inflation unexpected inflation is negative and inflationary expectations follow a gradual descent suggesting that professional forecasters adapt their expectations in line with past movements of inflation. This is particularly striking during the last phases of Volcker's disinflation in the first part of the eighties. A weaker form of the same phenomenon appears between 1990 and 1997 during which there was a mild downward trend in inflation and actual inflation was lower than expected inflation. This occurs again toward the end of the sample mostly because inflation decreased for a while below the two percent target. During the entire sample period more than half of the time unexpected inflation is negative. Such periods are highlighted by means of red vertical and horizontal lines.[14]

FIGURE 1 HERE

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[14]Since the beginning of the twenty first century fluctuations in actual inflation are less persistent and, in parallel, inflationary expectations are less sensitive to inflationary developments.

Figure 1: Actual vs Expected Inflation and Unexpected Inflation
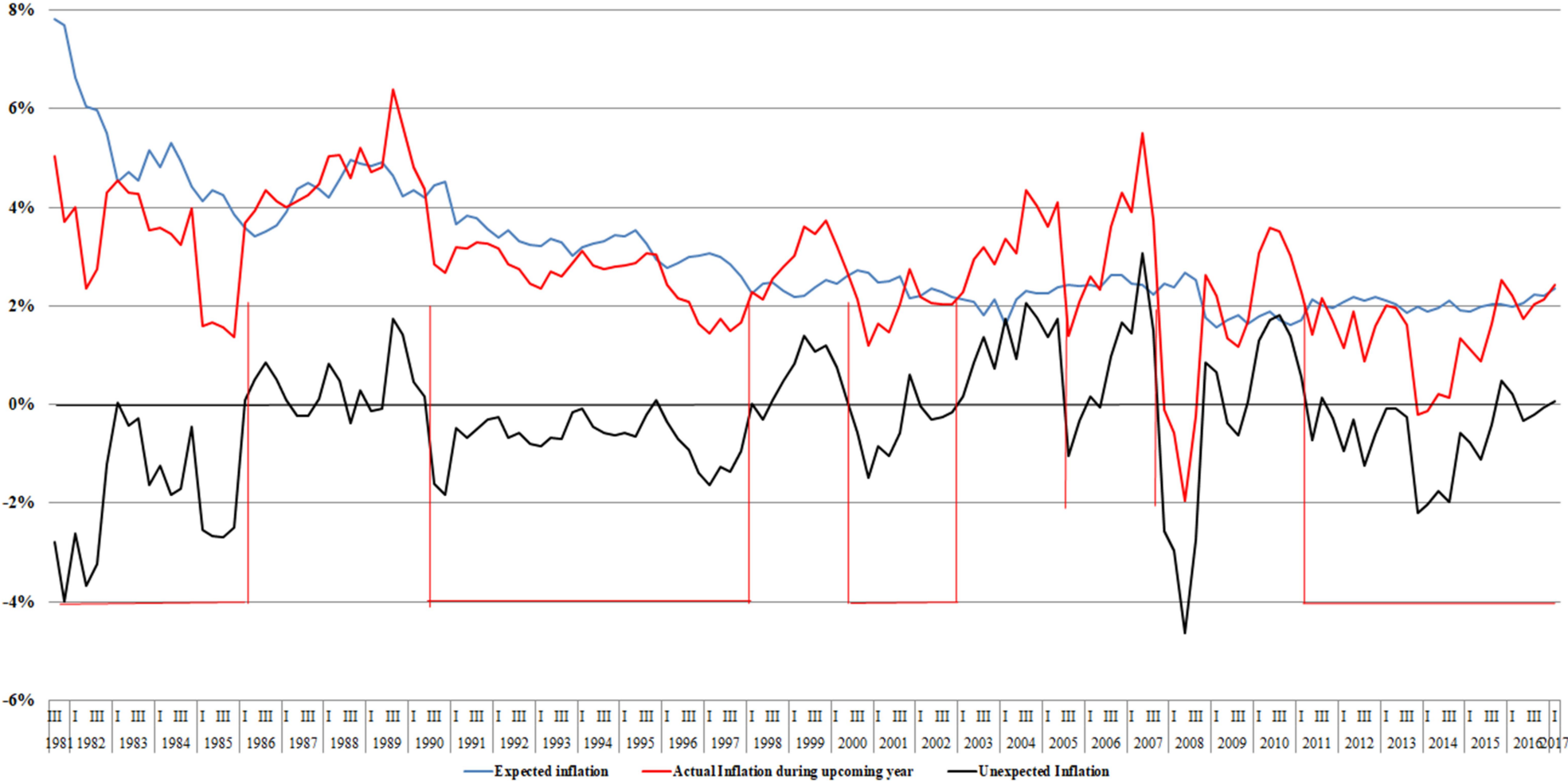
4.1 A test of the hypothesis that SPF expectations are backward looking within an illustrative PsTC framework

This subsection parametrizes SPF expectations within a PsTC framework, derives the implied optimal predictor and tests wether those expectations contain backward looking elements. To implement the test it is necessary to commit to some stochastic structure that features either the PsTC or the PTC, derive the corresponding optimal predictor and fit it to the directly measured SPF inflation expectations. In a broader self contained project experimentation with several alternative parametrizations of the stochastic structure would be desirable. But this is beyond the scope of this paper. Since the main objective of this section is to illustrate the methodology for testing whether directly measured expectations contain backward looking elements I focus on only one of many possible parametrizations. After some eyeballing of π_t in the data, as well as for analytical convenience, I decided to focus on the PsTC rather than the PTC.[15] In particular, the following parametrization of the inflationary process is used

$$\pi_t = A + p_t + \psi_t \tag{25}$$

$$p_t = \rho p_{t-1} + v_t, \ 0 < \rho < 1 \tag{26}$$

where A is a constant and ψ_t, v_t are respectively a white noise process and a random innovation. Equation (25) states that inflation is the the sum of a persistent Markovian component, p_t, and a transitory white noise process, ψ_t, none of which are ever observed separately. v_t and ψ_t are serially uncorrelated mutually independent normal variates with zero means and respective variances σ_v^2 and σ_ψ^2.

Given period's t information the optimal predictor of next period's inflation is

$$\pi_t^e \equiv E_t \pi_{t+1} = A + E_t p_t = A + (\rho - \theta)\pi_t + \theta E_{t-1} p_{t-1} \tag{27}$$

The second equality follows by noting that, since p_t has the same stochastic structure as in equation (4), its optimal predictor conditioned on period's t information is given by equation (15) with the signal u_t replaced by the signal π_t. Adding and substracting the term $\theta(A + \psi_{t-1})$ to the right hand side of equation (27) yields

$$\pi_t^e = (1 - \theta)A + (\rho - \theta)\pi_{t-4} + \theta \pi_{t-1}^e - \theta \psi_{t-1}. \tag{28}$$

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[15]It will be recalled that the difference between the two typesf confusions is that the first is stationary whereas the send is non-stationary.

where π^e and π are measured on a yearly basis although the time index t refers to quarters. $\pi_{t-1}^e \equiv E_{t-1}\pi_{t-1}$ and, due to a notation convention detailed in what follows, π_{t-4} is the last yearly inflation rate known in quarter t. In order to maintain comparability between realized and expected inflation over the same yearly forecast horizon the actual yearly inflation rate in quarter t (the quarter in which the forecast is formed) is defined as the yearly inflation in the upcoming year and denoted π_t. This notation implies that π_{t-4} is the last yearly inflation known in quarter t. Equation (28) can be estimated by regressing the SPF one year ahead inflation forecast, π_t^e, on the latest yearly inflation figure available (π_{t-4}) and the yearly inflation forecast produced in the previous quarter (π_{t-1}^e). $(1-\theta)A$ and $-\theta\psi_{t-1}$ are the regression constant and residual respectively.

With those adjustments the regression counterpart of equation (28) is

$$\pi_t^e = c_0 + c_1\pi_{t-4} + c_2\pi_{t-1}^e \tag{29}$$

where

$$c_0 \equiv (1-\theta)A = 0.177, \ c_1 \equiv (\rho - \theta) = 0.058, \ c_2 \equiv \theta = 0.876. \tag{30}$$

Given estimates of c_i, $i = 0, 1, 2$ estimates of ρ, θ and A can be obtained by using the relations in equation (30). The adjusted R-squared of the regression is 0.95 and all the c_i are positive and significant. Notably, c_2 is substantially higher and more significant than c_1 supporting the view that SPF forecasters rely on the past to predict the future. The fact that the coefficient $c_1 \equiv (\rho - \theta)$ that characterizes the speed of learning about persistent changes is relatively small implies that when a large persistent change in the inflationary process occurs forecasters internalize this relatively slowly. Given that actual and expected inflation are measured in percentages the estimated values of the structural paramaters are[16]

$$\widehat{\rho} = 0.93, \ \widehat{\theta} = 0.88, \ \widehat{A} = 1.43. \tag{31}$$

4.2 Evaluation of the optimal predictor in tracking the fluctuations in SPF expectations

One way to evaluate the fit of the optimal predictor in characterizing the behavior of SPF expectations is to calculate the goodness of fit between the original SPF data and its prediction by means of the estimated regression in equation (29). The 0.96 value for the adjusted R-squared suggest that the fit is quite good. This may be labelled as a one step ahead tracking method. Since one of the regressors in this equation

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[16]The units of expected and actual inflation only affect $\widehat{A}$.

is the lagged value of the original SPF expectation this is a relatively undemanding measure. Another, more demanding measure, can be obtained by replacing π_{t-1}^e in equation (29) with the integral form of π_{t-1}^e in order to generate fitted values. Since it utilizes the structural dependence of the optimal predictor along with the estimated coefficients on past inflations rather than the original expectation data the ability of the resulting fitted values to track the behavior of SPF expectations constitutes a stronger test of the optimal predictor fit. I shall refer to this method as a dynamic tracking method (DTM).

To generate the variable, $\widehat{\pi_{t-1}^e}$, that, given the structure of the optimal predictor and the estimates $\widehat{\rho}$ and $\widehat{\theta}$ from equation (31) replaces π_{t-1}^e in the DTM, lag equation (29) by one period to express the estimate of $\widehat{\pi_{t-1}^e}$ in terms of π_{t-5} and π_{t-2}^e then lag it again and substitute the resulting expression and substitute it into the first equation to express $\widehat{\pi_{t-1}^e}$ in terms of π_{t-5} and π_{t-2}^e. Proceeding like that T times yields the following expression for the dynamic estimate of π_{t-1}^e[17]

$$\widehat{\pi_{t-1}^e} = \sum_{j=0}^{T} \widehat{\theta}^j \pi_{t-5-j} + \widehat{\theta}^T \pi_{t-(T+1)}^e. \tag{32}$$

Given the magnitude of $\widehat{\theta}$ and since T was set to 19 the last term is of second order and can therefore be dropped. The dynamic predicted values of π_t are then obtained by replacing π_{t-1}^e in equation (29) by $\sum_{j=0}^{T} \widehat{\theta}^j \pi_{t-5-j}$.

The actual and dynamic predicted values of SPF expectations are shown in Figure 2. Eyeballing the two curves suggests that the fit of the DTM is reasonable. The standard deviation of the difference between the two curves over the entire sample is 0.72%. Between 1981 and 1990 the predicted values underestimate the SPF forecasts and are relatively large. Between 1990 and 1997 the fit is very tight. Since 1997 the fit is not as good but better than in the first subperiod and the predicted values overestimate the SPF forecasts. The behavior of deviations during the first and last subperiods may be due to changes in the speed of learning across subperiods or to the fact that during periods characterized by relatively persistent changes in the inflation process forecasters also utilize information not contained solely in observations on past inflation.

FIGURE 2 HERE.

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[17]The recursive substitutions add additional terms to the constant and the error terms. Although the addditional terms composing the constant change its interpretation they do not alter its estimation.

Figure 2: Actual and DTM Predicted values of SPF Expectations

Expected inflation   Predicted expected inflation
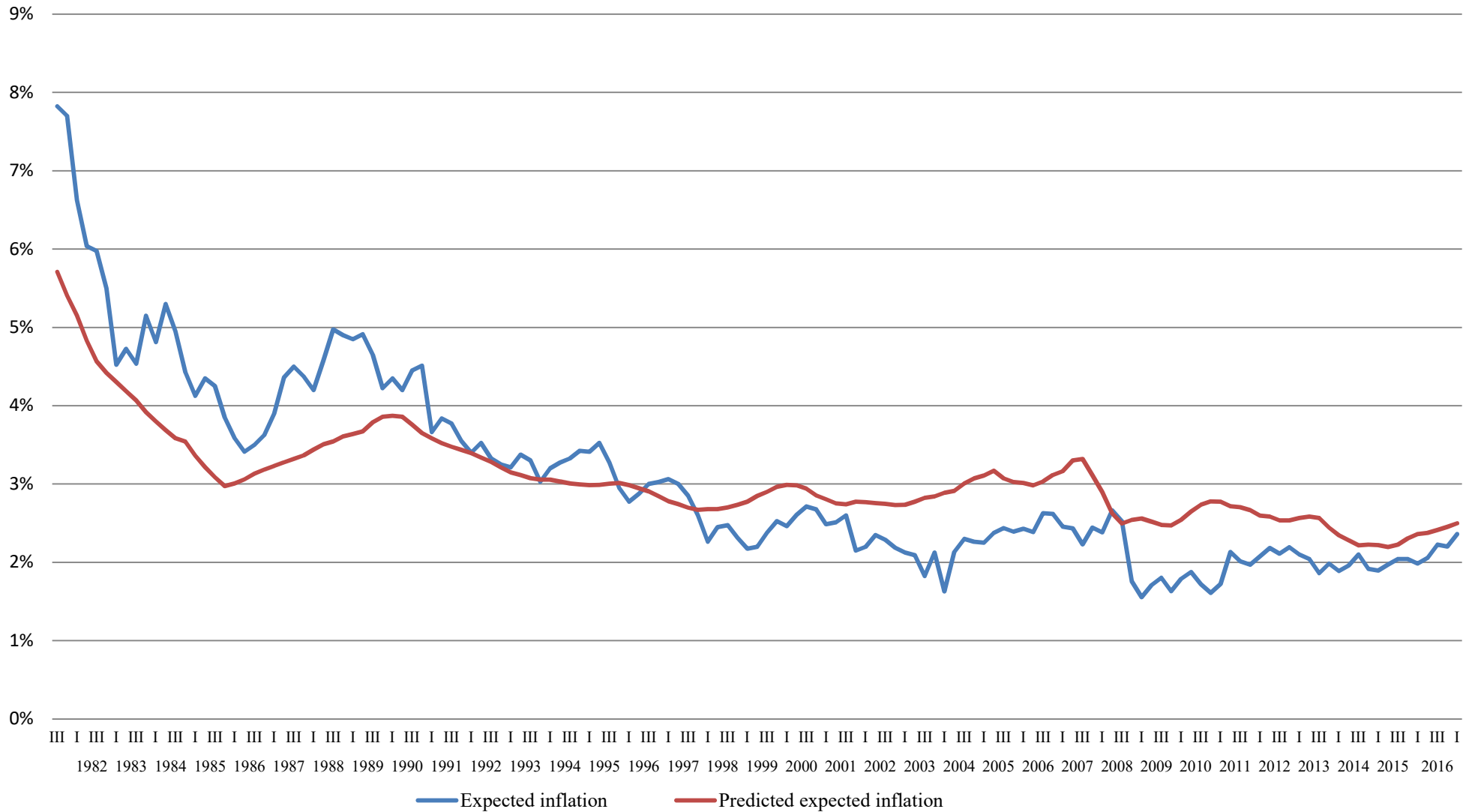
4.3 Illustration of the speed of learning implied by the stochastic process fitted to characterize SPF inflationary expectations

The fitted stochastic process in equation (29) has two components; one that does not vary with time while the other adapts in line with changes in actual and expected inflation in the previous period. The first part is represented by the constant c_0 in equation (29) and the part that adapts over time by the remaining terms in that equation. Since the constant term acts as a drag on the speed of learning it cannot be characterized only by a geometric distributed lag as would be the case in a Muth (1960) purely adaptive expectations process. To obtain a complete characterization of the estimated speed of learning for the SPF expectations I perform the following experiment. First, I find the inflationary steady state (ISS) path of the estimated process. The ISS is defined as a path along which actual and expected inflation are equal to the same constant inflation, π_{ss}. Formally, π_{ss} is obtained by plugging the condition

$$\pi_t^e = \pi_{t-4} = \pi_{t-1}^e = \pi_{ss} \text{ for all } t$$

into equation (29) and by solving for π_{ss}. Given the estimated parameters in equation (30)

$$\pi_{ss} = 2.68.$$

Second, I use the estimated parameters to find the value of the fixed rate of inflation, $\pi(\pi^e = 2)$, that would permanently maintain those expectations at the widely accepted two percent target. This can be readily calculated by solving $\pi(\pi^e = 2)$ from the following specialization of equation (29).

$$2 = \pi_t^e = c_0 + c_1 \pi(\pi^e = 2) + 2c_2 \text{ for all } t.$$

This yields

$$\pi(\pi^e = 2) = 1.21.$$

Figure 3 shows expected inflation as a function of time (measured in quarters). To characterize the speed of learning consider the following experiment: Suppose that the inflationary process is initially (period 0) along the 2.68 ISS path up to and including period 3. From period 4 and on actual inflation jumps down to $\pi(\pi^e = 2) = 1.21$ and remains there forever. Obviously, from that period and on, expectations will gradually decrease eventually converging to the two percent target. The dynamic path showing the gradual adjustment of expectations can be obtained by repeatedly applying equations (29) and (30) and is shown by the red line.

Figure 3: Speed of learning implied by the estimated stochastic process used to characterize SPF inflationary expectations
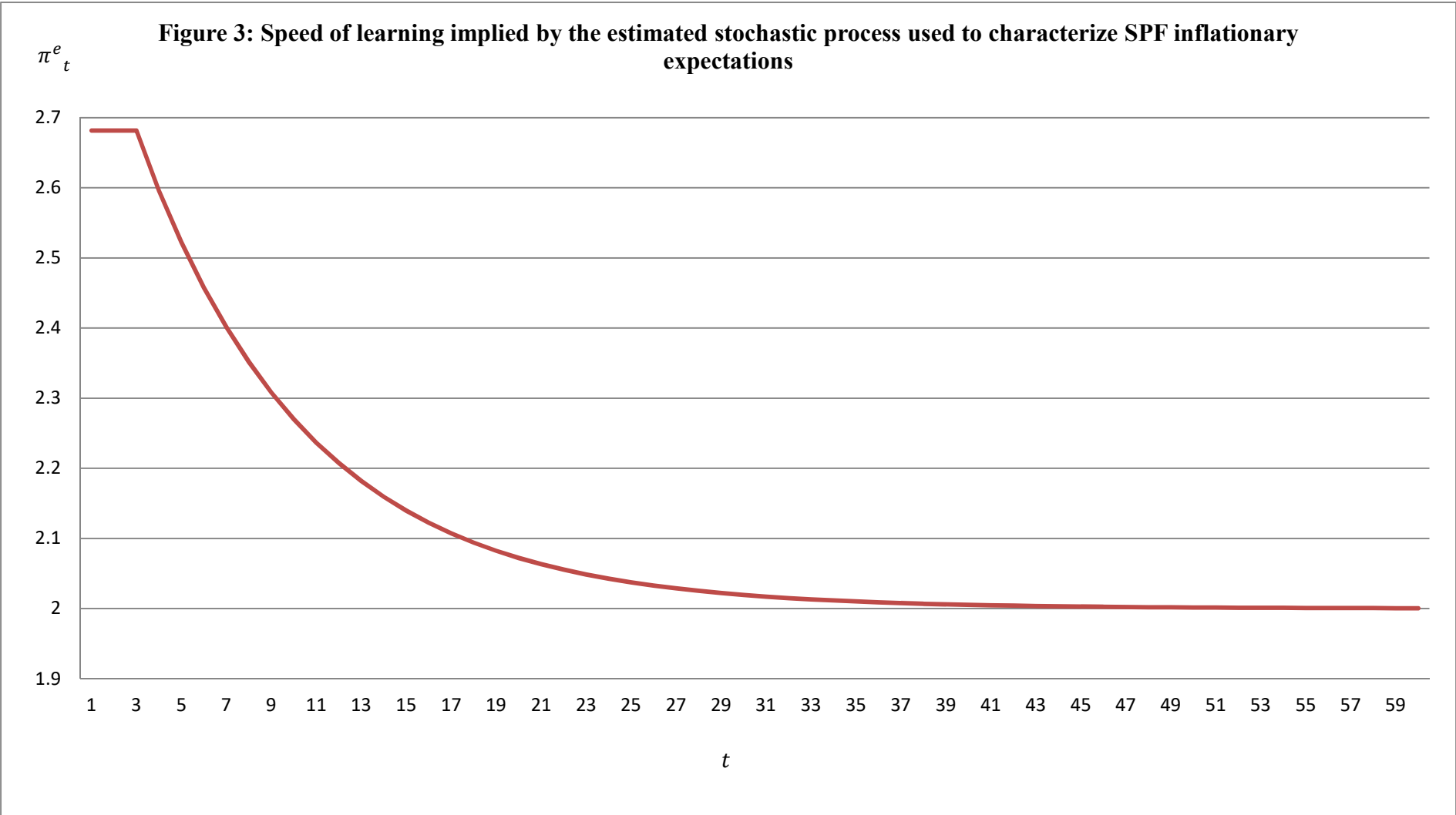
FIGURE 3 HERE

Not surprisingly the Figure confirms that the estimated process implies a rather slow speed of learning; It takes about ten quarters for expectations to travel half way between the ISS and the two percent target and about twenty quarters to complete 90% of the adjustment. The first four years at the beginning of the sample during which unexpected inflation is consistently negative (1981-1985 in Figure 1) are roughly consistent with this finding. Since this subperiod corresponds to the latter part of Volcker's gradual disinflation it supports the view that even when a determined effort to stabilize a gradual inflation is made it takes several years for inflationary expectations to fully internalize that this is the case.[18] Obviously this conclusion is not universal and should be qualified in the presence of effective forward guidance. This issue is discussed in the next section.

5 Brief reflections on the permanence of economic and policy changes in the aftermath of the global financial crisis

The global financial crisis (GFC) led to various changes in the structure of the economy as well as to innovations in monetary policy instruments and regulatory institutions. There was a flattening of the Phillips curve and short term interest rates that were reduced dramatically at the outset of the crisis are still much below their long run customary values. The crisis reinforced a long run downward trend in long term riskless rates.[19] [20]

Although it recovered from its depressed levels during the several years after Lehman's collapse net new credit formation is still lower than prior to the crisis.[21] The zero lower bound (ZLB) became a frequent effective constraint on monetary policy.[22] New monetary instruments such as quantitative easing (QE) and forward guidance (FG) are now used routinely to supplement interest rate policy. Capital requirements have been tightened and the regulatory authority of central banks have been expanded, particularly so, in the area of macroprudential supervision and regulation.

A central question lurking behind those changes concerns the extent

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[18]This contrasts with stabilizations of rapid inflation during which the speed of learning is substantially higher. One example is the Israeli 1985 stabilization in which expectations fully adjusted within six months (Cukierman (1988), Table 2.3).

[19]Bean et. al. (2015)

[20]Figure 5 in Cukierman (2016) documents this fact.

[21]Cukierman (2016), Figure 4.

[22]Laubach and Williams (2015).

to which they are likely to persist into the future. Generally, the answer to this broad question depends on more information than the particular features of the relevant stochastic processes discussed in the previous sections. For example regulatory and other financial market reforms that have been enshrined in legal institutions such as the Dodd-Frank act in the US and the banking union in the Eurozone are very likely to be correctly judged as persistent. The dramatic disappearance of net new issues of subprime mortgage backed securities is likely to be rather persistent. On the other hand persistence of the ZLB constraint and QE is less clear cut. Judging matters like the persistence of a flat Phillips curve and low rates most likely requires combining legal, instutional and political information with information about past values of relevant stochastic shocks.

During the last decade FG has been used with some success in both the US and the Eurozone. By partially affecting longer term expectations, the statement made by the Fed in December 2012 that the policy rate will not be raised as long as unemployment is above 6.5% and inflation less than 1.5% above the two percent target contributed to the reduction of long term rates and economic stimulation. Similarly, at the peak of the Eurozone (EZ) sovereign debt crisis Draghi's 2012 dramatic "whatever it takes" statement helped in restoring some confidence in the viability of the EZ.

However, it is important to stress that, if those statements had not been accompanied by further sizable expansions in monetary policy their impact would have swiftly faded away. FG also led to public misinterpretations as illustrated by the US 2013 taper tantrum that led to a premature increase in longer term rates. In spite of its somewhat mixed record forward guidance has been adopted by many other central banks and is likely to maintain it position as a permanent addition to the monetary policy toolbox.

The impact of FG on expectations formation can be incorporated into the stochastic frameworks of the previous sections by treating advance announcements of future monetary policy actions as noisy indicators of the actual policies to be implemented in the future. This modification of the stochastic information structure leads to optimal predictors that use both actual and past realization of the relevant variable as well as past and current realizations of FG announcements. Both past and current policy announcements appear in the optimal predictor because the announcements are noisy. The relative weights given to past information the realization of a predicted variable versus past announcements about its future behavior is determined by the relative magnitudes of the noises in those two signals.

The upshot is that, in the presence of FG optimal predictors are are still based on available current and past information. But the information set is augmented with current and past predictions on the relevant variables. Further detail appears in Cukierman and Meltzer (1986b). One explanation for the relative insensitivity of SPF expectations to actual inflationary developments during the latter part of the sample shown in Figure 1 is the gradually increasing use of FG along with the existence of a fixed two percent inflation target.[23]

6 Concluding remarks

An obvious universal truth is that, without any knowledge of the past, predictions of the future are just wild guesses. Although past and current information contain useful information for predicting the future this information is imperfect for two reasons. First, totally unforecastable events will no doubt realize in the future. Second, the information contained in past and current observations about the future persistent states of those observations is noisy. The contribution of economic and statistical models to forecasting is therefore naturally limited to making predictions that focus on identifying the parts of current and past information that are likely to persist into the future.

There are two complementary methods to do that. One is to identify the extent to which the behavior of a forecasted variable is enshrined in long term institutions. The more rigidly tied is the behavior of the variable to stable legal or informal institutions, the more likely its current value will persist into the future. The other, more statistically oriented approach, is to formulate economic variables as stochastic processes that are composed of both persistent (or permanent) components and of transitory shocks none of which is ever observed separately. Although somewhat narrower than the first this method has the virtue that predictions of the future can be reduced to the solution of signal extraction problems. An early example of this approach is Muth (1960) statistical foundation for rational-adaptive expectations that has been used by Friedman (1957) to model individuals' perceptions of permanent income. Kalman (1960) has shown that, in general, the solution to Gaussian signal extraction problems is equal to the expected value conditional on all available past and current information, I_t, and that it is a linear function of I_t.

This paper argues that, by abstracting from the learning process of individuals purely forward looking models miss an important element of reality and utilizes directly measured inflationary expectations from

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[23]Since it is preannounced an inflation target is a form of FG.

the US Survey of Professional Forecaster (SPF) to demonstrate that those expectations are backward looking and characterize their behavior in terms of past inflation. It also briefly surveys applications of signal extraction problems to economics since the sixties.

A problem encountered by early purely forward looking New-Keynesian models was that, when estimated, the fit of such models improved considerably when backward, as well as forward looking variables were used. Some of the New-Keynesian literature attempted to close the resulting gap between theory and evidence by postulating that price setters are (non-rational) backward looking (Gali and Gertler (2000), Steinsson (2003)). Using the well known CGG (1999) framework along with a cost shock that is subject to the PsTC the paper shows that, as a theoretical matter, such a single modification injects backward looking elements into the behavior of the economy as well as into that of policymakers even under fully rational expectations.

Fitting the optimal predictor of an inflationary process composed of a first order Markov process augmented by a constant and a white noise to SPF inflationary expectations since the early eighties till 2017 reveals that those expectations are backward looking and are characterized by a relatively low speed of learning. The global financial crisis led to changes in the structure of the economy as well as to the emergence of unconventional policy instruments. Most of those changes persist to this day raising important questions about the extent to which structural changes, such as low inflation and interest rates, and flatter Phillips curves are likely to persist into the future. In addition policymakers are still learning about the effectiveness of of new monetary policy instruments. Those learning processes call for the application of gradual learning methods about changing parameters of the type developed and applied by Evans and Honkapohja (2001). This process is ongoing within economic research institutions, such as central banks and is likely to go on as more post crisis observations accumulate.

Slow recognition of a large permanent drop in the productive capacity of the economy leads to underestimation of the output gap and to excessively loose monetary policy. Using Muth (1960) rationally adaptive expectations to model the PTC within an extended IS-LM framework Brunner et.al. (1980) explain the stagflation of the seventies under Fed chair Burns as a consequence of the implied gradual learning. Using real time data Orphanides (2001) and Orphanides and Williams (2005) provide empirical support for this view. Brunner et. al. (2003) appeal to the PTC along with a Lucas-Rapping mechanism to motivate slow rebuilding of inventories.[24]

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[24]Cukierman, Lustenberger and Meltzer (2018) explore the implications of the PTC

The methods used to model rational expectations when the past is an important input into prediction of the future have been around for quite a while and have been used extensively. In spite of this, the fact that they inject the past even into purely forward looking frameworks is occasionally forgotten leading to the use of various adhoc shortcuts to close frequent gaps between theory and evidence.

In summary, by analyzing the impact of the PsTC in a purely forward looking model, fitting it to SPF inflation forecasts in the US and surveying some previous applications, my hope is to convey the more general message that optimal gradual learning is the rule rather than the exception.

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