Notes on Limited-Information Tests of the New Keynesian Phillips Curve

Sophocles Mavroeidis
University of Oxford

Mikkel Plagborg-Møller*
Harvard University

James H. Stock
Harvard University

March 2, 2013

DISCLAIMER:

These notes were written over a period of several months and do not necessarily reflect the authors' current reading of the literature. The notes are only meant as rough summaries and can't substitute for actually reading the papers. We would be very happy to correct any errors and misinterpretations as well as entirely removing references to papers.

Abstract

This note reviews developments in the literature on limited-information empirical tests of the New Keynesian Phillips Curve since the seminal contribution of Galí and Gertler (1999, *JME*). Particular focus is placed on the role of forward-looking expectations in inflation dynamics as well as on the econometric issues connected with identifying said role. As the title indicates, full information (which we take to mean DSGE) estimation is not considered. The papers have been split into different categories, although there are of course substantial overlaps. At the end of each section we give short summaries of a number of additional references. A more concise version of our literature review is presented in Mavroeidis et al. (2013).

*Corresponding author: plagborg@fas.harvard.edu

Contents

1 Literature surveys

1.1 Gordon (2011, *Economica*): "The History of the Phillips Curve: Consensus and Bifurcation"

Presents a fairly detailed 20-page history of Phillips curve research. Gordon distinguishes between three schools of thought: The classic interpretation based on Phillips (1958), which was supplanted by a "left fork" and a "right fork" following the work of Friedman, Phelps and Lucas in the late 1960s and early 1970s. The "left fork" is the triangle model of Gordon and its variants, while the "right fork" is the NKPC. Gordon comes down heavily in favor of the triangle model for describing U.S. inflation, while the NKPC is deemed to have important insights for episodes of sudden jumps in expectations in other countries.

1.2 Henry and Pagan (2004, *OBES*): "The Econometrics of the New Keynesian Policy Model: Introduction"

This is the editors' introduction to a special supplement to the *Oxford Bulletin of Economics and Statistics* on econometric issues relating to the NKPC. The article provides a concise and easy-to-follow introduction to the NKPC in the context of the canonical three-equation NK model. Weak identification is discussed in some detail, as is the question of system versus single-equation estimation. The editors call for further research on identification robust testing of the NKPC.

1.3 Nason and Smith (2008*b*, *FRBR EQ*): "The New Keynesian Phillips Curve: Lessons From Single-Equation Econometric Estimation"

Nason and Smith provide an easy-to-read summary and illustration of recent research on the NKPC. They discuss the motivation behind the NKPC, instrument selection, estimation methods, weak identification and recent theoretical extensions to the framework (see their Table 5). Their empirical work corroborate the results of Galí and Gertler (1999) when the labor share is used, and they don't find evidence of parameter instability or sensitivity to the inflation measure. When SPF forecasts are used instead of next-period inflation, the results deteriorate. They run GMM estimation on nine different gap measures—two ULC and seven output gap—and find that the labor share measures give reasonable results, while none of the output gap measures are significant. At the end, international evidence on the NKPC is summarized.

1.4 Ólafsson (2006, *working paper*): "The New Keynesian Phillips Curve: In Search of Improvements and Adaptation to the Open Economy"

This central bank working paper is an obscure[1] but well-written, comprehensive (230 references!) and relatively non-technical survey of theoretical and empirical contributions to the New Keynesian aggregate supply relation. Ólafsson starts out with a brief historical account of the origin of the Phillips curve and proceeds to outline the development of the NKPC as well as how the literature has judged its ability to fit stylized facts about inflation dynamics. The survey focuses on the many, mostly theoretical, attempts to improve the baseline NKPC by adding, e.g., backward-looking behavior, labor market imperfections, other real rigidities, endogenous capital formation,

[1] It only has three published English-language cites on Google Scholar as of January 2012.

sticky information and learning. The main econometric approaches are summarized, albeit briefly, as is the most recent (as of 2006) empirical findings—econometric, survey-based and qualitative—on the closed-economy NKPC. The last part of the paper details the fledgling search for a serviceable open-economy NKPC.

1.5 Rudd and Whelan (2007, *JMCB*): "Modeling Inflation Dynamics: A Critical Review of Recent Research"

This paper summarizes most of the arguments against the (pure or hybrid) NKPC, particularly those raised by Rudd and Whelan (2005*b*, 2006). The authors begin by concisely reviewing the history of competing Phillips curve specifications. They then document the well-known empirical failure of the NKPC with the output gap (wrong sign on the gap) and explain it using the closed-form solution for inflation as a sum of future expected gaps. Citing the recent move to marginal cost measures instead of the output gap, the authors criticize the choice of the labor share as proxy: While intuition would suggest that marginal cost should be procyclical, the U.S. labor share has in fact been mostly countercyclical. Furthermore, the labor share version of the NKPC fails to generate a significant coefficient on the gap, as data revisions since 1999 have diluted Galí and Gertler's results. Finally, Rudd and Whelan investigate the hybrid NKPC. By solving for the closed-form solution for inflation, they demonstrate that almost no additional explanatory power can be ascribed to the labor share. From a theoretical perspective, they show that estimates of γ in the model

$$\pi_t = \gamma E_t \pi_{t+1} + (1-\gamma)\pi_{t-1} + \mu s_t + \varepsilon_t$$

may exceed 1/2 even if inflation is an AR process.

1.6 Other literature

Bernanke (2007, *NBER speech*): "Inflation Expectations and Inflation Forecasting." Summarizes recent literature on expectations anchoring and learning. Describes the Fed's implementations of the NKPC, including their use of survey inflation forecasts and expert judgement.

Bernanke (2008, *FRBB speech*): "Outstanding Issues in the Analysis of Inflation." Calls for further research on (1) the relationship between commodity prices and total inflation, (2) the measurement of marginal cost, (3) the real-time decision problem of policymakers and (4) the nature and effects of inflation expectations, specifically mentioning learning as a promising way forward for macro modeling.

Dennis (2007, *FRBSF EL*): "Fixing the New Keynesian Phillips Curve." Briefly summarizes the critique of and suggested extensions to the NKPC in the first part of the 2000s, focusing specifically on indexation and information stickiness.

Mankiw (2001, *EJ*): "The Inexorable and Mysterious Tradeoff between Inflation and Unemployment." Short presentation of the history of monetary nonneutrality (going back to Hume). Gives a brief theoretical motivation for the NKPC and then rejects it as it has counterfactual predictions about the path of unemployment following gradual monetary contraction.

Tsoukis, Kapetanios and Pearlman (2011, *JES*): "Elusive Persistence: Wage and Price Rigidities, the New Keynesian Phillips Curve and Inflation Dynamics." Comprehensive

review of the various theoretical New Keynesian approaches to modeling inflation dynamics. The models covered include time-dependent pricing (with and without endogenous choice of adjustment frequency), quadratic adjustment costs, sticky information, price indexation, combination of staggered wage and price setting, GE models of time-dependent pricing, signal extraction, and state-contingent pricing. A good amount of detail is given about how to derive the NKPC relationships. The authors state a number of concluding observations about the various modeling approaches' ability to generate intrinsic inflation persistence. Finally, the authors give a very brief summary of the empirical evidence for the U.S., Euro Area and OECD.

2 Macroeconomic theory

2.1 Blanchard and Galí (2007, *JMCB*): "Real Wage Rigidities and the New Keynesian Model"

Real wage rigidities are introduced into the standard Calvo framework. Specifically, it is assumed that real wages w_t evolve according to

$$w_t = \gamma w_{t-1} + (1-\gamma) mrs_t,$$

where mrs_t is the marginal rate of substitution between consumption and leisure (the canonical Calvo model corresponds to $\gamma = 0$). In an appendix Blanchard and Galí show how this assumption can be derived from staggered wage contracts where only a certain fixed fraction of workers, drawn at random, get to renegotiate their real wage every period. A lot of algebra leads to the modified NKPC (27)

$$\pi_t = \frac{\gamma}{1+\beta\gamma}\pi_{t-1} + \frac{\beta}{1+\beta\gamma}E_t\pi_{t+1} + \frac{\lambda}{1+\beta\gamma}x_{2t} + \zeta_t,$$

where ζ_t is white noise (orthogonal to time $t-1$ variables) and x_{2t} is a linear combination of the contemporaneous and once lagged output gaps. The authors remark that this equation is not estimable in practice as the output gap is not well observed. Instead their equation (28) shows that

$$\pi_t = \frac{1}{1+\beta}\pi_{t-1} + \frac{\beta}{1+\beta}E_t\pi_{t+1} - \frac{\lambda(1-\alpha)(1-\gamma)\phi}{\gamma(1+\gamma)}u_t + \frac{\alpha\lambda}{1+\beta}\Delta v_t + \tilde{\zeta}_t,$$

where u_t is the unemployment rate, Δv_t is the change in the relative price of the nonproduced input in the economy's production function (the white noise term $\tilde{\zeta}_t$ is again orthogonal to time $t-1$ variables). Blanchard and Galí note that this equation is very close to an old Phillips curve. When they estimate the relationship using IV on U.S. data, all reduced form coefficients are significant and have the right sign.

2.2 Blanchard and Galí (2010, *AEJMacro*): "Labor Markets and Monetary Policy: A New Keynesian Model with Unemployment"

The authors construct a model with labor market search frictions (hiring is costly), Calvo nominal price setting and real wage rigidities. The expression for the NKPC in terms of marginal cost is the canonical one, but the expression for marginal cost depends on the degree of labor market tightness x_t (ratio of hires to unemployment). Under certain approximations and the assumption

that productivity follows an AR(1) process with positive autoregressive parameter (pp. 14–15), the model implies the following Phillips curve relation (33):

$$\pi_t = -\delta_1 \hat{u}_t - \delta_2 \Delta \hat{u}_t - \delta_3 \hat{a}_t,$$

where $\delta_1, \delta_2, \delta_3 > 0$ are functions of structural parameters, u_t is the unemployment rate, a_t is the log of productivity and hats denote (absolute) deviations from steady state.

2.3 Christiano, Eichenbaum and Evans (2005, *JPE*): "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy"

A slight twist to the Calvo framework is introduced: A firm j that isn't touched by the Calvo fairy in period t simply indexes its price to lagged inflation: $P_{jt} = \pi_{t-1} P_{j,t-1}$ (pp. 10–11). The time-t pricing decision is assumed to be carried out based on time $t-1$ information. These considerations lead to the hybrid NKPC (32)

$$\hat{\pi}_t = \frac{1}{1+\beta}\hat{\pi}_{t-1} + \frac{\beta}{1+\beta} E_{t-1}\hat{\pi}_{t+1} + \frac{(1-\beta\theta)(1-\theta)}{(1+\beta)\theta} E_{t-1}\widehat{mc}_t,$$

where $\hat{\pi}$ is the absolute deviation of inflation from its steady state value, cf. the discussion on pp. 26–28.[2] The authors view the lagged inflation term as a way of rationalizing the inflation inertia observed in the empirical literature.

2.4 Guerrieri, Gust and López-Salido (2010, *AEJMacro*): "International Competition and Inflation: A New Keynesian Perspective"

The authors derive a hybrid NKPC for an open economy from explicit microfoundations. The demand schedule facing domestic firms is assumed to depend on the price of foreign goods. Partial inflation indexation is incorporated as in Smets and Wouters (2003). The resulting NKPC without firm-specific capital (i.e., marginal cost is constant across firms), their equation (20), is

$$\hat{\pi}_t - \delta_D \hat{\pi}_{t-1} = \beta E_t[\hat{\pi}_{t+1} - \delta_D \hat{\pi}_t] + \kappa \left[(1-\Psi)\hat{s}_t + \Psi\omega\frac{\varepsilon_A}{\varepsilon}\hat{p}_{Mt} + (2\Psi - 1)\hat{\gamma}_t\right],$$

where β is the discount factor, δ_D is the degree of indexation, κ plays the same role as λ in Galí and Gertler (1999), Ψ reflects the variations in the desired markup associated with competition from other firms, ω measures the home bias in goods preferences, ε_A is the elasticity of substitution between home and foreign goods, ε is the steady state elasticity demand elasticity, s_t is marginal cost, p_{Mt} is the relative price of foreign goods and γ_t is an exogenous preference shock.[3] Hats denote deviations from steady state, and all variables are in logs. Guerrieri et al. test their open-economy NKPC using a novel GMM approach, in which the structural equation is written in closed form and then estimated jointly with a reduced-form VAR for marginal cost and relative import price. They provide ML estimates as a robustness check. The two estimation approaches lead to similar results: The influence of foreign competition on U.S. inflation dynamics has been substantial since 1983, and when one accounts for movements in relative import prices, the degree of price indexation becomes insignificant. An LR test against an unrestricted VAR fails to reject the model restrictions.

[2] Note that in indexation models the introduction of a non-zero steady state rate of inflation does not alter the form of the Phillips curve.

[3] Firm-specific capital entails an NKPC with the same reduced form, but the expression for κ as a function of the underlying parameters changes, cf. their equation (24).

2.5 Mankiw and Reis (2002, *QJE*): "Sticky Information versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve"

The NKPC is criticized for delivering counterfactual predictions. In its stead, the authors propose a sticky information model in which firms set their prices every period but are only allowed to update their information set with a certain probability λ. The implication is that the average price level will be determined by a weighted sum of outdated expectations of the contemporaneous price level and output gap. This leads to the sticky information Phillips curve

$$\pi_t = \frac{\mu\lambda}{1-\lambda} x_t + \lambda \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-j-1}(\pi_t + \alpha \Delta x_t),$$

where x_t is the output gap and μ is the (constant) price markup. Mankiw and Reis provide evidence for their theory by considering various impulse responses, computing correlations of inflation changes with output and discussing the role of inflation persistence. They don't carry out a formal empirical test, however.

2.6 Smets and Wouters (2003, *JEEA*): "An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area"

The authors estimate a DSGE for the Euro Area. In terms of the NKPC, the authors extend the model of Christiano et al. (2005) by allowing for partial, rather than full, indexation by firms who are not touched by the Calvo Fairy. See p. 1133 for details, specifically the FOC (25) and law of motion for prices (26). The log-linearized hybrid NKPC is equation (32) on p. 1135, using the marginal cost equation (23) on p. 1132:

$$\hat{\pi}_t = \frac{\beta}{1+\beta\gamma_p} E_t \hat{\pi}_{t+1} + \frac{\gamma_p}{1+\beta\gamma_p} \hat{\pi}_{t-1} + \frac{1}{1+\beta\gamma_p} \frac{(1-\beta\xi_p)(1-\xi_p)}{\xi_p} (\widehat{mc}_t + \eta_t^p).$$

Here ξ_p is the Calvo parameter, γ_p is the fraction of indexing firms, mc_t is marginal cost and η_t^p is an idiosyncratic cost shock. Hats denote log deviations from steady state.

2.7 Other literature

Erceg and Levin (2003, *JME*): "Imperfect credibility and inflation persistence." The authors develop a DSGE model in which private agents optimally extract information about the central bank's inflation target from the evolution of the interest rate. When innovations to the inflation target are persistent, inflation persistence is generated. The fact that private agents have less information than the central bank leads to the inclusion of an extra autoregressive error term in the NKPC, which can explain the empirical superiority of the hybrid NKPC over the pure version.

Gertler and Leahy (2008, *JPE*): "A Phillips Curve with an Ss Foundation." An Ss model of state-dependent price adjustment is developed. It is shown that clever, rigorous Taylor approximations can reduce the firms' decision problem to a tractable form, yielding a conventional NKPC relation upon log-linearization. The validity of the approximation depends on relative magnitudes of adjustment costs, idiosyncratic and aggregate shocks. Surprisingly, the resulting NKPC has the exact same structural representation as the Calvo-based NKPC of Galí et al. (2001), except

that the Calvo parameter is replaced by the probability of a firm being hit by an idiosyncratic productivity shock.[4] Because firms don't always choose to adjust prices after being shocked, Gertler and Leahy's model leads to more price flexibility than under time-dependent (Calvo) pricing. Intuitively, the firms that adjust will be the ones with the biggest need to do so (labeled the "selection effect" by Golosov and Lucas, 2007). Gertler and Leahy recognize that it will be a challenge to reconcile the model with data on inflation persistence, given the empirical troubles of the traditional NKPC.

Yao (2011, *working paper*): "Monetary Policy, Trend Inflation and Inflation Persistence." The author investigates what happens if one relaxes the assumption of a constant probability of firms being touched by the Calvo fairy. When the hazard rate of price resetting is left general, additional leads and lags of inflation enter the NKPC.[5] The intuitive reason is that in the traditional Calvo set-up prices are given by $p_t = (1-\theta)\sum_{j=0}^{\infty}\theta^j p_{t-j}^*$, where p_t^* is the optimal reset price. Due to constancy of the Calvo parameter θ, this relationship may be written in the iterative form $p_t = (1-\theta)p_t^* + \theta p_{t-1}$. However, if reset probability varies over time, the pair (p_t^*, p_{t-1}) is no longer a sufficient statistic for the inflation-relevant past optimal pricing decisions. Hence, a non-constant hazard rate leads to an NKPC with what the literature labels intrinsic inflation persistence. However, Yao shows that the coefficients on these extra lags of inflation depend on the model's Taylor rule and so are subject to the Lucas critique. After log-linearizing around a steady state with positive trend inflation, the model is calibrated and simulated (the hazard rate of price resetting is modeled as a Weibull distribution). The author finds that the combination of a non-constant hazard rate and non-zero trend inflation is able to account for the changes in U.S. inflation persistence across time.

3 Evaluation of competing models

3.1 Bårdsen, Jansen and Nymoen (2004, *OBES*): "Econometric Evaluation of the New Keynesian Phillips Curve"

The empirical robustness of the hybrid NKPC is called into doubt. The authors first point out the inconsistency in the literature between the three (sometimes implicit) assumptions of homogeneity (i.e., that the coefficients on next and last period's inflation sum to 1), stationarity and exogeneity of the forcing variable. They then demonstrate that GMM estimates are sensitive to a change from 2SLS to CUE as well as to the choice of instruments. If the restrictions of the hybrid NKPC are tested in an IV regression that encompasses a wider range of alternative specifications of inflation dynamics, the model is generally rejected, and furthermore the addition of the extra terms tend to make the forward-looking term insignificant.

3.2 Boug, Cappelen and Swensen (2010, *JEDC*): "The new Keynesian Phillips curve revisited"

The authors estimate the pure and hybrid NKPCs in their exact and inexact forms (i.e., with and without an error term) on U.S. and Eurozone data, using the Galí and Gertler (1999) and Galí et al. (2001) datasets. They derive cross-equation restrictions from the NKPC and the assumption

[4] More precisely, it is the probability of the firm's small "island" being hit by a productivity shock.

[5] This has also been observed by Sheedy (2010).

that the reduced-form dynamic of inflation and marginal cost are well described by a finite-order VAR. The likelihood is derived, which is easy for the exact version of the NKPC but requires the Kurmann (2007) reverse-engineering approach in the inexact case. Boug et al. clearly spell out how to modify the analysis if the variables are non-stationary, and they show that a *necessary* condition for the NKPC holding in this case is that inflation and real marginal cost are cointegrated. They then estimate the NKPC by ML. For the Eurozone, both inflation and the labor share appear to be I(1), so the analysis allows for cointegration. Plots of the likelihood surface reveals an identification problem: Because the cointegrating vector is superconsistently estimated, the structural parameters may be expected to be functionally linked in large samples, and so the likelihood displays a sharp ridge (furthermore, the effective degrees of freedom is reduced, which should be taken into account in a LR test). The ML estimates are on the boundary of the economically admissible set, and LR tests clearly reject the model. For U.S. data (on the Galí and Gertler sample), inflation and the labor share appear stationary. While the pure and exact forms of the NKPC are rejected, the inexact hybrid NKPC fits the data rather well, and the likelihood surface is nicely concave. However, the estimated residuals from the model (*excluding* the RE forecast errors) are significantly autocorrelated, which violates an assumption of the model. The authors offer the interpretation that more than one lag is needed in the NKPC to capture the true process of inflation.

3.3 Chowdhury, Hoffmann and Schabert (2006, *EER*): "Inflation dynamics and the cost channel of monetary transmission"

Like Ravenna and Walsh (2006), the authors develop and estimate an NKPC featuring the cost channel, i.e., a direct supply-side impact of the interest rate on price setting. As usual, the cost channel is introduced by assuming that firms are subject to the financial friction that they must pay their wage bill up front every period, and these funds are borrowed from financial intermediaries. The authors go a bit further than Ravenna and Walsh, in that they model the lending practices of the financial intermediaries, which introduces a premium on the lending rate relative to the treasury rate (the coefficients on real unit labor cost and the interest rate may therefore differ in the NKPC). Furthermore, due to rule-of-thumb behavior, the NKPC is hybrid rather than pure. The model is estimated by GMM on data from the G-7 countries. Except for Germany and Japan, the treasury rate is significant, and the coefficient on the interest rate exceeds that on the labor share for all countries except France. Both the forward-looking and backward-looking inflation terms are significant in all countries. In extensions, the NKPC is estimated jointly with a Taylor rule, and subsequently a model is estimated in which marginal cost is allowed to depend directly on commodity prices as well as ULC.

3.4 Dufour, Khalaf and Kichian (2010*b*, *JEDC*): "On the precision of Calvo parameter estimates in structural NKPC models"

Three different recent Calvo-type models are estimated on U.S. data using Generalized Anderson-Rubin tests: The Eichenbaum and Fisher (2007) model of price indexation, the Blanchard and Galí (2007) model of real wage rigidities and the Blanchard and Galí (2010) model of labor market search frictions. All models have high-dimensional parameter sets and require calibration of nuisance parameters. The error term in the first model is an MA process due to implementation delays. The second model implies a role for current unemployment and supply shocks (real price of the non-produced good in the economy), while the third model rests on unemployment dynamics.

The labor share proxies for marginal cost. Dufour et al. find that identification is improved by including instruments suggested by models other than the one being estimated. They discuss the GAR test's built-in specification test of the dependence structure of model shocks. Estimates with the full instrument set are in line with micro data on price adjustment durations and yield significant coefficients on the labor share. While the results are sensitive to the instrument set and calibrations, the significance of the lagged inflation term is robust.

3.5 Dupor, Kitamura and Tsuruga (2010, *REStat*): "Integrating Sticky Prices and Sticky Information"

A model that combines Calvo-type sticky price setting with sticky information is presented. Each period a monopolistic firm has a certain probability of being allowed to change its price as well as a certain probability of updating its information set (the two events are independent). The interaction of sticky price changes with sticky information endogenously gives rise to a lagged inflation term in the inflation equation, i.e., without resorting to assumptions about indexation or rule-of-thumb behavior. The authors test the model on U.S. data using a two-step VAR-MD approach. Because the model is too complicated to allow writing out inflation in closed form, future expectations of inflation are also calculated with the first-step VAR (unlike in, say, Sbordone, 2002). The parameters estimated in the second step indicate that both price-setting stickiness and information stickiness are significantly present in the data, although the dual stickiness model achieves the same $\bar{R}^2$ as the hybrid Galí and Gertler NKPC. The authors derive a general model that nests the hybrid NKPC and find that the fraction of exogenously backward-looking firms is insignificant (in fact, negative). Results are robust to different choices of the forcing variable. Finally, a three-equation DSGE is simulated in order to show that impulse responses to a transitory cost-push shock are quite different for the dual stickiness and hybrid NKPC models, thus underlining the policy importance of distinguishing the two.

3.6 Eichenbaum and Fisher (2007, *JME*): "Estimating the frequency of price re-optimization in Calvo-style models"

This is a short version of the 2004 NBER working paper by the same authors. Eichenbaum and Fisher take the Christiano et al. (2005) price indexation model to the data. Pricing decisions are assumed to be made with an implementation lag $\tau \geq 0$. The econometric methodology is outlined in detail. They use GMM with a HAC matrix that exploits the model implication that $\{\xi_{t+1} X_{t-\tau}\}_{t \geq 0}$, where ξ_t is the expectational error and X_t the vector of instruments, is a moving average process of order τ. Imposing this restriction is found to increase the power of the test. They use two instrument sets: a conventional one à la Galí and Gertler (1999) (but with a lagged residual added[6]) and one which only includes monetary policy shocks estimated by Altig et al. (2005). Setting $\tau = 0$, the model is strongly rejected by the J test. However, for $\tau = 1$ the model easily fails to be rejected, regardless of inflation measure or subsample. Estimates of the Calvo parameter are too high to square with micro data, so the authors add two ingredients to their model: variable elasticity of demand and capital adjustment costs. These alterations do not change the reduced form—and thus the fit—of the model, but certain calibrations of the additional free parameters imply a sufficiently small Calvo parameter. Reduced form estimates are not presented. In the 2004 working paper, Eichenbaum and Fisher nest their indexation model along with the Galí

[6] It's not clear how the parameter values used to compute the residual are determined.

and Gertler rule-of-thumb hybrid NKPC in a general specification for the non-reoptimizing firms. The share of firms that use rules of thumb is shown to be insignificant in the data.

3.7 Faust and Wright (2011, *working paper*): "Forecasting Inflation"

The authors undertake an extensive comparison of the pseudo-out-of-sample (real-time) forecasting performance of 16 different models of inflation dynamics, including ARs, VARs, random walk models, UC-SV, DFMs, traditional Phillips curves, model averaging, DSGE approaches and survey forecasts. The NKPC has not yet been included in the exercise (listed as "to be written"). Where applicable, the models are also fitted in versions that allow for a time-varying trend. None of the technical models offer consistent improvements over a simple fixed-coefficient AR(1) inflation gap formula that is fitted on pre-1985 data. This holds regardless of the prevailing economic environment. Only judgemental survey forecasts beat the simple benchmark. The authors emphasize that the relative performance of technical models is mostly determined by their ability to successfully nowcast inflation and to get the long-term trend right, whereas sensitivity to intermediate factors is inconsequential at best. Faust and Wright also briefly discuss other related topics, such as the use of market-based measures of inflation expectations (e.g., break-even rates from TIPS), density forecasts and disaggregated price forecasts.

3.8 Galí and Gertler (1999, *JME*): "Inflation dynamics: A structural econometric analysis"

The authors derive a hybrid NKPC based on the ("admittedly ad hoc") assumption that a fraction of firms form rule-of-thumb inflation forecasts. The empirical issues with using the output gap as the forcing variable are outlined, and the labor share is proposed as a superior gap measure due to its smaller measurement error and performance in estimation. Galí and Gertler provide both reduced-form and structural GMM estimates for the hybrid NKPC and find that they line up well with theory and micro evidence.[7] The forward-looking component dominates the backward-looking, although the latter is statistically significant. The pure NKPC also does rather well with the new marginal cost measure. Two robustness exercises are carried out: First, extra lags of inflation on the right-hand side of the PC equation lead to minimal changes. Second, subsample estimation indicates that parameters are stable over time. Finally, the authors solve for the hybrid model's closed-form solution for inflation and find that it tracks actual inflation well (in this exercise a reduced-form VAR is used to generate forecasts of future marginal costs). They conclude that inflation persistence is probably inherited from sluggishness in the marginal cost process.

3.9 Galí, Gertler and López-Salido (2001, *EER*): "European inflation dynamics"

The authors apply an extended version of the Galí and Gertler (1999) analysis to aggregate Euro Area and U.S. data. Relative to the 1999 paper they limit the number of lags for non-inflation variables in the instrument list, citing weak instruments concerns,[8] and relax the assumption that firms face identical constant marginal costs, following the working paper version of Sbordone (2002).

[7] When estimating the structural parameters, two different normalizations of the moment conditions are used, as they lead to somewhat different results due to nonlinearities.

[8] The new instrument list yields a large first-stage F statistic.

The latter modifies the formula for the λ parameter on marginal cost in terms of the structural parameters. Estimates of the pure NKPC square up reasonably well with theory. When the hybrid specification is estimated, it is found that the fraction ω of backward-looking price setters is smaller (and indeed insignificant) for the Euro Area than for the U.S. If the labor share coefficient $1-\alpha$ (in the production function) and the elasticity of demand are calibrated to standard values, estimates of the Calvo parameter imply price durations that match micro evidence; if constant identical marginal costs are assumed, the match is much worse and λ becomes very insignificant. Noting that the GMM residuals are autocorrelated, the authors also try adding more lags of inflation to the hybrid NKPC but they turn out to be jointly insignificant. Finally, as in Galí and Gertler (1999) and Sbordone (2002), the closed-form solution for inflation in the NKPC is computed, where predictions of marginal costs are carried out with a first-stage VAR. While this measure of "fundamental" inflation seems to lag actual inflation, the constructed profile is quite similar to historical data.

3.10 Galí, Gertler and López-Salido (2005, *JME*): "Robustness of the estimates of the hybrid New Keynesian Phillips curve"

This is a rebuttal of the criticism raised by Rudd and Whelan (2005*b*) and Lindé (2005) against the original Galí and Gertler (1999) and Galí et al. (2001) analyses of the hybrid NKPC. The authors show that Rudd and Whelan's GMM estimation using the closed form solution fails to take into account the restrictions on the reduced form implied by the structural form. When these parameter restrictions are accounted for, the original 1999 results are reproduced. Lindé (2005) used non-linear least squares to arrive at very different estimates. Galí et al. argue that it is likely Lindé's covariates are correlated with the error term (which Lindé left out) and corroborate this with non-linear GMM estimation. Due to the robustness of the estimates across linear and non-linear specifications they argue that weak instruments are probably not an issue, stating without further elaboration that for all their instrument sets "the F-test of the first stage regression clearly supports the joint significance of the instruments." Lindé had also used a FIML procedure to arrive at another set of unfavorable estimates, which Galí et al. claim rest on a likely misspecified econometric model. Furthermore, they cite other papers which confirm the validity of the hybrid NKPC in an ML setting.

3.11 Kiley (2007, *JMCB*): "A Quantitative Comparison of Sticky-Price and Sticky-Information Models of Price Setting"

The paper compares various sticky-price and sticky-information Phillips curve specifications using ML methods. The model is fit by first estimating a reduced-form VAR in the labor share, output, the nominal interest rate and inflation. Taking the estimated reduced-form coefficients *and* disturbances as given, the AIM procedure (Anderson and Moore, 1985) is then used to derive the likelihood for any combination of structural parameters. Kiley argues that such treatment of the reduced form allows him to compare models purely based on their predictions about the structural inflation equation. Formal model comparison is carried out using the Bayesian Information Criterion (BIC) and implied pseudo-posterior odds. Kiley considers these measures as being more relevant for evaluating competing models than, e.g., the literature's obsession with statistical significance of marginal cost. Some Monte Carlo evidence is presented to support this claim. The empirical results suggest that the pure NKPC is a bad fit for U.S. data, while a hybrid NKPC with one lag

does better. A four-lag specification provides as good a fit as a completely unrestricted VAR(3) model of inflation (the hybrid NKPC is, however, strongly rejected by an LR test, as the latter does not reward parsimony, unlike the BIC). Sticky-information specifications are outperformed by an unrestricted VAR in the full sample but fare quite well in the post-1983 sample.

3.12 Korenok, Radchenko and Swanson (2010, *JAE'metrics*): "International Evidence on the Efficacy of New-Keynesian Models of Inflation Persistence"

The pure and hybrid NKPCs are compared with the Mankiw and Reis (2002) sticky information model of inflation, using time series data for 13 OECD countries and three forcing variables (output gap, ULC and unemployment). A reduced form VAR in inflation, the forcing variable, output and the interest rate is estimated, upon which the inflation equation is replaced with the structural specification in question. Recognizing that all three inflation models yield a transition equation for the observable variables and their expectations, the models are then estimated with the Kalman filter (details are spelled out in the 2006 working paper). For all models use of the output gap or unemployment mostly leads to the wrong sign for the estimated forcing variable coefficient. The labor share yields the right sign, but the coefficient is generally small, and indeed insignificant for the hybrid NKPC. The coefficient on forward-looking inflation expectations are not estimated, as the calibration of the discount factor pins them down. Neither of the three models produce residuals that are close to white noise. The first-order autocorrelation implied by the parameter estimates for the pure NKPC or sticky information model falls dramatically short of the historical degree of inflation persistence, while the hybrid NKPC does better on this measure (in fact, it overshoots the target).

3.13 Ravenna and Walsh (2006, *JME*):"Optimal monetary policy with the cost channel"

Barth and Ramey (2002) find a significant role for the cost channel of monetary policy, i.e., direct supply-side effects of interest rate shocks. Building on the literature, Ravenna and Walsh develop an otherwise standard New Keynesian model in which firms have a need for working capital, i.e., at the start of every period they must borrow funds from financial intermediaries to pay the end-of-period wage bill. As a result, firms' effective marginal cost depend both on the unit labor cost and the interest rate. In the implied NKPC, real ULC and the interest rate enter with the same coefficient, although the coefficient on the interest rate is lowered if only part of a firm's wage bill has to be paid in advance. The structural (pure) NKPC is estimated using GMM on U.S. data, with the 3-month T-bill rate proxying for the interest rate. Different choices of instrument sets are employed, guided by first-stage F tests. Although estimates of the degree of working capital financing are fairly imprecise, the evidence points to a significant role for the cost channel. When adding the cost channel, the estimate of the discount factor drops and that of the Calvo parameter rises (i.e., more price stickiness), but in neither case by much.

3.14 Roberts (2005, *Contrib's to Macro*): "How Well Does the New Keynesian Sticky-Price Model Fit the Data?"

Roberts argues that it is necessary to include lags of inflation in the NKPC to adequately fit U.S. data. He estimates the model using VAR-ML, IV and impulse response function matching, using the (HP filtered) output gap as the forcing variable. Lagged values of inflation are very significant (also economically) across all specifications and estimation methods. A four-quarter moving average of past inflation performs better than one lag. The conclusions are robust to explicitly accounting for correlation in the error term and to estimation on subsamples. Roberts criticizes the use of labor costs as the forcing variable: First, when matching impulse response functions, it makes a big difference for parameter estimates whether one tries to match shocks to unit labor costs or not, which is consistent with the view that ULC are measured with considerable error. Second, when allowing for an extra (theoretically motivated) work effort term in the Phillips curve to complement the labor costs, the parameter estimates are counterintuitive.

3.15 Rudd and Whelan (2005*b*, *JME*): "New tests of the new-Keynesian Phillips curve"

The assertion that the hybrid NKPC does a good job of fitting the data is criticized. Using an intuitive argument based on the logic of two-stage least squares, the authors show how omitted variable bias in the GMM equation for the hybrid NKPC may well generate the results found by Galí and Gertler (1999), even if the true process for inflation is purely backward-looking: The first-stage projection of next period's inflation on the instrument set may be picking up the explanatory power of omitted variables which are correlated with the instruments. Rudd and Whelan also provide an algebraic example. They then estimate the hybrid NKPC in its closed-form version (i.e., with an infinite sum of discounted future expected values of the forcing variable), arguing that such an estimation strategy has greater power, as there is no a priori reason to expect the infinite sum to be correlated with omitted variables. This approach finds no significant role for the forcing variable in fitting the data. Rudd and Whelan explain the empirical failure of the NKPC by the observation that inflation doesn't Granger cause the labor share (or the output gap).

3.16 Rudd and Whelan (2006, *AER*): "Can Rational Expectations Sticky-Price Models Explain Inflation Dynamics?"

This is a more detailed analysis of the closed-form estimation of the hybrid NKPC than what is presented in Rudd and Whelan (2005*b*). The authors respond (although not explicitly) to the critique in Galí et al. (2005) by carefully deriving the closed forms and relating these to the deeper model parameters. It is confirmed that the relevant sums of discounted expected future values of the forcing variable don't have much relation to inflation in the data. When the forcing variable is modeled as a reduced-form VAR, it doesn't increase the fit when added to a regression of inflation on its past values. The (present value of the) forcing variable is also insignificant in GMM estimation. The results hold for both the output gap and the labor share, and for quarterly and annual frequencies. Due to the discontinuous nature of the closed-form solution (a result of imposition of stationarity), estimates of the coefficient on next period's inflation may easily exceed 1/2 even if inflation is actually an AR(1) process.

3.17 Sbordone (2002, *JME*): "Prices and unit labor costs: a new test of price stickiness"

Sbordone introduces a two-step estimation technique akin to that of Campbell and Shiller (1987, 1988) for evaluating the empirical performance of the pure NKPC with no error term (a related two-step ML approach was pioneered by Fuhrer and Moore, 1995). This involves solving the NKPC forward to obtain the closed-form solution for prices in terms of the present value of future marginal cost. The PV is to be computed using a reduced-form VAR for marginal cost and inflation. In the second step, parameters are estimated (taking the forecast of future unit labor costs as given) so as to minimize the sum of squared errors. Independently of Galí and Gertler (1999), Sbordone suggests using the labor share as a more accurate proxy for real marginal cost than the output gap. The second step involves two free parameters (which are functions of deeper structural ones), one of which is calibrated, as unrestricted estimation leads to coefficients that imply a negative discount rate. The one free parameter measures the degree of price stickiness. The author concludes from the data that prices are clearly sticky (i.e., the baseline RBC assumption is rejected), and that the Calvo parameter lines up well with micro data for reasonable calibrations of the other structural parameters. The forward-looking terms are essential for the model to fit the data. If the labor share is replaced with the output gap, the fit deteriorates markedly. A number of robustness exercises are carried out: changes in the VAR specification, introduction of labor adjustment costs or overhead labor, and a switch to the Taylor (1980) model of staggered wages. The main conclusions are found to hold across specifications.

3.18 Other literature

Atkeson and Ohanian (2001, *FRBM QR*): "Are Phillips Curves Useful for Forecasting Inflation?" The pseudo-out-of-sample forecasting performance of three different Phillips curve specifications (one classical and two accelerationist) and Greenbook forecasts are compared with the benchmark of predicting a constant inflation rate. The naive benchmark comes out on top. The authors conclude that "the search for yet another Phillips curve-based forecasting model should be abandoned."

Ball (2000, *working paper*): "Near-Rationality and Inflation in Two Monetary Regimes." Striking a middle ground between simple backward-looking expectations and rational expectations, Ball considers a Phillips curve in which inflation expectations are optimally formed in the *univariate* sense. It is found that this model is able to fit both the post-1960 and the 1879–1914 episodes in the U.S., whereas neither the simple backward-looking nor the rational expectations Phillips curve can explain both eras.

Batini, Jackson and Nickell (2005, *JME*): "An open-economy new Keynesian Phillips curve for the U.K." The authors use the Rotemberg (1982) quadratic adjustment cost framework to motivate three additions to the NKPC for an open economy: (1) employment adjustment costs, (2) the relative price of imported inputs and (3) a varying equilibrium markup due to foreign competition or the domestic business cycle. The model is estimated on UK data by GMM in reduced form. Each of the three extensions significantly improve the fit of the model and they all get the right sign. Inflation expectations are found to be mostly forward-looking, and the labor share is mostly significant and correctly signed.

Benati (2008, *QJE*): "Investigating Inflation Persistence Across Monetary Regimes." Documents that reduced-form inflation persistence (as measured by the sum of autoregressive coefficients) has been low for countries within the EMU, with inflation targets or under a gold standard. Within a structural DSGE framework, these same countries exhibit insignificant indexation terms in estimates of their hybrid NKPCs. Thus, the notion of intrinsic inflation persistence seems to violate the Lucas critique.

Benigno and López-Salido (2006, *JMCB*): "Inflation Persistence and Optimal Monetary Policy in the Euro Area." Hybrid NKPCs for Germany, France, Italy, Spain and the Netherlands are estimated by GMM, with the labor share as the forcing variable. For Germany the evidence points toward fully forward-looking inflation dynamics, while the backward-looking term is statistically and economically significant for the other countries.

Byrne, Kontonikas and Montagnoli (2010, *working paper*): "International Evidence on the New Keynesian Phillips Curve Using Aggregate and Disaggregate Data." The authors claim that aggregation bias accounts for the poor empirical performance of the hybrid NKPC. They use annual data from 15 sectors in 14 OECD countries to estimate disaggregated NKPCs that are then averaged using panel data methods. The underlying estimation framework is ML with a reduced-form AR(1) specification for the labor share. The authors find that the use of disaggregate data paints a more positive picture of the Calvo theory, with a larger degree of forward-looking behavior and a significant labor share. The model seems to be a worse fit for small OECD countries, however.

Coenen, Levin and Christoffel (2007, *JME*): "Identifying the influences of nominal and real rigidities in aggregate price-setting behavior." The paper generalizes the traditional New Keynesian price setting model in several ways. The hazard rate of price resetting is not restricted to be exponential as in Calvo (1983); instead, the ex ante probability of a firm's prices being fixed for j periods is a free parameter, although it's assumed that there is an upper bound J on price durations ($J = 4$ in the empirics). As in Eichenbaum and Fisher (2004), the production function is not restricted to be isoelastic; instead, the super-elasticity (elasticity of the elasticity) is a free parameter. The authors show that the degree of real rigidity may be summarized by a single parameter that determines the curvature of the profit function (in a log-linearization). Finally, the authors consider two types of indexation: indexation to past inflation and indexation to the Central Bank's target. The model is estimated on U.S. data from 1983–2003 (allowing for a break in the Fed's inflation target in 1991Q1) and German data from 1975–1998. An indirect inference estimator that matches the model-implied VAR dynamics to the estimated reduced-form VAR is used. For both countries, the degree of indexation is insignificant and the Calvo assumption of constant exponential decay of the resetting probability is counterfactual. The estimated hazard rate is bimodal, with the clear majority of contracts lasting either 1 or 4 quarters. The mean duration is about 2–3 quarters, depending on the specification. New contracts appear quite insensitive to real marginal cost, as the estimated degree of real rigidity is much larger than benchmark values in the literature. The overidentifying restrictions are not rejected, and the reduced-form dynamics of the estimated model matches the data well by several measures. In contrast, the best-fitting model with Calvo hazard rate does not come close to matching the reduced-form VAR dynamics in the data.

Dotsey (2002, *FRBR EQ*): "Pitfalls in Interpreting Tests of Backward-Looking Pricing

in New Keynesian Models." The author argues that existing tests of the hybrid NKPC can't identify the preponderance of forward-looking firms if there is uncertainty about the true model. Running Monte Carlo experiments, he uses a version of the Taylor (1980) staggered contracts model (in which all firms are perfectly forward-looking but contract lengths are rigid) as DGP and shows that GMM estimation of the hybrid NKPC on the artificial data can generate estimates similar to those of Galí and Gertler (1999), i.e., indicate a sizeable fraction of rule-of-thumb price setting.

Dufour, Khalaf and Kichian (2010*a*, *CSDA*): "Estimation uncertainty in structural inflation models with real wage rigidities." The Generalized Anderson-Rubin test is applied to the Blanchard and Galí (2007, 2010) models of real wage rigidities and labor market frictions. The data is for Canada (see the 2010 *JEDC* paper for U.S. results). The fit of the 2007 model is dubious, with a very small Calvo parameter; however, Hodges-Lehmann point estimates suggest that real wage rigidities and cost-push shocks are important. The 2010 model fits the data nicely and indicates an economically significant tradeoff between inflation and unemployment.

Estrella and Fuhrer (2002, *AER*): "Dynamic Inconsistencies: Counterfactual Implications of a Class of Rational-Expectations Models." The pure NKPC implies that the *level* of inflation is positively correlated with the output gap, whereas the *change* in the rate of inflation is negatively correlated with the gap. The authors show that this is at odds with the data and that the most obvious theoretical extensions to the model do not eradicate the problem. Using the Anderson and Moore (1985) procedure, Estrella and Fuhrer compute impulse response functions for the restricted VAR implied by the NKPC, a dynamic IS curve and a policy reaction function. It is found that the canonical model can't deliver the hump-shaped behavior exhibited by many macroeconomic variables. The restrictions of the model are also strongly rejected by an LR test against an unrestricted VAR.

Fuhrer (2006, *IJCB*): "Intrinsic and Inherited Inflation Persistence." Employing a baseline model involving the hybrid NKPC and a strictly exogenous AR(1) process for the forcing variable, Fuhrer shows that inflation persistence in the U.S. in primarily intrinsic rather than inherited from properties of the forcing variable. The primary reason is that estimates of the slope of the NKPC tend to be too small to imply substantial persistence spillover. Both MLEs of the two-equation model and single-equation GMM estimates are provided in Section 3.3 (using various different instrument sets and subsamples). ML points to a larger share of forward-looking behavior, but both approaches generally fail to yield statistically or economically significant coefficients on the forcing variable, whether it is the output gap or labor share. The appendix presents useful closed-form solutions of the two-equation model.

Groen, Paap and Ravazzolo (2009, *FRBNY Staff Report*): "Real-Time Inflation Forecasting in a Changing World." The authors build a vast reduced-form model for inflation forecasting. Model uncertainty (in terms of the number and selection of explanatory variables) and infrequent structural breaks (in the form of time-varying coefficients and volatilities) are incorporated into the specification. The model is estimated using Gibbs sampling. Full-sample estimates point towards the importance of Michigan survey expectations as well as measures of cost-push shocks. The estimated degree of intrinsic inflation persistence is small compared to results in the literature. In pseudo-out-of-sample exercises the model outperforms alternative inflation forecasting models.[9]

[9]The Stock and Watson (2007) UC-SV model has comparable performance in the 1995-2008 subsample.

Gwin and VanHoose (2008, *JMacro*): "Alternative measures of marginal cost and inflation in estimations of new Keynesian inflation dynamics." The authors extend the analysis of Galí and Gertler (1999) by using a more direct measure of firm costs, industry-level average variable costs from Compustat. This alteration on its own does not materially change the estimation results. Apart from the GDP deflator, they also consider PPI inflation, which is deemed to be a more relevant variable from the perspective of firms' price setting. Furthermore, the authors argue that HP detrending of the marginal cost measure is needed to account for a time-varying steady state. The resulting estimates imply less price stickiness than found by Galí and Gertler, although the share of forward-looking behavior is still dominant.

Khan and Zhu (2006, *JMCB*): "Estimates of the Sticky-Information Phillips Curve for the United States." The authors estimate Mankiw and Reis (2002) sticky information Phillips curve. Expectations are proxied by either AR or bivariate VAR recursive forecasts. Confidence intervals are bootstrapped. The null of no information stickiness is rejected across all specifications, but point estimates of the probability of updating are sensitive to the inflation measure.

Kiefer (2010, *working paper*): "Alternative Phillips Curves Models with Endogenous Real-Time Expectations." The author proposes to estimate unobservable inflation and output gap expectations with the Kalman filter using real-time data. The observation equations are determined from assumptions on the conduct of monetary policy. After having backed out expectations, Kiefer substitutes them into four different models of inflation dynamics. Given the Kalman-smoothed expectations, the Calvo sticky price and Rotemberg adjustment cost models fit the actual path of inflation best, while the Mankiw and Reis sticky information and Taylor staggered contracts models perform worse.

Krause, Lopez-Salido and Lubik (2008, *JME*): "Inflation dynamics with search frictions: A structural econometric analysis." The Calvo price setting model is extended to incorporate search and matching frictions. The implications of the theoretical derivations are that firms' marginal cost will, apart from ULC, depend on the degree of labor market tightness and the job finding rate. Under standard calibrations in the literature the dynamics of the adjusted measure of real marginal cost do not deviate markedly from those of the labor share. As a result, single-equation GMM estimates of the closed form NKPC yield results similar to Galí et al. (2001). In particular, marginal cost is significant and correctly signed. A full-information Bayesian analysis corroborates the conclusions.

Lawless and Whelan (2011, *JMacro*): "Understanding the dynamics of labor shares and inflation." The theoretical prediction of the hybrid NKPC with regard to the *joint* dynamics of inflation and the labor share are carefully explained and illustrated. GMM estimates of the hybrid NKPC on aggregate Euro Area data are found to imply an unrealistically high degree of price stickiness and rate of time preference. Lawless and Whelan argue that given the microfoundations of the model, one would expect the NKPC to work better on sectoral data. Using EU and NBER datasets, they show that the NKPC performs even worse at the sectoral level, often delivering negative coefficients on the labor share.

Liu and Jansen (2011, *EmpEc*): "Does a factor Phillips curve help? An evaluation of the predictive power for U.S. inflation." The authors execute a pseudo-out-of-sample forecasting exercise on U.S. data for various models of inflation dynamics. It is found that dynamic

factor models tend to slightly outperform bivariate (i.e., traditional backwards-looking Phillips curves) and univariate (i.e., AR) models, especially at longer horizons. Surprisingly, however, forecasts based on the pure NKPC do even better at long horizons: If the NKPC is solved forward and estimates of the forcing variable are generated from a bivariate VAR (à la Campbell and Shiller, 1987, or Sbordone, 2002, 2005), the pseudo-out-of-sample performance beats that of every other model considered at the 12- and 24-month horizons, regardless of whether the output gap or labor share is used.

Mazumder (2010, *JMacro*): "The new Keynesian Phillips curve and the cyclicality of marginal cost." The paper criticizes the use of the labor share as a proxy for marginal cost on two grounds: The labor share is countercyclical (as pointed out by Rudd and Whelan, 2007) and its theoretical motivation hinges on an implicit assumption of labor flexibility on the extensive margin. Mazumder argues that due to hiring and firing rigidities, a measure of marginal cost based on straight-time and overtime hours will provide a better test of the NKPC. He constructs such a measure using data on compensation in the manufacturing sector; the new variable turns out to be procyclical. A disaggregated (sectoral) NKPC is derived and tested using the "optimal instruments" GMM approach of Fuhrer and Olivei (2004). Hours-based marginal cost consistently gets the wrong sign, while the reduced-form split between forward- and backward-looking behavior is about 50-50.

McAdam and Willman (2010, *working paper*): "Technology, Utilization and Inflation: Re-assessing the New Keynesian Fundamental." The authors argue that a more careful construction of the marginal cost measure is needed to assess the validity of the NKPC. They extend the baseline model to a more general CES production function with varying capacity utilization and convex adjustment costs for work hours. Technological change is modeled as a slow-moving process to disentangle its effects from those of capacity utilization. In the extended model marginal cost is a sum of a labor share-type term (which is exactly the labor share in the Cobb-Douglas case) and a utilization term (that is procyclical in the data). The authors estimate the pure and hybrid NKPC on U.S. data by 2-step GMM and CUE. Adding capacity utilization to the mix increases the magnitude and significance of the slope coefficient and reduces the weight on the forward-looking term to about 50%.

Neiss and Nelson (2005, *JMCB*): "Inflation Dynamics, Marginal Cost, and the Output Gap: Evidence from Three Countries." It is argued that the empirical failure of the output gap driven NKPC is due to the arbitrary use of detrending measures. Neiss and Nelson propose a method for measuring the output gap in a manner consistent with the canonical New Keynesian model. Their implementation of the model introduces a multiplicative shock to consumption preferences. They show that potential output, defined as the flexible-price output level, may be written as a distributed lag of model shocks. These may be backed out by calibration of parameters. The generated theory-consistent output gap series is shown to have little relation to quadratically detrended output. NKPCs for the U.S., UK and Australia are estimated by GMM. When adjusted for variable capacity utilization, the new output gap measure yields coefficients comparable in magnitude to those for the labor share but with an even more significant slope.

Rudd and Whelan (2005*a*, *JMCB*): "Does Labor's Share Drive Inflation?" A wide range of reduced-form VAR specifications involving the labor share are considered in trying to determine

whether said share adds incremental ability to forecasting inflation. It is found that none of the specifications do.

Shapiro (2008, *JMCB*): "Estimating the New Keynesian Phillips Curve: A Vertical Production Chain Approach." Shapiro's point is that the instruments used in traditional GMM estimation of the NKPC are only marginally relevant for firms' price setting decisions, leading to poor instrument relevance and thus weak identification. He instead constructs proxies for marginal cost based on an assumed vertical production chain, with real *input* unit costs of upstream firms replacing real unit labor costs (in practice, the PPIs of crude, intermediate and finished goods are used). A model is formulated that microfounds the use of upstream input costs as relevant and orthogonal instruments. The new instruments generate much higher first-stage F-type statistics (several variants from the literature are considered) and smaller standard errors for the pure NKPC, whereas this is not the case for the hybrid one. For the pure NKPC, the new instruments for marginal cost also have the advantage of making the estimates robust to various additions to the instrument set. Across specifications, Shapiro's point estimates are qualitatively similar to those of Galí and Gertler (1999), although the coefficient on real marginal cost is estimated as being minuscule (but positive).

Tillmann (2008, *JEDC*): "Do interest rates drive inflation dynamics? An analysis of the cost channel of monetary transmission." Tillmann proposes a different way to assess the importance of the cost channel than the difference-equation GMM methods used by Chowdhury et al. (2006) and Ravenna and Walsh (2006). The (pure or hybrid) NKPC is used to derive a present-value relationship between inflation, marginal cost and interest rates, using a VAR assumption to evaluate expectations. Conditional on the VAR parameters and thus the inflation expectation, the semi-structural NKPC parameters are estimated by GMM (standard errors are bootstrapped). The predicted and actual series for inflation are plotted and some summary statistics for the goodness of fit are provided, as in Galí and Gertler (1999). Data for the U.S., UK and Euro Area is used. In all three regions, the introduction of the cost channel improves the measures of fit. In the U.S., the main use of the cost channel is to explain the relatively high rates of inflation during Volcker interest rate hikes, as well as to explain the relatively low rate of inflation in the low-interest years of the mid-2000s.

4 Forecasts as proxies for expectations

4.1 Adam and Padula (2011, *EI*): "Inflation Dynamics and Subjective Expectations in the United States"

Adam and Padula use SPF one-quarter-ahead forecasts as proxies for inflation expectations in the NKPC. They argue that this is a direct and non-restrictive way of accounting for possible deviations from rational expectations in price formation.[10] It is shown that the SPF forecasts are biased and have autocorrelated errors. Because a Hausman test cannot reject the joint consistency of OLS and GMM, the authors use OLS in their regressions. The use of survey expectations as the expectation term in the pure NKPC leads to reasonable parameter estimates, regardless of whether the output

[10]They theoretically derive a non-rational-expectations version of the NKPC. The result requires a version of the law of iterated expectations for aggregate subjective forecasts, so the NKPC seems less general then the fully non-RE NKPC in Preston (2005).

gap or the labor share is chosen as the forcing variable (it is significant in both cases). The authors show that the surprisingly pretty results can be ascribed to the fact that SPF inflation forecasts, unlike actual inflation, are uncorrelated with the current output gap. A hybrid NKPC is also estimated, which again leads to similar results for the two forcing variables. The weight on the forward-looking term relative to the backward-looking is approximately 0.6:0.4.

4.2 Ang, Bekaert and Wei (2007, *JME*): "Do macro variables, asset markets, or surveys forecast inflation better?"

A pseudo-out-of-sample one-year-ahead forecasting horserace is executed with a wide array of inflation models: univariate ARMA models, Phillips curve relationships,[11] term structure models and survey forecasts (Michigan, Livingstone and SPF). Four different inflation measures are considered (three CPI-based and PCE). Only the survey measures are able to consistently beat a simple ARMA(1,1) model in terms of RMSE. The Michigan forecasts seem slightly worse than the Livingstone and SPF ones. For the three CPI inflation measures various model combination techniques strongly prefer the survey information to the other models. However, when forecasting PCE inflation, ARMA and Phillips curve models come out on top, while the survey forecasts (which are tailored to CPI) do significantly worse. Ang et al. speculate that the superior CPI forecasting performance of the survey measures may be due to them aggregating information from many different sources and thus essentially serving as model averages.

4.3 Brissimis and Magginas (2008, *IJCB*): "Inflation Forecasts and the New Keynesian Phillips Curve"

GMM estimation of the pure and hybrid NKPCs is undertaken, substituting in SPF and Greenbook forecasts, respectively, for the expectations term. The resulting parameter estimates line up very well with theory in every subsample considered, as the weight on expectations of next-period inflation is almost one and the labor share gets a positive and significant coefficient. In hybrid specifications the lagged inflation term receives insignificant but positive weight (the weight decreases even further when real-time GDP deflator data is used for the lagged inflation term). The authors interpret their results along the lines of Roberts (1997), i.e., that inflation persistence is mainly a result of somewhat irrational expectations. Results with various measures of the output gap are not nearly as nice.

4.4 Clark and Davig (2008, *working paper*): "An Empirical Assessment of the Relationships Among Inflation and Short- and Long-Term Expectations"

The authors are interested in the influence of survey expectations on inflation, as well as how these expectations are themselves influenced by economic conditions. They take care to distinguish between short- and long-term expectations. A detailed 12-page summary of the literature on survey inflation expectations, trend inflation and expectation anchoring is provided, although most of the focus is on VAR-type modeling rather than explicit tests of structural relationships such as the NKPC. Using SPF forecasts, the authors estimate three different models of inflation and

[11] No explicitly forward-looking model is considered. The authors note that some of their richer Phillips curve specifications with term structure data should provide a close reduced-form approximation to a forward-looking relationship.

expectation dynamics: an unobserved components model, a small VAR model with stochastic volatility and a larger VAR model. They find that long-term expectations play a dominant role in the dynamics of both actual inflation and short-run expectations. However, expectations seem to have become increasingly anchored.

4.5 Nunes (2010, *JMCB*): "Inflation Dynamics: The Role of Expectations"

The paper estimates hybrid NKPCs that allow simultaneous roles for rational expectations and SPF survey forecasts:

$$\pi_t = \lambda mc_t + \gamma_f E_t \pi_{t+1} + \gamma_s \pi_{t+1}^{SPF} + \gamma_a \pi_{t-1} + u_t.$$

The forecasts are one quarter ahead. Nunes provides a theoretical extension to the Galí and Gertler framework that motivates the above specification, in which rule-of-thumb firms forecast inflation using published surveys. When estimated by GMM on U.S. data, the coefficient on rational expectations dominates, although the survey forecast term is significant for the output gap specification (insignificant in the labor share specification). However, the lagged inflation term is insignificant in most specifications. The forcing variable receives the right sign; it is almost significant at the 95% level for the output gap and insignificant for the labor share. Nunes is aware of the weak instruments problem, which seems to be a real issue for the hybrid specification according to a first-stage F test. An S set approach yields a very large confidence region. The NKPC is also estimated with full information maximum likelihood using a reduced-form VAR for the endogenous variables (in our terminology this is closer to LIML). The point estimates are somewhat different although the qualitative conclusions are the same as under GMM.

4.6 Paloviita (2006, *EmpEc*): "Inflation dynamics in the euro area and the role of expectations"

The author uses annual OECD data and Economic Outlook forecasts to estimate the pure and hybrid NKPCs of (pooled) Euro Area countries, with inflation forecasts substituting for the rational expectations term. The forecasts are found to exhibit possible non-rationality, including biases in subsamples and positively autocorrelated forecast errors. Three different forcing variables are considered: The labor share, HP detrended output and the OECD output gap (based on the production function approach and an estimate of the NAIRU). OLS estimates mostly yield a wrong and very insignificant sign on the forcing variable. GMM estimates, on the other hand, give results that are consistent with the theory, although the forcing variable in the hybrid NKPC is mostly deemed insignificant. The weight on last period's inflation is about 0.6. Estimates on subsamples indicate that the share of forward-looking behavior has increased over time.

4.7 Paloviita and Mayes (2005, *NAJEF*): "The use of real-time information in Phillips-curve relationships for the euro area"

The hybrid NKPC is estimated on annual data for Euro Area countries. Estimation is carried out in a pooled panel setting, using both OLS and GMM. OECD forecasts are used as proxies for expectations, and the authors go to great lengths to discuss and contrast the use of revised and real-time data for both regression equation variables and instruments. Using real-time regression equation variables increases the weight on the forward-looking term slightly, although it gives the

output gap the wrong sign. When one additionally uses real-time data for the instruments, the forward-looking weight substantially *decreases*, while yielding a *positive* and significant output gap coefficient. The pure NKPC is rejected when using real-time data, while the expectations augmented Phillips Curve (i.e., with the forecast $E_{t-1}\pi_t$ replacing the expectation of next period's inflation) receives more empirical support.

4.8 Preston (2005, *IJCB*): "Learning about Monetary Policy Rules when Long-Horizon Expectations Matter"

While the paper is primarily about learning, Preston's results are potentially important for understanding identification issues when using survey expectations in tests of the NKPC. The author points out that the microfoundations of the NKPC do not permit researchers to simply replace the rational expectation of next period's inflation with a survey expectation, if it is believed that inflation forecasts are sub-rational. The reason is that the presence of a *single* forward-looking term in the NKPC rests heavily on properties of rational expectations. It is shown, cf. equation (11), that in the standard Calvo framework inflation dynamics will be

$$\pi_t = \kappa x_t + (1-\alpha)\beta \sum_{j=0}^{\infty} (\alpha\beta)^j \hat{E}_t \pi_{t+j+1} + \alpha\beta\kappa \sum_{j=0}^{\infty} (\alpha\beta)^j \hat{E}_t x_{t+j+1}, \tag{1}$$

in obvious notation (different from Preston's). $\hat{E}_t$ denotes possibly non-rational expectations. The assumptions on expectations is that firms form subjective probabilities, identical across firms, and that the equilibrium relation between marginal cost and the output gap is understood by all. The way in which the above relation reduces to the standard NKPC difference equation under rational expectations is outlined in Section 1.3, and it is emphasized that the law of iterated expectations (at the aggregate level, i.e., averaged over firms) as well as the individual price setters' ability to correctly shift forward the structural inflation equation are the crucial features of rational expectations.[12] Preston does not discuss the implications of equation (1) for studies that use survey expectations without adjusting the NKPC to include additional leads of expected inflation and output gaps (cf. the theoretical derivations in Adam and Padula, 2011).[13]

4.9 Smith (2009, *JEDC*): "Pooling forecasts in linear rational expectations models"

The rational expectations model

$$y_t = \beta E[y_{t+1} \mid \mathcal{F}_t] + \delta' x_t$$

is analyzed in the event that the econometrician has data on survey forecasts $y^s_{t,t+1} = E[y_{t+1} \mid \mathcal{F}^s_t]$, where $\mathcal{F}^s_t \subset \mathcal{F}_t$. If $x_t \in \mathcal{F}^s_t$, Smith's Proposition and Corollary on pp. 1860-61 show that the economic parameters (β, δ) along with the auxiliary parameter m in the expanded regression

$$y_t = \beta[(1-m)y^s_{t,t+1} + m y_{t+1}] + \delta' x_t + \text{error}_t$$

[12] Angeletos and La'O (2009) derive a relation similar to (1) and note that if firms have private information about shocks, the aggregate law of iterated expectations will break down. They provide three different models in which heterogenous information generates significant inflation inertia in the face of shocks to nominal demand.

[13] It is perhaps also of note that equation (1) looks a lot like Cogley and Sbordone's (2008) NKPC under trend inflation. Cf. also the sticky information Phillips curve of Mankiw and Reis (2002), which includes an infinite sum of discounted *past* forecasts of *current* economic conditions rather than *current* forecasts of *future* conditions.

may be estimated consistently *by OLS*, and with greater efficiency than the specification imposing $m = 0$. The proof is a straight-forward application of the Frisch-Waugh Theorem. In other words, pooling forecasts and rational expectations when estimating the NKPC is meaningful from a purely statistical standpoint, even if one doesn't believe the economic rationale of Nunes (2010). Smith estimates the hybrid NKPC on U.S. data using one-quarter-ahead SPF forecasts and concludes that 70% weight is put on forward-looking terms, with about 40% of that weight attributed to survey forecasts (this latter share is estimated rather precisely). The labor share is insignificant but gets a positive coefficient.

4.10 Zhang, Osborn and Kim (2008, *JMCB*): "The New Keynesian Phillips Curve: From Sticky Inflation to Sticky Prices"

The authors rigorously and exhaustively test for structural breaks in the specifications in their 2009 *OBES* paper (which had previously existed as a discussion paper) using the Andrews and Ploberger (1994) procedure. As in the 2009 paper, expectations are proxied by SPF, Greenbook and Michigan survey forecasts, although the rational expectations specification is also considered for robustness. Only the CBO output gap is considered as a forcing variable. Zhang et al. find strong evidence of a structural break in 1981Q1 as well as an (upward) shift in the intercept in 2001Q1. No further breaks appear necessary to fit the data. When the hybrid NKPC is estimated on the pre- and post-1981 subsamples with an intercept shift dummy for 2001, coefficients generally receive the correct signs and the output gap enters significantly for most specifications. Inflation dynamics appear to have changed from being predominantly backward-looking before 1981 to being mostly forward-looking afterwards. The slope of the Phillips curve has decreased over time. Unlike when using survey forecasts, rational expectations estimates favor the forward-looking term in both subsamples and produce insignificant and often negative slope coefficients. Stock and Yogo (2002) generalized F tests are provided for every IV regression.

4.11 Zhang, Osborn and Kim (2009, *OBES*): "Observed Inflation Forecasts and the New Keynesian Phillips Curve"

The authors use one-quarter-ahead SPF, one-quarter-ahead Greenbook and one-year-ahead Michigan survey forecasts for inflation to evaluate the hybrid NKPC on U.S. data. Only HP detrended output and the CBO output gap are considered as forcing variables. Under GMM estimation the output gap almost exclusively gets a correctly signed and significant coefficient. Backward-looking expectations dominate somewhat, but forward-looking expectations are significant statistically and economically. The first-stage generalized F test indicates that weak instruments could be an issue, particularly for Greenbook and Michigan forecasts. Because the residuals are serially correlated, the authors argue that the model ought to be extended to allow for further lags of inflation. They find that inclusion of up to four lags eliminates the residual autocorrelation without qualitatively changing the conclusions regarding the output gap or the split between forward- and backward-looking behavior.

4.12 Other literature

Coibion (2010, *REStat*): "Testing the Sticky Information Phillips Curve." The empirical performance of the Mankiw and Reis (2002) sticky information Phillips Curve (SIPC) is evaluated

relative to the pure NKPC. SPF inflation and output forecasts are used as proxies for expectations (agents are assumed to perfectly forecast CBO's potential output). Estimates of informational and real rigidity in the SIPC specification come out as insignificant, and the model is rejected in non-nested as well as encompassing comparisons to the pure NKPC. The author argues that a key failure of previous literature that has tested the SIPC is that these papers have generated forecasts from VARs that were estimated over the entire sample.

Fuhrer (2012, *IJCB*): "The Role of Expectations in Inflation Dynamics." A number of regression results are presented to disentangle the differing roles of short-run inflation expectations (in the paper these are 1-year SPF expectations), long-run expectations (10-year Greenbook expectations) and the unemployment gap in explaining inflation. First a reduced-form NKPC is estimated by OLS over rolling samples. Then ML estimates of an NKPC difference equation with both VAR expectations and survey forecasts are presented (GMM estimates are also produced but the author dismisses them due to weak instrument problems). The results indicate that one-year expectations are significant, while long-run expectations are not. VAR expectations are mostly insignificant. The restrictions implied by a deviation-from-trend model (with the trend equal to long-run expectations) are rejected. Finally, the author derives restrictions on the process for survey forecasts of inflation by postulating that the usual hybrid difference equation NKPC holds. The model-implied survey forecasts then depend on survey forecasts of the unemployment gap. He proceeds to estimate the derived process for survey forecasts and the inflation equation jointly.

Gerberding (2001, *Bundesbank Discussion Paper*): "The information content of survey data on expected price developments for monetary policy." Gerberding tests the NKPC using Consensus Forecasts as well as qualitative consumer survey measures of inflation expectations for Germany, France and Italy. Her specification includes import price shocks and a moving average of the output gap. OLS and 2SLS regressions generally yield coefficients near unity for future expected inflation, an insignificant lagged inflation term, a marginally significant output gap and a moderately significant role for supply shocks. These results hold for both measures of inflation expectations. Orthogonality tests of the survey expectations suggest that these are not rationally formed and that past inflation carries a very large weight in expectation formation.

Henzel and Wollmershäuser (2008, *EcMod*): "The New Keynesian Phillips curve and the role of expectations: Evidence from the CESifo World Economic Survey." The authors use the CESifo World Economic Survey of transnational and national organizations to test the hybrid NKPC.[14] As the survey responses are qualitative (UP/SAME/DOWN), quantitative inflation expectations are imputed. OLS estimates for France, Germany, Italy, the UK, the U.S. and the Euro Zone indicate about a 50-50 split between forward- and backward-looking price setting behavior on average. The forcing variable (labor share or output gap) is insignificant across specifications. A Hausman test relative to 2SLS (with a weak instruments pretest) cannot reject consistency of OLS. Appendix D provides a table of point estimates of the hybrid NKPC in the literature.

Koop and Onorante (2011, *working paper*): "Estimating Phillips Curves in Turbulent Times using the ECB's Survey of Professional Forecasters." Inflation forecasts from the ECB's Survey of Professional Forecasters is used as a proxy for inflation expectations in the

[14]Following Adam and Padula (2011), the authors derive a hybrid NKPC under non-rational expectations.

Euro Area.[15] Because only about 12 years of quarterly data is available, the authors employ Dynamic Model Averaging to dynamically select the model with the best predictive power in a Bayesian fashion. In a reduced-form NKPC-type regression set-up, the DMA procedure puts about 50-50 weight on the forward- and backward-looking terms until the financial crisis, after which the forward-looking term clearly dominates. The procedure has a hard time discerning between different choices of forcing variables, although the labor share is favored during the early part of the financial crisis. Oil prices, interest rates and asset prices are not selected by DMA in the first half of the sample but become important at various stages during the crisis. The variance of SPF point forecasts turns out to be an insignificant explanatory variable throughout.

Mazumder (2011, *EcMod*): "The empirical validity of the New Keynesian Phillips curve using survey forecasts of inflation." This paper essentially replicates the results of Mazumder (2010) using survey expectations of inflation in the NKPC. Michigan, SPF and Greenbook forecasts for various horizons are considered. The forcing variable is the procyclical adjusted measure of marginal cost from Mazumder (2010). In all specifications this forcing variable receives a negative and significant coefficient, which according to the author presents strong evidence against the pure or hybrid NKPC. Estimation is carried out by both GMM and "optimal instruments" GMM (Fuhrer and Olivei, 2004).

Rudebusch (2002, *EJ*): "Assessing Nominal Income Rules for Monetary Policy with Model and Data Uncertainty." While the paper is mainly concerned with monetary policy rules, it is widely cited in the survey expectations literature, as Rudebusch estimates (by OLS) an NKPC-type relationship using one-year Michigan consumer survey expectations. The weight on the forward-looking term is about one-third that of the backward-looking term (which is a four-quarter moving weighted average). The output gap, which is lagged one period, receives a positive and significant coefficient. Rudebusch goes on to briefly survey the early literature on the empirical properties of the NKPC, highlighting the controversies surrounding the magnitude of the forward-looking parameter.

Thomas (1999, *JEP*): "Survey Measures of Expected U.S. Inflation." The author provides a detailed institutional and quantitative overview of inflation forecasts from the Livingstone, Michigan and SPF surveys. Survey expectations are found to outperform naive random walk and Fisher equation based forecasts. Michigan household forecasts compare well with the professional forecasts from the Livingstone and SPF datasets. All three survey expectations are found to be biased and inefficient. Thomas cautions against indiscriminate use of survey information due to possible lack of incentives for honest reporting and the presence of structural breaks.

5 Expectation anchoring

5.1 Ball and Mazumder (2011, BPEA): "Inflation Dynamics and the Great Recession"

Most of this paper deals with the traditional backward-looking Phillips curve. However, the last part is relevant for this literature review. In Section 5.2 the authors estimate a backward-looking

[15] These forecasts are recorded as distributions over possible outcomes, not just point estimates. Only the latter are used in the paper, however.

Phillips curve with a time-varying weight on the anchored expectation of 2.5% CPI inflation p.a. (as suggested by Mishkin, 2007):

$$\pi_t = \delta_t 2.5 + (1-\delta_t)\tfrac{1}{4}(\pi_{t-1}+\pi_{t-2}+\pi_{t-3}+\pi_{t-4}) + \alpha(u_t - u^*) + \text{error}_t.$$

The time-path of δ_t is estimated using the Kalman smoother. It indicates that inflation expectations anchoring has increased gradually from 0 in the late 1980s to about 0.45 in 2010. This can potentially explain the "missing deflation" during the latest recession. In Section 6 Ball and Mazumder estimate the pure NKPC on subsamples extending up until 2010Q4. They find that the labor share has become increasingly insignificant over time.

5.2 Fuhrer and Olivei (2010, *FRBB Brief*): "The Role of Expectations and Output in the Inflation Process: An Empirical Assessment"

The authors present a number of simulations (based on an estimated small NK model of the economy) illustrating the effects of a shock to the output gap under different public perceptions of the central bank's inflation target and under different degrees of inflation persistence. It is shown that well-anchored expectations can only hinder a large disinflation if the degree of intrinsic inflation persistence is relatively small. Subsequently, a very general regression equation is estimated on rolling 10 year samples:

$$\pi_t = c + \mu_1 \pi_{t-1}^{avg} + \mu_2 E_{t-1}\pi_{t+1} + \mu_3 \pi_t^{S1} + (1-\mu_1-\mu_2-\mu_3)\pi_t^{S10} + \gamma\tilde{y}_t + \delta\Delta\tilde{p}_t^o + \text{error}_t,$$

where π_{t-1}^{avg} is a rolling average of inflation over the previous four quarters, π_t^{S1} is the one-year-ahead SPF forecast of inflation, π_t^{S10} is the 10-year SPF (average) inflation forecast, $\tilde{y}_t$ is the forcing variable (output gap or marginal cost) and $\Delta\tilde{p}_t^o$ is the change in the relative price of oil. Because 10-year inflation expectations have hovered around 2.5% in the past couple of decades, it may be interpreted as a measure of the publicly perceived inflation target. The rational expectation $E_{t-1}\pi_{t+1}$ is computed using a first-stage VAR. Second-stage inference is carried out using standard Bayesian methods to obtain posterior distributions for the parameters. A Cogley and Sbordone (2008) specification with a time-varying trend is also considered. While results differ across measures of inflation and the forcing variable, the authors highlight the following broad conclusions:

- The weight μ_1 on lagged inflation seems to have decreased in the last decade.
- The weight μ_2 on rational expectations is small throughout.
- The weight on the 10-year inflation forecast has risen in the last decade after having been insignificant in previous samples, particularly for PCE inflation.
- When CPI inflation is used, the weight μ_3 on one-year-ahead inflation expectations is substantial.
- The forcing variable generally gets a small but significant coefficient.

Fuhrer and Olivei acknowledge that multicollinearity is likely to be an issue but they don't attempt to elaborate further on this point.

5.3 Sbordone, Tambalotti, Rao and Walsh (2010, *FRBNY EPR*): "Policy Analysis Using DSGE Models: An Introduction"

This educational paper sets up and simulates a three-equation DSGE model with habit formation, interest rate smoothing and no intrinsic inflation persistence. The interest rate policy equation includes an inflation target which moves slowly over time according to an AR(1). It is shown that the small-scale DSGE does well in terms of capturing the second moments of key economic variables, although inflation is a bit too volatile in the simulations. Kalman-smoothed estimates of the inflation target (Chart 3) indicate that it has fallen over time, dipping to about 1% p.a. in 2003 and then rising back up to around 2% p.a. The authors use the rise in the inflation target in 2004 to explain the unexpected and sudden one percentage point jump in inflation during that year: Only the estimated shock to the inflation target falls outside the model's pre-2003 75% forecast bounds. It is shown that without shocks to the target during 2003, the evolution of inflation would have been more subdued. Subsequently, a counterfactual policy exercise is conducted. The authors consider two scenarios in which the Fed stabilizes inflation at 1.6% through 2004:

1. "No-communication strategy:" The Fed achieves the adjustment in inflation by appropriately shocking the interest rate rule, i.e., the otherwise i.i.d. shocks are chosen so as to engineer the desired inflation path. Because monetary policy shocks don't change inflation expectations from their historical level, the inflation adjustment must happen through the nominal interest rate and so is rather volatile and comes at a large cost to the real economy.

2. "Full-communication strategy:" The Fed adjusts inflation by shocking the inflation target, i.e. by picking an appropriate series of shocks to the AR(1) process. Due to the persistence in the inflation target, these shocks affect agents' expectations greatly, meaning that the evolution of inflation can be achieved smoothly and with comparatively small real effects.

5.4 Other literature

Canova and Gambetti (2010, *AEJ:M2*): "Do Expectations Matter? The Great Moderation Revisited." The authors seek to evaluate the "bad policy" explanation of the Great Moderation, i.e., that improved policy after the mid-1980s got the U.S. economy out of an indeterminate equilibrium. In an indeterminate equilibrium, an extra sunspot shock variable will enter into the model solution. Since this shock creates a wedge between the dynamics of economic variables y_t and the underlying fundamental shocks e_t, past expectations $E_{t-1}y_t$ become useful in predicting the future evolution of y_t. Under determinacy, instead, lags of y_t are sufficient to predict the future, and past expectations offer no additional forecasting power. Furthermore, due to the extra sunspot shock, if a researcher inspects forecast errors from simple VAR regressions, they will tend to have a larger variance in the indeterminate region even if the variance of fundamental shocks stays constant; this may explain results that some researchers have produced. Canova and Gambetti estimate reduced-form VAR models of key economic variables, using lagged survey expectations (Michigan, SPF, Livingstone and Greenbook) as additional regressors. The data shows no clear difference in the importance of past expectations over time, which suggests that the "bad policy" explanation is insufficient.

Kohn (2010, *Carleton University speech*): "The Federal Reserve's Policy Actions during the Financial Crisis and Lessons for the Future". Kohn prominently mentions expec-

tations anchoring as having been a primary objective and useful tool for the Fed during the recent crisis.

Mishkin (2007, *IntFin*): "Inflation Dynamics." Mishkin sums up a few stylized facts about changes in U.S. inflation dynamics, seen from the perspective of the Fed. He discusses the literature on the flattening of the Phillips curve as well as the decrease in inflation persistence since the 1970s and 1980s. To explain these two phenomena he makes the case, mostly informally, that inflation expectations have become more anchored in the past two decades to a level around 2% PCE inflation p.a. Policy and forecasting implications are outlined.

Williams (2006, *FRBSF EL*): "Inflation Persistence in an Era of Well-Anchored Inflation Expectations." In a short note, Williams uses rolling autoregressions to argue that inflation persistence has decreased markedly in the past 15 years. Citing a few theoretical papers as well as the historical analysis in Ball (2000), he concludes that this change is primarily due to expectations anchoring stemming from a shift in monetary policy.

6 Trend inflation

6.1 Ascari (2004, *RED*): "Staggered prices and trend inflation: some nuisances"

The author investigates what happens to the standard NK model with Calvo price setting when the steady state rate of inflation is positive. First, it is shown through calibrations that steady state output depends dramatically on the steady state rate of money growth. Furthermore, the impulse response function to a money growth shock has markedly different profiles for different values of steady state inflation. When the aggregate Calvo price setting equation is log-linearized around a non-zero trend inflation rate, extra terms must be added to the zero-inflation-steady-state NKPC, and trend inflation enters the coefficient on marginal cost. The Taylor model of staggered contracts isn't nearly as sensitive to the level of trend inflation. Also, the indexation extension to the Calvo model suggested by Christiano et al. (2005) cancels out any positive rate of steady state inflation, so that their hybrid NKPC may simply be written in terms of deviations of inflation from trend.

6.2 Barnes, Gumbau-Brisa, Lie and Olivei (2011, *working paper*): "Estimation of Forward-Looking Relationships in Closed Form: An Application to the New Keynesian Phillips Curve"

This paper touches upon the issue raised by Sbordone (2005) of the econometric differences between imposing parameter restrictions from the one-quarter-ahead NKPC versus imposing those from a fully solved forward NKPC. Barnes et al. refer to the first specification as the "difference equation" (DE) approach and of the other as the "closed-form" (CF) approach. The DE restrictions do not impose the NKPC structure on expectations of next period's inflation, unlike the CF restrictions. Of course, if the coefficient matrix A for the first-stage VAR were known and the model were correct, the two approaches would lead to the same parameter estimates. However, since in practice A must be estimated, the authors argue that the CF approach—with its additional structure on expectations—is more efficient (no theoretical derivations of the efficiency gain are provided). The algebraic relationships between the DE and CF restrictions are outlined, and it is shown that the minimum distance criterion function under the CF specification is essentially a weighted version of

the DE criterion function. A variety of Monte Carlo exercises indicate that the CF estimates are better centered and more precise.

The CF method is applied to the NKPC with trend inflation to investigate the robustness of the results obtained by Cogley and Sbordone (2008). Unlike the latter authors, Barnes et al. allow for two periods of indexation instead of one in their extended NKPC. Apart from the fact that parameter restrictions are written in the CF version, the estimation procedure and data are the same. With the new specification, it is found that indexation is now significant and two lags of inflation are necessary to properly account for it. The median Calvo parameter estimate is more than 50% higher than that obtained by Cogley and Sbordone.

6.3 Cogley and Sbordone (2008, *AER*): "Trend Inflation, Indexation, and Inflation Persistence in the New Keynesian Phillips Curve"

The pure Calvo price setting equation is log-linearized around a steady state with trend inflation evolving as a driftless random walk.[16] It is assumed that non-reoptimizing firms partially index their prices to past inflation (this degree of partial indexation is later estimated). The modified NKPC, their equation (8), is

$$\hat{\pi}_t = \tilde{\rho}_t(\hat{\pi}_{t-1} - \hat{g}_t^{\bar{\pi}}) + \zeta_t \widehat{mc}_t + b_{1t}\tilde{E}_t\hat{\pi}_{t+1} + b_{2t}\tilde{E}_t \sum_{j=2}^{\infty} \varphi_{1t}^{j-1}\hat{\pi}_{t+j} + b_{3t}\tilde{E}_t \sum_{j=0}^{\infty} \varphi_{1t}^{j}(\hat{Q}_{t+j,t+j+1} + \hat{g}_{t+j+1}^{y}) + u_t,$$

where hats denote deviations from steady state, $g_t^{\bar{\pi}}$ and g_t^y are the gross growth rate of trend inflation and output, respectively, Q_t is a stochastic discount factor, $\tilde{E}_t$ denotes somewhat irrational expectations[17] and the error term u_t is included due to the approximations used in the derivation. The time-varying coefficients depend on the structural model parameters. These are estimated using a complicated two-step, semi-Bayesian MCMC procedure. First a reduced-form VAR in inflation, log marginal cost, output growth and the nominal discount factor with drifting (random walk) parameters and stochastic volatility is estimated in a Bayesian fashion, with the prior generated from a training sample. Trend inflation at date t is defined as the "local mean" for inflation, computed using the coefficient matrix at date t for the companion form of the VAR. In the second stage, for a given path of reduced-form VAR parameters, structural parameters are chosen to best fit the quadratic distance between the expected inflation gap implied by the reduced form and the gap implied by the structural NKPC.[18] This generates a pseudo-posterior distribution for the structural parameters (but note that Bayes' rule isn't used in the second step—the authors cite computational difficulties).

The computed trend inflation shows a hump-shaped evolution since the 1960s. The authors find that the first autocorrelation of the inflation *gap* is much smaller than that of raw inflation, at least since 1984. The median posterior draw of the partial indexation share parameter is 0. The posterior for the Calvo parameter lines up well with micro-level data. Cogley and Sbordone

[16] "Steady state" is somewhat of a misnomer due to the non-stationarity of trend inflation. The economic situation around which Cogley and Sbordone log-linearize is one in which aggregate inflation coincides with the trend.

[17] Agents are assumed to irrationally expect drifting parameters to remain constant going forward. This allows multiperiod expectations made at time t to be expressed as powers of the VAR coefficient matrix A_t.

[18] Both sides of the trend-inflation NKPC are projected onto past values $z_{t-1} = (x_{t-1}, x_{t-2}, \ldots, x_{t-p+1})$ of the VAR variables. The requirement that equality hold for all values of z_{t-1}, along with a steady state equation, lead to a vector of restrictions $F_t(\mu_t, A_t, \psi) = 0$, conditional on the reduced-form VAR coefficient matrix A_t and mean vector μ_t. Given estimates $\hat{A}_t, \hat{\mu}_t$, $t = 1, \ldots, T$, the structural parameter estimate is $\hat{\psi} = \arg\min_\psi \sum_{t=1}^{T} F_t(\hat{\mu}_t, \hat{A}_t, \psi)' F_t(\hat{\mu}_t, \hat{A}_t, \psi)$.

provide two informal model specification tests. First, they graph the expected inflation implied by the reduced-form VAR and the structural NKPC, respectively. The two time paths are very close. Second, they graph the difference and its confidence band and conclude that 0 is included in the latter for almost all dates. Finally, the authors show the evolution of the reduced-form NKPC parameters. They all have marked hump-shaped paths, which—it is argued—can explain much of the confusion about inflation persistence in the literature.

6.4 Kozicki and Tinsley (2002, *working paper*): "Alternative Sources of the Lag Dynamics of Inflation"

Four different tweaks to the NKPC are presented, each of which can explain the presence of additional lags of inflation in the dynamic equation:

1. If the model is log-linearized around a non-zero steady state rate of inflation, inflation must be measured in deviations from this long-run anchor. The dependence of reduced-form parameters on structural parameters changes. Furthermore, an additional term must be added to the NKPC, although the authors find this term to be negligible.

2. Along the lines of Galí and Gertler (1999), a fraction of the price setters may be irrationally backward-looking.

3. Price setting may be dominated by staggered contracts à la Taylor (1980) or Fuhrer and Moore (1995). This introduces additional lags and leads into the inflation equation, depending on the duration of contracts.

4. Firms may be unwilling to change their prices too much at a time, preferring smoother price paths. Such frictions on price adjustment generate lagged dependence in the inflation dynamics.

Kozicki and Tinsley take these theories to U.S. and Canadian data. The inflation anchor is modeled as a random walk and estimated using the Kalman filter (not smoother).[19] Survey data (SPF forecasts in the U.S.) is used as a proxy for inflation expectations. Estimation is carried out using GMM. It is found that the introduction of a moving nominal anchor is important in explaining inflation persistence, although it doesn't get rid of all the dependence on lagged values. Neither of the Taylor, Fuhrer and Moore or price adjustment friction models outperform the others for both countries.

6.5 Other literature

Bakhshi, Khan, Burriel-Llombart and Rudolf (2007, *JMacro*): "The New Keynesian Phillips curve under trend inflation and strategic complementarity." The authors consider a Calvo model with positive trend inflation. They show that the effects of adding trend inflation to the model depends crucially on the degree of strategic complementarity (i.e., how a firm's optimal price depends on the prices set by other firms). Under standard calibrations and strategic complementarity, firms' optimal price is not defined for levels of trend inflation above 5.5%, since their implicit discount factor exceeds unity (Ascari, 2004, had derived a much higher

[19] When used in later estimation, the Kalman filtered series is spliced with long-horizon survey expectations to expand the sample relative to just using the latter.

threshold due to an implicit assumption of strategic *substitutability*). Furthermore, the slope of the Phillips curve will tend to decrease with the level of trend inflation, which runs counter to stylized facts about inflation. The authors suggest modifying the Calvo framework to allow the probability of price resetting to depend positively on trend inflation.

Gumbau-Brisa, Lie and Olivei (2011, *working paper*): "A Response to Cogley and Sbordone's Comment on *Closed-Form Estimates of the New Keynesian Phillips Curve with Time-Varying Trend Inflation.*" The authors elaborate on the critique in Barnes et al. (2011) of Cogley and Sbordone's (2008) empirical method. Cogley and Sbordone had claimed that their difference equation (DE) specification provided more robust inference than a fully solved-forward closed-form (CF) specification. However, Gumbau-Brisa et al. demonstrate that the conditions required for the CF specification to hold are precisely those needed to ensure determinacy of the inflation equation and thus validity of the expectation rule implied by the VAR. Furthermore, they present evidence that the Barnes et al. model outperforms the Cogley and Sbordone specification in terms of goodness of fit.

Hornstein (2007, *FRBR EQ*): "Evolving Inflation Dynamics and the New Keynesian Phillips Curve." Fuhrer's (2006) analysis of inflation dynamics under the hybrid NKPC is extended to allow for time-varying trend inflation. A different parameterization of the model is used to arrive at a simpler NKPC under non-zero trend inflation than that presented in Kozicki and Tinsley (2002) (which is essentially the same as in Ascari, 2004, and Cogley and Sbordone, 2008). It is found that, as with the baseline hybrid NKPC, the extended model's implied auto- and cross-correlations of inflation and marginal cost are largely counterfactual for sensible calibrations.

Kim and Kim (2008, *SNDE*): "Is the Backward-Looking Component Important in a New Keynesian Phillips Curve?" The authors argue that structural breaks in the trend rate of inflation generate spuriously large estimates of the coefficient on backward-looking behavior in the hybrid NKPC. They set up a model consisting of (1) a hybrid NKPC with survey expectations, a trend inflation term and coefficients undergoing regime shifts, as well as (2) two equations relating the output gap and survey expectations to a set of instruments.[20] It is shown how to arrive at a likelihood function to which the Hamilton (1989) filter may be applied, while accounting for endogeneity of survey expectations and the output gap. The empirical implementation on U.S. data (using SPF forecasts) finds evidence of two structural breaks (1974Q4 and 1982Q2). Neither the backward-looking term nor the output gap is significant when allowing for two breaks.

Kim and Manopimoke (2011, *working paper*): "Trend Inflation and the New Keynesian Phillips Curve." A bivariate unobserved components model of inflation and the output gap is estimated. The measurement equation is consistent with a hybrid NKPC with stochastic (random walk) trend inflation, while the output gap is assumed to follow an exogenous AR(2) process. An alternative specification in which the output gap is unobserved and actual output enters the measurement equation instead is also considered. Two known structural breaks for output and unknown regime-shifts for inflation are taken into account. The estimate of the slope of the NKPC is positive but tiny. The data indicates that structural breaks in the inflation process took place in 1971 and 1980. Between these two break years intrinsic inflation persistence was high, while it was insignificant before and after. The filtered value of the unobserved output gap in the second model

[20]The Phillips curve-type relation is not derived from explicit log-linearization of optimality conditions, unlike in Kozicki and Tinsley (2002) or related papers. Instead, trend inflation enters as an intercept subject to regime shifts.

conforms well with the official CBO gap. The pseudo-out-of-sample forecasting abilities of the two bivariate unobserved component models are compared to those of the Atkeson and Ohanian (2001) benchmark and a univariate unobserved components model for inflation. Neither of the models significantly outperform the others over the full sample, but the bivariate ones come out on top in the subsample starting in 2001.

Sahuc (2006, *EL*): "Partial indexation, trend inflation, and the hybrid Phillips curve." The author derives an NKPC with partial indexation (as in Smets and Wouters, 2003) and positive trend inflation. Confirming the results of Ascari (2004), it is found in numerical examples that if one neglects the influence of trend inflation on the NKPC, the estimate of the indexation parameter will be biased upwards. However, this bias decreases with the degree of partial indexation. The author concludes that estimates of the hybrid NKPC are more robust to omission of trend inflation than estimates of the pure NKPC, due to the lagged inflation term picking up part of the omitted effects.

7 Weak identification

7.1 Dufour, Khalaf and Kichian (2006, *JEDC*): "Inflation dynamics and the New Keynesian Phillips Curve: An identification robust econometric analysis"

The introduction discusses the growing literature on weak identification and its relation to the NKPC. The first published paper to do so, the AR statistic is presented in some detail and applied to the data. To improve power, the Kleibergen (2002) K-test is also used as a refinement of the AR procedure (Dufour et al. interpret it as a method for optimally selecting instruments). In the empirical implementation, the labor share is used as the forcing variable. Both U.S. and Canadian data are considered, and the authors test both the rational expectations version of the NKPC as well as a version with survey forecasts substituting for inflation expectations. Hodges-Lehman point estimates are provided. The U.S. rational expectations robust confidence region is large but the point estimate is in favor of substantial forward-looking behavior. The U.S. survey forecast confidence region is empty. For Canadian data these results are reversed but the non-empty survey forecast confidence region only contains implausible parameter values. Two-dimensional confidence regions for the forward- and backward-looking parameters are drawn (for U.S. data), and they indicate that the sum of these coefficients are well identified as being about 1.

7.2 Fuhrer and Olivei (2004, *working paper*): "Estimating Forward-Looking Euler Equations with GMM Estimators: An Optimal Instruments Approach"

The authors argue that conventional GMM estimates of the hybrid NKPC (and output Euler equation) exhibit small-sample bias due to weak identification. They recommend using an "optimal instruments" approach to strengthen identification:

1. Estimate a reduced form VAR for the forcing variable(s) via OLS.

2. Plug this reduced form along with the structural inflation equation into the AIM algorithm (Anderson and Moore, 1985) to compute the closed form solution for inflation.

3. Based on the above, calculate the implied optimal forecast for inflation and the output gap given the date-t information set.

4. Use these optimal forecasts as instruments for just-identified GMM estimation of the hybrid NKPC.

Monte Carlo evidence (based on a model in which a true finite-order reduced form VAR exists) suggests that conventional GMM exhibits small-sample bias, whereas ML and "optimal instruments" GMM are much more accurate. The first-stage generalized F statistic for "optimal instruments" GMM easily clears the bar except when the weight on the forward-looking term in the data-generating NKPC is small (no d.f. correction is made by the authors). Applying the method to U.S. data, Fuhrer and Olivei find that—in contrast to conventional GMM—ML and "optimal instruments" GMM agree on putting a smaller weight on future inflation expectations, while the forcing variable (output gap or labor share) coefficient has the right sign and is significant. The weight on the forward-looking term is much higher for the labor share (∼.45) specification than when using the output gap (∼0.20).

7.3 Kapetanios, Khalaf and Marcellino (2011, *working paper*): "Factor based identification-robust inference in IV regressions"

The authors extend the results of Kapetanios and Marcellino (2010) to develop identification-robust IV tests based on first-stage principal components estimation of the instruments. They build on three identification-robust procedures: the AR statistic, the Kleibergen (2002) K-test and the Moreira (2003) conditional LR test. Efficiently distilling all available information into a few factor-based instruments before applying the robust tests has two advantages, it is argued: It increases degrees of freedom and thus power, and it deals with the omitted-instruments problem associated with the Kleibergen and Moreira tests. Asymptotic theory for the three principal-component-augmented identification-robust tests is stated for the linear case under the assumption that the number of candidate instruments (from which the principal components are extracted) increases sufficiently fast with the sample size. If the factor structure is weak, such that the explanatory power of the factors decreases with the sample size at some rate, the number of candidate instruments must increase at a faster rate.

Monte Carlo evidence indicates that the factor-augmented identification-robust tests have better size and power properties than their conventional counterparts, especially for the Kleibergen and Moreira tests in the case of omitted instruments. However, when instruments are weak, all tests have low power. In an empirical application, the hybrid NKPC is tested under three different specifications (two structural and one reduced form). The authors use *monthly* U.S. data taken from Stock and Watson (2005); the labor share is interpolated. For two of the three specifications, the projection-based confidence interval for the slope coefficient shrinks substantially with the introduction of factor-based instruments (but in the "wrong" direction, i.e. fewer large values are included in the interval). The parameters that govern forward- and backward-looking behavior remain entirely unidentified.

7.4 Kleibergen and Mavroeidis (2009, *JBES*): "Weak Instrument Robust Tests in GMM and the New Keynesian Phillips Curve"

The paper provides a concise overview of weak identification issues as they relate to the NKPC.[21] Kleibergen and Mavroeidis start out by summarizing the (generic) identification and weak ID analysis of Mavroeidis (2005). Four weak ID tests are then presented and motivated: The Stock and Wright (2000) S test, the KLM and JKLM tests of Kleibergen (2005), and MQLR, a GMM extension of Moreira's 2003 CLR test developed by Kleibergen (2005). A theoretical contribution of the paper is to provide asymptotic theory for subset versions of these tests (i.e., where nuisance parameters are concentrated out). The authors argue theoretically and through simulations that these subset tests are more powerful than projection-based approaches, leading to more informative confidence regions for the parameters of interest. Citing the Lucas critique as motivation, Kleibergen and Mavroeidis also review available tests of the stability over time of the NKPC parameters. Extensive simulations, with a two-equation New Keynesian model as DGP, are carried out to gauge the properties of the various weak ID robust tests; the MQLR statistic is found to be most powerful. A weak ID robust empirical assessment of the NKPC on U.S. data is then undertaken. The authors plot one- and two-dimensional confidence sets for the four tests, while going into some detail about choice of instruments and HAC estimator. Their conclusion is that the NKPC is weakly identified and relatively flat, whether it is estimated in semistructural or structural form. Inflation dynamics appear to be predominantly forward-looking, but they cannot rule out considerable backward-looking behavior. Formal structural break tests are inconclusive about the presence of breaks in the data, as the answer depends on assumptions about identification. Subsample point estimates before and after 1984 do, however, indicate that the slope of the NKPC has been reduced dramatically, which Kleibergen and Mavroeidis interpret as being one of the causes of the pervasive weak identification.

7.5 Ma (2002, *EL*): "GMM estimation of the new Phillips curve"

Ma makes two observations that calls the GMM results of Galí and Gertler (1999) into question. First, the structural parameters β (discount factor) and θ (Calvo parameter) in the pure NKPC aren't identified, as any pair (β, θ) is observationally equivalent to $(\beta, (\beta\theta)^{-1})$ (a similar issue arises with the hybrid NKPC). Since conventional GMM doesn't take this special structure of the objective function into account, confidence regions are invalid. Second, Galí and Gertler's instruments are likely to be weak. The 90% S-set (Stock and Wright, 2000) covers the entire unit cube parameter set for β, θ and ω (the fraction of backward-looking price setters).

7.6 Magnusson and Mavroeidis (2010, *JMCB*): "Identification-Robust Minimum Distance Estimation of the New Keynesian Phillips Curve"

Weak identification robust versions of the Sbordone (2002, 2005) VAR-MD tests are developed for use in estimation of the NKPC. Building on a separate paper by Magnusson, the authors demonstrate that in a minimum distance framework, weak identification obtains when the derivative of the distance function with respect to the structural parameters is nearly of reduced rank (this reduces to the usual weak IV analysis when the distance function is an IV moment function). Intuition

[21] The same issue of the *JBES* includes very interesting comments from several authors discussing Kleibergen and Mavroeidis' analysis.

for the failure of standard first-order asymptotics is provided through an analytic example. MD analogs of the Anderson-Rubin and Kleibergen (2005) tests are developed and their robustness to weak ID asymptotics is proved. Magnusson and Mavroeidis emphasize that VAR-MD exploits more restrictions than GMM when proxying for the expectation term in the NKPC: GMM projects next period's inflation directly on lagged variables, whereas VAR-MD proxies the expectation with the VAR-implied forecast. This distinction is akin to the difference between direct and iterative multistep time series forecasts. Consistent with this, simulations show that the robust VAR-MD tests are more powerful than corresponding robust GMM tests when the finite-order VAR is correctly specified. Using U.S. data from 1984 to 2008 and a labor share specification, the authors find that robust VAR-MD yields substantially smaller confidence regions for the structural NKPC parameters than robust GMM. The indexation parameter is fairly narrowly bounded between 0.3 and 0.5 at the 90% level. However, the confidence regions include values for the Calvo parameter from 0.8 to 1.0, indicating that the mean price duration remains weakly identified.

7.7 Martins and Gabriel (2009, *JMacro*): "New Keynesian Phillips Curves and potential identification failures: A Generalized Empirical Likelihood analysis"

Martins and Gabriel use Generalized Empirical Likelihood (GEL) moment condition analysis—specifically continuous updating (CUE), empirical likelihood (EL) and exponential tilting (ET)—to evaluate the empirical validity of the hybrid NKPC on U.S. data. Since GEL inference, unlike two-step GMM, is invariant to the normalization of the IV moment conditions, the authors argue that this procedure provides a more agnostic test of the hybrid theory. Results using standard asymptotic confidence intervals deliver point estimates in line with two-step GMM but bring into question the significance of marginal cost (proxied by the labor share), particularly if the data set is updated from that of Galí and Gertler (1999) to include quarters up to 2006Q4. To address concerns about weak instruments, Martins and Gabriel provide identification robust confidence regions in the form of the Kleibergen (2005) combined J-K tests as well as the GEL-based LM test introduced by Guggenberger and Smith (2008). The two-dimensional 90% confidence regions for the deep parameters θ (Calvo parameter) and ω (share of backward-looking firms) are very large for both identification robust procedures. When the strongly identified θ is partialed out to tighten inference, the robust confidence intervals for ω are still unreasonably wide. The CUE, EL and ET implementations all deliver similar results. The authors interpret their work as casting doubt on the empirical validity of the hybrid NKPC and as contradicting the identification robust findings of Dufour et al. (2006).

7.8 Mavroeidis (2004, *OBES*): "Weak Identification of Forward-looking Models in Monetary Economics"

This paper provides a structural weak identification analysis similar to, but more theoretically explicated than, Mavroeidis (2005). The first section is a primer on weak identification. Mavroeidis then specializes the analysis to forward-looking macro models estimated by GMM, particularly the NKPC and the Taylor rule. Conditions for generic identification are given (cf. also Mavroeidis, 2005). Moving on to empirical identification, a simple analytic NKPC example illustrates the role of the concentration parameter as well as its determinants: the existence of higher-order dynamics in the forcing variable and the relative magnitudes of unpredictable and predictable (by

the instruments) variation in inflation. A plug-in estimate of the analytic concentration parameter gives a very small value. Since weak identification cannot be ruled out *a priori*, the author advises researchers to use weak identification robust estimation procedures.

7.9 Mavroeidis (2005, *JMCB*): "Identification Issues in Forward-Looking Models Estimated by GMM, with an Application to the Phillips Curve"

A careful discussion of determinacy, generic identification and the strength of empirical (GMM) identification of the parameters in the hybrid NKPC is undertaken. The analysis is based on a complete but general joint model of inflation and the forcing variable. Possible rational expectations solutions (forward/backward and determinate/indeterminate) are described. Applying the analysis of Pesaran (1987), the paper gives conditions for identification of the structural parameters. It is shown that generic identification relies on the existence of higher-order dynamics in the forcing variable. An F-test of exclusion restrictions indicates that the necessary higher-order dynamics for identification are not present in U.S. data. Mavroeidis goes on to discuss weak identification, which may obtain even if identification holds. Analytic and numerical examples illustrate the determinants of the concentration parameter in the NKPC case. Simulations show the severe bias and size distortions created by weak identification. Strikingly, the simulated distribution of the GMM estimator is more or less invariant to whether the true model is completely backward-looking or predominantly forward-looking; the estimated forward-looking parameter tends to dominate the backward-looking one regardless of the true model. Contrary to the preceding analysis, a reduced-rank pretest suggests that the model is not weakly identified. The author explains this finding, using an analytic example, with omitted dynamics in the NKPC. Simulations show that the reason why the Hansen J-test does not detect misspecification is due to low finite-sample power. This may be ameliorated by using a model-consistent MA covariance estimator rather than the standard Newey-West HAC estimator with long lags.

7.10 Nason and Smith (2008*a*, *JAE'metrics*): "Identifying the New Keynesian Phillips Curve"

The authors make a number of observations that underscore the difficulty in obtaining enough relevant instruments in estimation of the hybrid NKPC. In particular, they emphasize the need for higher-order dynamics in the forcing variable.[22] They further show that if the economy follows a structural three-equation NK model, identification must rely on cross-equation restrictions, as neither shock persistence nor interest-rate smoothing provides identification in single-equation estimation. Given these theoretical results, Nason and Smith provide identification robust tests of the U.S., UK and Canadian labor share NKPCs, using both the AR statistic (an idea that was conceived of independently of Dufour et al., 2006) as well as the Guggenberger and Smith (2008) Empirical Likelihood based LM test. In contrast with traditional GMM estimates, the two identification robust tests firmly reject the forward-looking NKPC for all three countries.

[22] This was first established by Pesaran (1981, Prop. 2). Mavroeidis (2005) and Kleibergen and Mavroeidis (2009) provide further details.

7.11 Other literature

Canova and Sala (2009, *JME*): "Back to square one: Identification issues in DSGE models." The authors discuss identification issues in DSGE models, focusing on the case where parameters are estimated by impulse response matching (minimum distance). Non- and weak identification are illustrated analytically and numerically.

Choi and Escanciano (2010, *working paper*): "Exploiting Nonlinear Dependence to Identify and Estimate the New Keynesian Phillips Curve." This paper, which is marked as preliminary and incomplete, is a chapter in Choi's dissertation. The authors suggest an identification strategy that may be better suited to extracting all available information from the instrument set, thus getting around the weak identification problem in linear GMM. In addition, the approach gets rid of the arbitrary selection of instrument lag lengths. The main insight is to exploit the equivalence between the (infinitely many and nonlinear) restrictions

$$E[\varepsilon_t(\beta) \mid Z_{t-j}] = 0 \quad \text{for all } j \geq 1 \tag{2}$$

and

$$\gamma_t(x) := E[\varepsilon_t(\beta) \exp(ix'Z_{t-j})] = 0 \quad \text{for all } x \in \Pi \subset \mathbb{R}^d \text{ and } j \geq 1. \tag{3}$$

The authors construct a Kolmogorov-Smirnov-type test based on a weighted sum of the sample analog of $\gamma_t(\cdot)$. As the test statistic is not a pivot, confidence intervals must be bootstrapped. Choi and Escanciano suggest a two-step procedure to test the NKPC. First they give necessary and sufficient conditions for identification of model parameters and write these in the form (2), which may then be tested as discussed above. If the null of no identification is rejected, the parameters are estimated by a Generalized Spectral Estimator (GSE), which is based on a Fourier-type transformation of the regression equation along the lines of (3). The GSE may be interpreted as a generalization of Hannan's frequency domain regression. Asymptotic theory is provided for the GSE. The authors' empirical results indicate that the GSE method yields confidence sets that are tighter and more stable across specifications than AR.

Fuhrer and Rudebusch (2004, *JME*): "Estimating the Euler equation for output." While the paper primarily deals with the Euler equation for output, the results in Section 4 are relevant for understanding estimation of the NKPC. The authors conduct Monte Carlo simulations of the dynamic IS curve and document a clear tendency for GMM estimates of the forward-looking parameter to be biased toward 0.5 in small samples. They attribute the finding to weakness of the instruments and show that ML or an "optimal instruments" approach (Fuhrer and Olivei, 2004) mitigates the problem.

Kapetanios and Marcellino (2010, *CSDA*): "Factor-GMM estimation with large sets of possibly weak instruments." The paper develops asymptotic theory for a GMM procedure in which instruments are constructed from a large set of candidates by principal components. This Factor-IV estimator is shown to be consistent and asymptotically normal, provided that the number of candidate instruments increases sufficiently fast with the sample size. Factor-based instruments are proposed as a method for dealing with weak instruments, as they efficiently summarize the available information. The authors state necessary conditions on the convergence rates of the number of candidate instruments and the weakness of instruments to ensure asymptotic normality of

the Factor-IV estimator.[23] The authors also consider settings in which the explanatory power of the estimated factors decreases with the sample size (weak factors). A weak factor robust information criterion for selecting the number of factors is introduced. The IV framework is generalized to GMM. Monte Carlo simulations suggest that the Factor-GMM approach often offers efficiency improvements. Factor-GMM estimates of the hybrid NKPC (and, separately, a Taylor rule) on *monthly* U.S. data are presented. Point estimates are close to standard GMM estimates but the confidence intervals are smaller, particularly if the set of candidate instruments is narrowed down in a pretest of their correlation with inflation.

8 Miscellaneous econometric issues

8.1 Fanelli (2008, *OBES*): "Testing the New Keynesian Phillips Curve Through Vector Autoregressive Models: Results from the Euro Area"

Traditional tests of the NKPC are criticized for not accounting properly for possible non-stationarity of the variables. To allow for I(1) behavior and cointegration, and to improve the finite-sample performance when the variables are stationary but highly persistent, Fanelli posits a reduced-form VECM for inflation and the driving variable(s). À la Campbell and Shiller (1987)—and as used by Sbordone (2002, 2005)—he derives cross-equation restrictions implied by the structure of the hybrid NKPC (which here includes an MDS error term) and the VAR conditional expectations. The VECM is subsequently tested on Euro Area data. A cointegrating relationship between inflation and the driving variable is found when using either the labor share or the output gap, suggesting that the previous literature has been too careless when addressing issues of non-stationarity. The NKPC restrictions on the model are strongly rejected for both driving variables. Fanelli notes, however, that the MLE in both cases points to a large share of forward-looking price setting.

8.2 Fukač and Pagan (2010, *JAE'metrics*): "Limited Information Estimation and Evaluation of DSGE Models"

The paper goes into some theoretical and historical detail about the use of full- and limited-information estimation of structural equations, particularly those featuring rational expectations terms.[24] The authors come out in favor of limited-information estimation to counter possible system misspecification. Different meta-strategies for testing are laid out. The handling of permanent components (i.e., time-varying steady states) is considered; the authors argue that "off-model" filters (such as HP) are theoretically unsatisfactory and instead propose a decomposition method for jointly dealing with latent permanent components while staying in a limited-information framework. Finally, the NKPC-type inflation equation of Lubik and Schorfheide (2007) is estimated using three different methods: FIML, LIML with FIML estimates substituted into the reduced-form equations, and straight-up LIML. The influence of the output gap on inflation declines substantially from left to right in this succession of approaches, illustrating the non-triviality of system restrictions.

[23] The weak instrument asymptotic assumptions are non-standard, as the concentration parameter grows with sample size, although at a slower rate.

[24] McCallum (1976) is described as having invented the idea of IV estimation of equations involving rational expectations as explanatory variables. The "optimal instruments" approach of Fuhrer and Olivei (2004) is cast as an application of the idea behind the FIVE estimator of Brundy and Jorgenson (1971). Furthermore, methods used by Sbordone (2006)—a two-equation version of Sbordone (2005)—and Kurmann (2007) are discussed at length.

8.3 Jondeau and Le Bihan (2003, *working paper*): "ML vs GMM Estimates of Hybrid Macroeconomic Models"

The authors seek to reconcile the difference between GMM and ML estimates of the forward-looking parameter γ_f in the hybrid NKPC (in the literature GMM estimates typically point to a larger degree of forward-looking behavior than ML). A number of simple DGPs are considered in order to analyze the difference between reduced-form 2SLS and closed-form ML estimators. First, the authors establish through Monte Carlo simulations that finite-sample bias is unlikely to explain the disparate results in the literature, as weak instruments would imply that GMM should be biased towards OLS, and the latter has a plim for γ_f around 0.5, i.e., the finite-sample bias goes in the wrong direction.[25] Instead it is found, partly analytically, that when the forcing variable is measured with error, the estimates typically satisfy $\hat{\gamma}_f^{ML} < \gamma_f < \hat{\gamma}_f^{GMM}$ (assuming that the instrument set includes both the mismeasured and the true forcing variable). The bias can be substantial for both estimators. When higher-order dynamics in the inflation process are mistakenly omitted from the estimating equation (e.g., when inflation also depends on its second lag but this isn't recognized by the econometrician), GMM exhibits extreme bias, whereas ML generally does a much better job.

The authors estimate an NKPC with three lags of inflation (and a VAR for the output gap) on U.S. data by ML and find that the third lag of inflation is significant; γ_f is estimated at 0.4. They then conduct a Monte Carlo exercise assuming that their estimated VAR is correct. Misspecified hybrid (one-lag) NKPC GMM estimates of γ_f are found to be biased upward, and the distance between the misspecified ML and GMM estimates is almost but not entirely as large as the discrepancies found in the literature.

The published version of this working paper (Jondeau and Le Bihan, 2008, *JE*) focuses less on the NKPC.

8.4 Kurmann (2007, *JEDC*): "VAR-based estimation of Euler equations with an application to New Keynesian pricing"

Kurmann criticizes the existing literature on ML estimation of the NKPC on the grounds that these studies tacitly impose uniqueness of the rational expectations solution without justifying this severe restriction on the parameter space. He considers models of the form

$$y_t = aE[y_{t+1} \mid z_t] + bx_t + u_t, \tag{4}$$

where z_t is a vector of variables generating the agents' information set. The econometrician forecasts expectations with the companion-form VAR $z_t = Mz_{t-1} + v_t$, where $v_t \overset{\text{i.i.d.}}{\sim} N(0, \Sigma)$. As in Sargent (1979), cross-equation restrictions on the reduced-form VAR may be derived by projecting both sides of (4) on z_{t-1} and using the reduced form VAR to compute conditional expectations:

$$e_y M = ae_y M^2 + be_x M, \tag{5}$$

where e_x, e_y are selection vectors.[26] The conventional approach—as used by Sargent (1979) and implicitly by Fuhrer in his papers—is then to solve (5) in terms of the VAR coefficients $m_{y\cdot}$ on y_t. Because (5) is a system of polynomial equations, there are many solutions and so the literature

[25] However, the analysis is limited to 2SLS with at most one overidentifying restriction and so issues of consistent estimation of weight matrices as well as large instrument sets are ignored.

[26] This assumes $E[u_t \mid z_{t-1}] = 0$.

imposes the additional parameter restriction that the rational expectations solution is unique and stable.[27] Having solved for $m_{y.}$ in terms of a, b and other parameters in M, maximization of the likelihood function is then straight-forward. However, Kurmann questions the empirical relevance of the uniqueness assumption and shows with an example that it can lead to serious misestimation. Instead he suggests solving (5) in terms of the coefficients $m_{x.}$ on the forcing variable x_t, as they are always uniquely determined and thus don't require further restrictions on the parameter space.

When applying VAR-based ML estimation to the hybrid NKPC with labor share as the forcing variable (using the Galí and Gertler, 1999, dataset), he finds that the MLE changes drastically depending on whether the conventional tacit uniqueness assumption is imposed. Without this extraneous assumption the forward-looking term clearly dominates and the labor share is significant.[28]

8.5 Lindé (2005, *JME*): "Estimating New-Keynesian Phillips curves: A full information maximum likelihood approach"

The author starts out by rewriting the hybrid NKPC in its exact form (no error term) so that next period's inflation is the LHS variable and the RHS error term is a rational expectations forecast error. He then performs non-linear least squares (NLS) estimation of this specification. The results give extreme weight (>1.3) to forward-looking behavior, regardless of whether the output gap or labor share is used. To explain the discrepancy between GMM and NLS estimates, Lindé conducts a small-sample Monte Carlo exercise with a canonical three-equation NK model. He finds that the single-equation GMM estimate (considering only a just-identified case) of the forward-looking parameter is biased in small samples (the direction depends on specifics), especially if the variables are measured with white-noise error. In the latter case, the NLS estimate is also severely biased. Monte Carlo evidence suggests that a FIML approach—where model-implied expectations are solved for, leading to a likelihood function after some rearrangements of the equations—is much more accurate, even when errors are non-normal. FIML estimates indicate that backward-looking behavior dominates in U.S. inflation dynamics, but the forward-looking term is significant. Furthermore, the output gap coefficient is very significant and has the right sign.

8.6 Nymoen, Swensen and Tveter (2010, *working paper*): "The New Keynesian Phillips Curve: A meta-analysis"

The authors make the case that the finding in the empirical literature that $\gamma_f + \gamma_b \approx 1$ (i.e., that the coefficients on forward- and backward-looking terms in the hybrid NKPC sum to one) invalidates the theory behind the equation since it implies that inflation is non-stationarity (provided one further assumes that marginal cost is strictly exogenous). The closed form rational expectations solution for inflation and the conditions for its stationarity are carefully explained. Since the hybrid NKPC relies on log-linearization around a fixed steady state, it is argued that unit-root behavior of inflation is a serious blow to the New Keynesian framework.

[27] I.e., that the number of generalized eigenvalues with modulus larger than 1 in the structural system equals the number of endogenous variables (Blanchard and Kahn, 1980). See Kurmann's Section 3 for further details. Fuhrer and his coauthors employ the Anderson and Moore (1985) AIM procedure, which automatically imposes stability and uniqueness of the rational expectations solution.

[28] If the output gap is used as the forcing variable, the additional restriction does not change the MLE.

8.7 Sbordone (2005, *JME*): "Do expected future marginal costs drive inflation dynamics"

This paper reinterprets and addresses some of the weaknesses of Sbordone (2002). The author shows that the two-step estimation technique (using a first-step reduced-form VAR) may be interpreted as a test of certain model-implied parameter restrictions, and as such the second-step least-squares estimator is simply an unweighted minimum distance estimator. The GMM approach of Galí and Gertler (1999) may similarly, given that the VAR model is well-specified, be cast as a minimum distance estimator of a related set of parameter restrictions. The two sets of restrictions are not the same, however, as one set is in infinite horizon form, while the GMM set is in single period form. Sbordone shows how uncertainty in the VAR estimation may be incorporated into the confidence region for the second-step parameters using either asymptotics or a bootstrap procedure (the first-step uncertainty was not taken into account in the 2002 paper). Finally, a set of updated empirical results are presented. They broadly confirm conclusions along the lines of Galí and Gertler (1999).

8.8 Other literature

Beyer, Farmer, Henry and Marcellino (2008, *E'metricsJ*): "Factor analysis in a model with rational expectations." The authors discuss the identification issue in the U.S. hybrid NKPC and compare the empirical performance of single-equation versus systems GMM estimation. In the latter case diagnostics tests point to instability in the canonical New Keynesian relationships. To capture any missing pieces in the econometricians information set, Beyer et al. recommend including factors as additional regressors and instruments. Using the J.H. and M.W. (2002) variables, they consider the effect of adding the first six principal components to the systems regression. Some of the factors enter significantly. They lead to decreased standard errors, a correct sign for the output gap and a smaller coefficient on the forward-looking term.

Castle, Doornik, Hendry and Nymoen (2010, *working paper*): "Testing the Invariance of Expectations Models of Inflation." The authors spell out the need to account for breaks when estimating the hybrid NKPC. Their analysis uses the recently developed technique of impulse-indicator saturation, which entails sequentially adding large groups of one-period dummy variables to the regression. When carefully controlling for size, tests of significance of these dummies provide information about location shifts in the model as well as diagnostics tests of the structural equation. Monte Carlo exercises demonstrate that if the econometrician ignores the possibility of location shifts in the forcing variable, the results are likely to spuriously indicate a sizeable degree of forward-looking behavior in the NKPC. The authors apply their procedure to Euro Area and U.S. data. In both cases they find evidence of several break points and need for additional explanatory variables to whiten the residuals. Estimation of the corrected NKPCs on subsamples yield no evidence of forward-looking behavior.

Clark and McCracken (2006, *JMCB*): "The Predictive Content of the Output Gap for Inflation: Resolving In-Sample and Out-of-Sample Evidence." Clark and McCracken analyze the power of out-of-sample tests of inflation forecasting models. They bootstrap DGPs for inflation and the output gap from U.S. data. Simulations show that even if the Phillips curve relationship were completely stable over time, traditional out-of-sample tests based on RMSE are unable to discern between the correct model and an incorrect benchmark AR model. Furthermore,

if the output gap is modeled to undergo a shift, traditional out-of-sample tests of the Phillips curve will tend to prematurely conclude that the relationship breaks down.

Dees, Pesaran, Smith and Smith (2009, *JMCB*): "Identification of New Keynesian Phillips Curves from a Global Perspective." The paper takes a global perspective to overcoming the identification problem in the NKPC as well as accurately measuring steady states. The authors start out by outlining possible identification problems in the standard framework. They then estimate a reduced form global cointegrating VAR (GVAR) encompassing five economic variables for each of 33 countries. Steady states are measured as long-run conditional expectations in a way consistent with the GVAR. Valid instruments for each country are likewise derived using the GVAR. Global information substantially reduces standard errors, and the output gap (measured relative to long-run expectations) gets the correct sign for the largest countries. The U.S. output gap is particularly significant. Forward-looking behavior dominates for all large countries.

Estrella and Fuhrer (2003, *REStat*): "Monetary Policy Shifts and the Stability of Monetary Policy Models." While the paper deals with systems estimation of the New Keynesian model, and so isn't relevant for this survey, Appendix B presents one the clearest available guides to implementing ML estimation of the NKPC based on the Anderson and Moore (1985) AIM procedure (further details are available in Fuhrer et al., 1995, and Fuhrer and Moore, 1995).

Guay and Pelgrin (2005, *working paper*): "The U.S. New Keynesian Phillips Curve: An Empirical Assessment." The sensitivity of NKPC estimates with respect to the GMM method is investigated. Advantages and drawbacks of 2-step GMM and CUE are discussed, with emphasis on higher-order bias and invariance to normalization of the moment conditions. In reference to Hall (2000), the authors recommend demeaning the moment conditions when calculating the HAC covariance matrix (Mavroeidis, 2005, this was also pointed out by). A large portion of the paper is devoted to establishing the time series properties of a new estimator, 3-step GMM, which uses implied probabilities to weight the sample moment conditions. It is shown that this estimator is asymptotically unbiased at an order greater than that of CUE. CUE and 3-step GMM estimates of the U.S. NKPC are presented. The (demeaned) J test rejects the overidentifying restrictions for the original Galí and Gertler (1999) data set and instruments. While the J test doesn't reject on a revised data set, marginal cost is insignificant, and modifications involving adjustment costs or overhead labor are unable to salvage the model. The choice of instrument set is found to be critical throughout.

Harvey (2011, *AFE*): "Modelling the Phillips curve with unobserved components." Harvey estimates an unobserved components (UC) model for inflation, where inflation is a sum of a random-walk trend (core inflation), a cycle, a term containing lags of the output gap and an i.i.d. error. Unlike in Stock and Watson (2007), volatilities are assumed constant. While the baseline model is backward-looking, it is shown under what conditions the equation may be interpreted as forward-looking. For the full sample extending back to 1947 lagged values of the output gap are significant, although since 1986 a good fit is obtained by only using the contemporaneous output gap (which is significant). Harvey concludes that, due to the everchanging nature of core inflation, the UC model provides a more reasonable description of inflation dynamics than simply including lagged values of inflation in hybrid Phillips curves.

Kuester, Müller and Stölting (2009, *EL*): "Is the New Keynesian Phillips curve flat?" Using a canonical New Keynesian DSGE as DGP, the authors show through a Monte Carlo exercise

that GMM estimates of the slope of the NKPC are biased downward when cost-push shocks are autocorrelated. The Hansen J test cannot be relied upon to detect the issue in realistic sample sizes. The bias is large enough to reconcile GMM estimates of the Calvo parameter (which tend to imply an average price duration of more than a year) with micro evidence (which find price durations of about two quarters).

Kurmann (2005, *JME*): "Quantifying the uncertainty about the fit of a new Keynesian pricing model." As informal evidence of the validity of the hybrid NKPC, Galí et al. (2001) provided a plot comparing actual and model-implied inflation over time. The latter series was computed conditional on a bivariate VAR in inflation and the labor share, which was used to generate inflation expectations. Kurmann shows that this Campbell and Shiller (1987) measure of goodness-of-fit depends dramatically on the specification of the reduced-form VAR and on whether the reduced-form coefficients are bootstrap bias corrected. He concludes that the fit of the hybrid NKPC is very difficult to assess based on such procedures.

Nelson and Lee (2007, *JAE'metrics*): "Expectation Horizon and the Phillips Curve: The Solution to an Empirical Puzzle." The authors set up a bivariate UC model of inflation and unemployment in which the unobserved trend inflation and NAIRU evolve as random walks. The cyclical component of inflation is modeled as a distributed lag of the cyclical component of unemployment. This leads to an expectation-augmented PC of the form: $\pi_t = E_t\pi_\infty + \alpha(u_t - u_t^{\text{NAIRU}}) + \varepsilon_t$. Estimation is carried out by the Kalman filter. The authors point out that the model implies a specific form for the NKPC (with unemployment as the forcing variable), in which the slope coefficient depends on the persistence of cyclical unemployment as well as on the forecast horizon for rational expectations. If the former is high, the estimated slope will be small in magnitude. Furthermore, uncertainty about unemployment persistence and the relevant forecast horizon translate into larger standard deviations for the slope in the NKPC. Nelson and Lee believe these observations reconcile the difference in slope estimates for traditional and New Keynesian Phillips curves.

Zhang and Clovis (2010, *JAE'mics*): "The New Keynesian Phillips Curve of Rational Expectations: A Serial Correlation Extension." Zhang and Clovis hold the residual serial correlation for GMM estimates of the U.S. hybrid NKPC against the model. Serial correlation tests are performed as in Godfrey (1994). They also argue that residual serial correlation invalidates the use of lagged inflation as an instrument. Adding three extra lags of inflation to the hybrid NKPC gets rid of the residual serial correlation and delivers a correctly signed and significant coefficient on the output gap (unlike for the labor share). The extension is motivated by positing a richer rule-of-thumb behavior by backward-looking firms.

References

Adam, K. and Padula, M. (2011), 'Inflation dynamics and subjective expectations in the United States', *Economic Inquiry* **49**(1), 13–25.

Altig, D., Christiano, L., Eichenbaum, M. and Linde, J. (2005), 'Firm-Specific Capital, Nominal Rigidities and the Business Cycle', *National Bureau of Economic Research Working Paper Series* (11034).

Anderson, G. and Moore, G. (1985), 'A linear algebraic procedure for solving linear perfect foresight models', *Economics Letters* **17**(3), 247–252.

Andrews, D. W. K. and Ploberger, W. (1994), 'Optimal Tests when a Nuisance Parameter is Present Only Under the Alternative', *Econometrica* **62**(6), 1383–1414.

Ang, A., Bekaert, G. and Wei, M. (2007), 'Do macro variables, asset markets, or surveys forecast inflation better?', *Journal of Monetary Economics* **54**(4), 1163–1212.

Angeletos, G.-M. and La'O, J. (2009), 'Incomplete information, higher-order beliefs and price inertia', *Journal of Monetary Economics* **56**(Supplement), S19–S37.

Ascari, G. (2004), 'Staggered Prices and Trend Inflation: Some Nuisances', *Review of Economic Dynamics* **7**(3), 642–667.

Atkeson, A. and Ohanian, L. E. (2001), 'Are Phillips Curves Useful for Forecasting Inflation?', *Federal Reserve Bank of Minneapolis Quarterly Review* **25**(1), 2–11.

Bakhshi, H., Khan, H., Burriel-Llombart, P. and Rudolf, B. (2007), 'The New Keynesian Phillips curve under trend inflation and strategic complementarity', *Journal of Macroeconomics* **29**(1), 37–59.

Ball, L. (2000), 'Near-Rationality and Inflation in Two Monetary Regimes', *National Bureau of Economic Research Working Paper Series* (7988).

Ball, L. and Mazumder, S. (2011), 'Inflation Dynamics and the Great Recession', *Brookings Papers on Economic Activity* **42**(1), 337–405.

Bårdsen, G., Jansen, E. S. and Nymoen, R. (2004), 'Econometric Evaluation of the New Keynesian Phillips Curve', *Oxford Bulletin of Economics and Statistics* **66**, 671–686.

Barnes, M. L., Gumbau-Brisa, F., Lie, D. and Olivei, G. P. (2011), 'Estimation of Forward-Looking Relationships in Closed Form: An Application to the New Keynesian Phillips Curve', *Federal Reserve Bank of Boston Working Papers* (11-3). June version.

Barth, M. and Ramey, V. (2002), The Cost Channel of Monetary Transmission, *in* B. S. Bernanke and K. Rogoff, eds, 'NBER Macroeconomics Annual 2001', Vol. 16, MIT Press, pp. 199–240.

Batini, N., Jackson, B. and Nickell, S. (2005), 'An open-economy new Keynesian Phillips curve for the U.K.', *Journal of Monetary Economics* **52**(6), 1061–1071.

Benati, L. (2008), 'Investigating Inflation Persistence across Monetary Regimes', *The Quarterly Journal of Economics* **123**(3), 1005.–1060.

Benigno, P. and López-Salido, J. D. (2006), 'Inflation Persistence and Optimal Monetary Policy in the Euro Area', *Journal of Money, Credit and Banking* **38**(3), 587–614.

Bernanke, B. S. (2007), 'Inflation Expectations and Inflation Forecasting'. Speech at the Monetary Economics Workshop of the National Bureau of Economic Research Summer Institute.

Bernanke, B. S. (2008), 'Outstanding Issues in the Analysis of Inflation'. Speech at the Federal Reserve Bank of Boston's 53rd Annual Economic Conference.

Beyer, A., Farmer, R. E. A., Henry, J. and Marcellino, M. (2008), 'Factor analysis in a model with rational expectations', *Econometrics Journal* **11**(2), 271–286.

Blanchard, O. and Galí, J. (2007), 'Real Wage Rigidities and the New Keynesian Model', *Journal of Money, Credit and Banking* **39**, 35–65.

Blanchard, O. and Galí, J. (2010), 'Labor Markets and Monetary Policy: A New Keynesian Model with Unemployment', *American Economic Journal: Macroeconomics* **2**(2), 1–30.

Blanchard, O. J. and Kahn, C. M. (1980), 'The Solution of Linear Difference Models under Rational Expectations', *Econometrica* **48**(5), 1305–1311.

Boug, P., Cappelen, d. and Swensen, A. R. (2010), 'The new Keynesian Phillips curve revisited', *Journal of Economic Dynamics and Control* **34**(5), 858–874.

Brissimis, S. N. and Magginas, N. S. (2008), 'Inflation Forecasts and the New Keynesian Phillips Curve', *International Journal of Central Banking* **4**(2), 1–22.

Brundy, J. M. and Jorgenson, D. W. (1971), 'Efficient Estimation of Simultaneous Equations by Instrumental Variables', *The Review of Economics and Statistics* **53**(3), 207–224.

Byrne, J. P., Kontonikas, A. and Montagnoli, A. (2010), 'International Evidence on the New Keynesian Phillips Curve Using Aggregate and Disaggregate Data'. Working paper, July 9 version.

Calvo, G. A. (1983), 'Staggered prices in a utility-maximizing framework', *Journal of Monetary Economics* **12**(3), 383–398.

Campbell, J. and Shiller, R. (1988), 'The dividend-price ratio and expectations of future dividends and discount factors', *Review of Financial Studies* **1**(3), 195–228.

Campbell, J. Y. and Shiller, R. J. (1987), 'Cointegration and Tests of Present Value Models', *Journal of Political Economy* **95**(5), 1062–1088.

Canova, F. and Gambetti, L. (2010), 'Do Expectations Matter? The Great Moderation Revisited', *American Economic Journal: Macroeconomics* **2**(3), 183–205.

Canova, F. and Sala, L. (2009), 'Back to square one: Identification issues in DSGE models', *Journal of Monetary Economics* **56**(4), 431–449.

Castle, J. L., Doornik, J. A., Hendry, D. F. and Nymoen, R. (2010), 'Testing the Invariance of Expectations Models of Inflation'. Working paper, November 9 version.

Choi, J. and Escanciano, J. C. (2010), 'Exploiting Nonlinear Dependence to Identify and Estimate the New Keynesian Phillips Curve'. Working paper, April 4 version.

Chowdhury, I., Hoffmann, M. and Schabert, A. (2006), 'Inflation dynamics and the cost channel of monetary transmission', *European Economic Review* **50**(4), 995–1016.

Christiano, L. J., Eichenbaum, M. and Evans, C. L. (2005), 'Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy', *Journal of Political Economy* **113**(1), 1–45.

Clark, T. E. and Davig, T. (2008), 'An Empirical Assessment of the Relationships Among Inflation and Short- and Long-Term Expectations', *Federal Reserve Bank of Kansas City Research Working Papers* (08-05).

Clark, T. E. and McCracken, M. W. (2006), 'The Predictive Content of the Output Gap for Inflation: Resolving In-Sample and Out-of-Sample Evidence', *Journal of Money, Credit and Banking* **38**(5), 1127–1148.

Coenen, G., Levin, A. T. and Christoffel, K. (2007), 'Identifying the influences of nominal and real rigidities in aggregate price-setting behavior', *Journal of Monetary Economics* **54**(8), 2439–2466.

Cogley, T. and Sbordone, A. M. (2008), 'Trend Inflation, Indexation, and Inflation Persistence in the New Keynesian Phillips Curve', *American Economic Review* **98**(5), 2101–26.

Coibion, O. (2010), 'Testing the Sticky Information Phillips Curve', *The Review of Economics and Statistics* **92**(1), 87–101.

Dees, S., Pesaran, M. H., Smith, L. V. and Smith, R. P. (2009), 'Identification of New Keynesian Phillips Curves from a Global Perspective', *Journal of Money, Credit and Banking* **41**(7), 1481–1502.

Dennis, R. (2007), 'Fixing the New Keynesian Phillips Curve', *Federal Reserve Bank of San Francisco Economic Letter* (35), 1–3.

Dotsey, M. (2002), 'Pitfalls in interpreting tests of backward-looking pricing in New Keynesian models', *Federal Reserve Bank of Richmond Economic Quarterly* **88/1**, 37–50.

Dufour, J.-M., Khalaf, L. and Kichian, M. (2006), 'Inflation dynamics and the New Keynesian Phillips Curve: An identification robust econometric analysis', *Journal of Economic Dynamics and Control* **30**, 1707–1727.

Dufour, J.-M., Khalaf, L. and Kichian, M. (2010*a*), 'Estimation uncertainty in structural inflation models with real wage rigidities', *Computational Statistics and Data Analysis* **54**(11), 2554–2561.

Dufour, J.-M., Khalaf, L. and Kichian, M. (2010*b*), 'On the precision of Calvo parameter estimates in structural NKPC models', *Journal of Economic Dynamics and Control* **34**(9), 1582–1595.

Dupor, B., Kitamura, T. and Tsuruga, T. (2010), 'Integrating sticky prices and sticky information', *The Review of Economics and Statistics* **92**(3), 657–669.

Eichenbaum, M. and Fisher, J. D. (2004), 'Evaluating the Calvo Model of Sticky Prices', *National Bureau of Economic Research Working Paper Series* (10617).

Eichenbaum, M. and Fisher, J. D. (2007), 'Estimating the frequency of price re-optimization in Calvo-style models', *Journal of Monetary Economics* **54**(7), 2032–2047.

Erceg, C. J. and Levin, A. T. (2003), 'Imperfect credibility and inflation persistence', *Journal of Monetary Economics* **50**(4), 915–944.

Estrella, A. and Fuhrer, J. C. (2002), 'Dynamic Inconsistencies: Counterfactual Implications of a Class of Rational-Expectations Models', *The American Economic Review* **92**(4), 1013–1028.

Estrella, A. and Fuhrer, J. C. (2003), 'Monetary Policy Shifts and the Stability of Monetary Policy Models', *The Review of Economics and Statistics* **85**(1), 94–104.

Fanelli, L. (2008), 'Testing the New Keynesian Phillips Curve Through Vector Autoregressive Models: Results from the Euro Area', *Oxford Bulletin of Economics and Statistics* **70**(1), 53–66.

Faust, J. and Wright, J. H. (2011), 'Forecasting Inflation'. Working paper, June 10 version.

Fuhrer, J. (2006), 'Intrinsic and Inherited Inflation Persistence', *International Journal of Central Banking* **2**(3), 49–86.

Fuhrer, J. (2012), 'The Role of Expectations in Inflation Dynamics', *International Journal of Central Banking* **8**, 137–165.

Fuhrer, J. C., Moore, G. R. and Schuh, S. D. (1995), 'Estimating the linear-quadratic inventory model Maximum likelihood versus generalized method of moments', *Journal of Monetary Economics* **35**(1), 115–157.

Fuhrer, J. C. and Olivei, G. (2004), 'Estimating Forward Looking Euler Equations with Gmm Estimators: An Optimal Instuments Approach', *FRB of Boston Research Paper Series* (04-2).

Fuhrer, J. C. and Olivei, G. P. (2010), 'The Role of Expectations and Output in the Inflation Process: An Empirical Assessment', *Federal Reserve Bank of Boston Public Policy Briefs* (10-2).

Fuhrer, J. C. and Rudebusch, G. D. (2004), 'Estimating the Euler equation for output', *Journal of Monetary Economics* **51**(6), 1133–1153.

Fuhrer, J. and Moore, G. (1995), 'Inflation Persistence', *The Quarterly Journal of Economics* **110**(1), 127–159.

Fukač, M. and Pagan, A. R. (2010), 'Limited information estimation and evaluation of DSGE models', *Journal of Applied Econometrics* **25**(1), 55–70.

Galí, J. and Gertler, M. (1999), 'Inflation dynamics: A structural econometric analysis', *Journal of Monetary Economics* **44**(2), 195–222.

Galí, J., Gertler, M. and López-Salido, J. (2001), 'European inflation dynamics', *European Economic Review* **45**(7), 1237–1270.

Galí, J., Gertler, M. and López-Salido, J. D. (2005), 'Robustness of the estimates of the hybrid New Keynesian Phillips curve', *Journal of Monetary Economics* **52**(6), 1107–1118.

Gerberding, C. (2001), 'The information content of survey data on expected price developments for monetary policy', *Deutsche Bundesbank discussion paper* (9/01).

Gertler, M. and Leahy, J. (2008), 'A Phillips Curve with an *Ss* Foundation', *Journal of Political Economy* **116**(3), 533–572.

Godfrey, L. G. (1994), 'Testing for Serial Correlation by Variable Addition in Dynamic Models Estimated by Instrumental Variables', *The Review of Economics and Statistics* **76**(3), 550–559.

Golosov, M. and Lucas, R. E. (2007), 'Menu Costs and Phillips Curves', *Journal of Political Economy* **115**(2), 171–199.

Gordon, R. J. (2011), 'The History of the Phillips Curve: Consensus and Bifurcation', *Economica* **78**(309), 10–50.

Groen, J. J., Paap, R. and Ravazzolo, F. (2009), 'Real-Time Inflation Forecasting in a Changing World', *FRB of New York Staff Report* (388).

Guay, A. and Pelgrin, F. (2005), 'The U.S. New Keynesian Phillips Curve: An Empirical Assessment'. Working paper, September 7 version.

Guerrieri, L., Gust, C. and López-Salido, J. D. (2010), 'International Competition and Inflation: A New Keynesian Perspective', *American Economic Journal: Macroeconomics* **2**(4), 247–280.

Guggenberger, P. and Smith, R. J. (2008), 'Generalized empirical likelihood tests in time series models with potential identification failure', *Journal of Econometrics* **142**(1), 134–161.

Gumbau-Brisa, F., Lie, D. and Olivei, G. P. (2011), 'A Response to Cogley and Sbordone's Comment on "Closed-Form Estimates of the New Keynesian Phillips Curve with Time-Varying Trend Inflation"', *Federal Reserve Bank of Boston Working Papers* (11-4). June version.

Gwin, C. R. and VanHoose, D. D. (2008), 'Alternative measures of marginal cost and inflation in estimations of new Keynesian inflation dynamics', *Journal of Macroeconomics* **30**(3), 928–940.

Hall, A. R. (2000), 'Covariance Matrix Estimation and the Power of the Overidentifying Restrictions Test', *Econometrica* **68**(6), 1517–1528.

Hamilton, J. D. (1989), 'A New Approach to the Economic Analysis of Nonstationary Time Series and the Business Cycle', *Econometrica* **57**(2), 357–384.

Harvey, A. (2011), 'Modelling the Phillips curve with unobserved components', *Applied Financial Economics* **21**(1–2), 7–17.

Henry, S. G. B. and Pagan, A. R. (2004), 'The Econometrics of the New Keynesian Policy Model: Introduction', *Oxford Bulletin of Economics and Statistics* **66**, 581–607.

Henzel, S. and Wollmershäuser, T. (2008), 'The New Keynesian Phillips curve and the role of expectations: Evidence from the CESifo World Economic Survey', *Economic Modelling* **25**(5), 811–832.

Hornstein, A. (2007), 'Evolving inflation dynamics and the New Keynesian Phillips curve', *Federal Reserve Bank of Richmond Economic Quarterly* **93**(4), 317–339.

J.H., S. and M.W., W. (2002), 'Forecasting Using Principal Components From a Large Number of Predictors', *Journal of the American Statistical Association* **97**, 1167–1179.

Jondeau, E. and Le Bihan, H. (2003), 'ML vs GMM Estimates of Hybrid Macroeconomic Models (With an Application to the New Phillips Curve)', *Banque de France notes d'études et de recherche* (103).

Jondeau, E. and Le Bihan, H. (2008), 'Examining bias in estimators of linear rational expectations models under misspecification', *Journal of Econometrics* **143**(2), 375–395.

Kapetanios, G., Khalaf, L. and Marcellino, M. (2011), 'Factor based identification-robust inference in IV regressions'. Working paper, March 22 version.

Kapetanios, G. and Marcellino, M. (2010), 'Factor-GMM estimation with large sets of possibly weak instruments', *Computational Statistics and Data Analysis* **54**(11), 2655–2675.

Khan, H. and Zhu, Z. (2006), 'Estimates of the Sticky-Information Phillips Curve for the United States', *Journal of Money, Credit and Banking* **38**(1), 195–207.

Kiefer, D. (2010), 'Alternative Phillips Curves Models with Endogenous Real-Time Expectations'. Working paper, January version.

Kiley, M. T. (2007), 'A Quantitative Comparison of Sticky-Price and Sticky-Information Models of Price Setting', *Journal of Money, Credit and Banking* **39**(1), 101–125.

Kim, C.-J. and Kim, Y. (2008), 'Is the Backward-Looking Component Important in a New Keynesian Phillips Curve?', *Studies in Nonlinear Dynamics & Econometrics* **12**. Issue 3, Article 5.

Kim, C.-J. and Manopimoke, P. (2011), 'Trend Inflation and the New Keynesian Phillips Curve'. Working paper, July 11 version.

Kleibergen, F. (2002), 'Pivotal Statistics for Testing Structural Parameters in Instrumental Variables Regression', *Econometrica* **70**(5), 1781–1803.

Kleibergen, F. (2005), 'Testing Parameters in GMM without Assuming That They Are Identified', *Econometrica* **73**(4), 1103–1123.

Kleibergen, F. and Mavroeidis, S. (2009), 'Weak Instrument Robust Tests in GMM and the New Keynesian Phillips Curve', *Journal of Business & Economic Statistics* **27**(3), 293–311.

Kohn, D. L. (2010), 'The Federal Reserve's Policy Actions during the Financial Crisis and Lessons for the Future'. Speech at Carleton University.

Koop, G. and Onorante, L. (2011), 'Estimating Phillips Curves in Turbulent Times using the ECBs Survey of Professional Forecasters'. Working paper, February version.

Korenok, O., Radchenko, S. and Swanson, N. R. (2006), 'International Evidence on the Efficacy of new-Keynesian Models of Inflation Persistence'. Working paper, June version (revised August 2008).

Korenok, O., Radchenko, S. and Swanson, N. R. (2010), 'International evidence on the efficacy of new-Keynesian models of inflation persistence', *Journal of Applied Econometrics* **25**(1), 31–54.

Kozicki, S. and Tinsley, P. (2002), 'Alternative Sources of the Lag Dynamics of Inflation', *Federal Reserve Bank of Kansas City Research Working Paper* (02-12).

Krause, M. U., Lopez-Salido, D. and Lubik, T. A. (2008), 'Inflation dynamics with search frictions: A structural econometric analysis', *Journal of Monetary Economics* **55**(5), 892–916.

Kuester, K., Müller, G. J. and Stölting, S. (2009), 'Is the New Keynesian Phillips curve flat?', *Economics Letters* **103**(1), 39–41.

Kurmann, A. (2005), 'Quantifying the uncertainty about the fit of a new Keynesian pricing model', *Journal of Monetary Economics* **52**(6), 1119–1134.

Kurmann, A. (2007), 'VAR-based estimation of Euler equations with an application to New Keynesian pricing', *Journal of Economic Dynamics and Control* **31**(3), 767–796.

Lawless, M. and Whelan, K. T. (2011), 'Understanding the dynamics of labor shares and inflation', *Journal of Macroeconomics* **33**(2), 121–136.

Lindé, J. (2005), 'Estimating New-Keynesian Phillips curves: A full information maximum likelihood approach', *Journal of Monetary Economics* **52**(6), 1135–1149.

Liu, D. and Jansen, D. (2011), 'Does a factor Phillips curve help? An evaluation of the predictive power for U.S. inflation', *Empirical Economics* **40**, 807–826.

Lubik, T. A. and Schorfheide, F. (2007), 'Do central banks respond to exchange rate movements? A structural investigation', *Journal of Monetary Economics* **54**(4), 1069–1087.

Ma, A. (2002), 'GMM estimation of the new Phillips curve', *Economics Letters* **76**(3), 411–417.

Magnusson, L. M. and Mavroeidis, S. (2010), 'Identification-Robust Minimum Distance Estimation of the New Keynesian Phillips Curve', *Journal of Money, Credit and Banking* **42**(2–3), 465–481.

Mankiw, N. G. (2001), 'The Inexorable and Mysterious Tradeoff between Inflation and Unemployment', *The Economic Journal* **111**(471), C45–C61.

Mankiw, N. G. and Reis, R. (2002), 'Sticky Information versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve', *The Quarterly Journal of Economics* **117**(4), 1295–1328.

Martins, L. F. and Gabriel, V. J. (2009), 'New Keynesian Phillips Curves and potential identification failures: A Generalized Empirical Likelihood analysis', *Journal of Macroeconomics* **31**(4), 561–571.

Mavroeidis, S. (2004), 'Weak Identification of Forward-looking Models in Monetary Economics', *Oxford Bulletin of Economics and Statistics* **66**(supplement), 609–635.

Mavroeidis, S. (2005), 'Identification Issues in Forward-Looking Models Estimated by GMM, with an Application to the Phillips Curve', *Journal of Money, Credit and Banking* **37**(3), 421–48.

Mavroeidis, S., Plagborg-Møller, M. and Stock, J. H. (2013), 'Empirical evidence on inflation expectations in the new Keynesian Phillips curve'. Working paper, February 23 version.

Mazumder, S. (2010), 'The new Keynesian Phillips curve and the cyclicality of marginal cost', *Journal of Macroeconomics* **32**(3), 747–765.

Mazumder, S. (2011), 'The empirical validity of the New Keynesian Phillips curve using survey forecasts of inflation', *Economic Modelling* **28**(6), 2439–2450.

McAdam, P. and Willman, A. (2010), 'Technology, Utilization and Inflation: Re-assessing the New Keynesian Fundamental'. Working paper, October 15 version.

McCallum, B. T. (1976), 'Rational Expectations and the Natural Rate Hypothesis: Some Consistent Estimates', *Econometrica* **44**(1), 43–52.

Mishkin, F. S. (2007), 'Inflation Dynamics', *International Finance* **10**(3), 317–334.

Moreira, M. J. (2003), 'A Conditional Likelihood Ratio Test for Structural Models', *Econometrica* **71**(4), 1027–1048.

Nason, J. M. and Smith, G. W. (2008*a*), 'Identifying the new Keynesian Phillips curve', *Journal of Applied Econometrics* **23**(5), 525–551.

Nason, J. M. and Smith, G. W. (2008*b*), 'The New Keynesian Phillips Curve: Lessons From Single-Equation Econometric Estimation', *Federal Reserve Bank of Richmond Economic Quarterly* **94**(4), 361–395.

Neiss, K. S. and Nelson, E. (2005), 'Inflation Dynamics, Marginal Cost, and the Output Gap: Evidence from Three Countries', *Journal of Money, Credit and Banking* **37**(6), 1019–1045.

Nelson, C. R. and Lee, J. (2007), 'Expectation horizon and the Phillips Curve: the solution to an empirical puzzle', *Journal of Applied Econometrics* **22**(1), 161–178.

Nunes, R. (2010), 'Inflation Dynamics: The Role of Expectations', *Journal of Money, Credit and Banking* **42**(6), 1161–1172.

Nymoen, R., Swensen, A. R. and Tveter, E. (2010), 'The New Keynesian Phillips Curve: A meta-analysis'. Working paper, October 7 version.

Ólafsson, T. T. (2006), 'The New Keynesian Phillips Curve: In Search of Improvements and Adaptation to the Open Economy', *Central Bank of Iceland Working Papers* (31).

Paloviita, M. (2006), 'Inflation Dynamics in the Euro Area and the Role of Expectations', *Empirical Economics* **31**, 847–860.

Paloviita, M. and Mayes, D. (2005), 'The use of real-time information in Phillips-curve relationships for the euro area', *The North American Journal of Economics and Finance* **16**(3), 415–434.

Pesaran, M. H. (1981), 'Identification of rational expectations models', *Journal of Econometrics* **16**(3), 375–398.

Pesaran, M. H. (1987), *The Limits to Rational Expectations*, Basil Blackwell.

Phillips, A. W. (1958), 'The relation between unemployment and the rate of change of money wage rates in the United Kingdom, 1861–1957', *Economica* **25**, 283–299.

Preston, B. (2005), 'Learning about Monetary Policy Rules when Long-Horizon Expectations Matter', *International Journal of Central Banking* **1**(2), 81–126.

Ravenna, F. and Walsh, C. E. (2006), 'Optimal monetary policy with the cost channel', *Journal of Monetary Economics* **53**(2), 199–216.

Roberts, J. M. (1997), 'Is inflation sticky?', *Journal of Monetary Economics* **39**(2), 173–196.

Roberts, J. M. (2005), 'How Well Does the New Keynesian Sticky-Price Model Fit the Data?', *Contributions to Macroeconomics* **5**. Issue 1, Article 10.

Rotemberg, J. J. (1982), 'Sticky Prices in the United States', *Journal of Political Economy* **90**(6), 1187–1211.

Rudd, J. and Whelan, K. (2005*a*), 'Does Labor's Share Drive Inflation?', *Journal of Money, Credit and Banking* **37**(2), 297–312.

Rudd, J. and Whelan, K. (2005*b*), 'New tests of the new-Keynesian Phillips curve', *Journal of Monetary Economics* **52**(6), 1167–1181.

Rudd, J. and Whelan, K. (2006), 'Can Rational Expectations Sticky-Price Models Explain Inflation Dynamics?', *The American Economic Review* **96**(1), 303–320.

Rudd, J. and Whelan, K. (2007), 'Modeling Inflation Dynamics: A Critical Review of Recent Research', *Journal of Money, Credit and Banking* **39**, 155–170.

Rudebusch, G. D. (2002), 'Assessing Nominal Income Rules for Monetary Policy with Model and Data Uncertainty', *The Economic Journal* **112**(479), 402–432.

Sahuc, J.-G. (2006), 'Partial indexation, trend inflation, and the hybrid Phillips curve', *Economics Letters* **90**(1), 42–50.

Sargent, T. J. (1979), 'A note on maximum likelihood estimation of the rational expectations model of the term structure', *Journal of Monetary Economics* **5**(1), 133–143.

Sbordone, A. M. (2002), 'Prices and unit labor costs: a new test of price stickiness', *Journal of Monetary Economics* **49**(2), 265–292.

Sbordone, A. M. (2005), 'Do expected future marginal costs drive inflation dynamics?', *Journal of Monetary Economics* **52**(6), 1183–1197.

Sbordone, A. M. (2006), 'U.S. Wage and Price Dynamics: A Limited-Information Approach', *International Journal of Central Banking* **2**(3), 155–191.

Sbordone, A. M., Tambalotti, A., Rao, K. and Walsh, K. (2010), 'Policy Analysis Using DSGE Models: An Introduction', *Federal Reserve Bank of New York Economic Policy Review* (October issue), 23–43.

Shapiro, A. H. (2008), 'Estimating the New Keynesian Phillips Curve: A Vertical Production Chain Approach', *Journal of Money, Credit and Banking* **40**(4), 627–666.

Sheedy, K. D. (2010), 'Intrinsic inflation persistence', *Journal of Monetary Economics* **57**(8), 1049–1061.

Smets, F. and Wouters, R. (2003), 'An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area', *Journal of the European Economic Association* **1**(5), 1123–1175.

Smith, G. W. (2009), 'Pooling forecasts in linear rational expectations models', *Journal of Economic Dynamics and Control* **33**(11), 1858–1866.

Stock, J. H. and Watson, M. W. (2005), 'Implications of Dynamic Factor Models for VAR Analysis', *National Bureau of Economic Research Working Papers* (11467).

Stock, J. H. and Watson, M. W. (2007), 'Why Has U.S. Inflation Become Harder to Forecast?', *Journal of Money, Credit and Banking* **39**(1), 3–33.

Stock, J. H. and Wright, J. (2000), 'GMM with Weak Identification', *Econometrica* **68**(5), 1055–1096.

Stock, J. H. and Yogo, M. (2002), 'Testing for Weak Instruments in Linear IV Regression', *National Bureau of Economic Research Working Papers* (0284).

Taylor, J. B. (1980), 'Aggregate Dynamics and Staggered Contracts', *Journal of Political Economy* **88**(1), 1–23.

Thomas, L. B. (1999), 'Survey Measures of Expected U.S. Inflation', *Journal of Economic Perspectives* **13**(4), 125–144.

Tillmann, P. (2008), 'Do interest rates drive inflation dynamics? An analysis of the cost channel of monetary transmission', *Journal of Economic Dynamics and Control* **32**(9), 2723–2744.

Tsoukis, C., Kapetanios, G. and Pearlman, J. (2011), 'Elusive Persistence: Wage and Price Rigidities, the New Keynesian Phillips Curve and Inflation Dynamics', *Journal of Economic Surveys* **25**(4), 737–768.

Williams, J. C. (2006), 'Inflation persistence in an era of well-anchored inflation expectations', *Federal Reserve Bank of San Francisco Economic Letter* (27), 1–3.

Yao, F. (2011), 'Monetary Policy, Trend Inflation and Inflation Persistence'. SFB 649 Discussion Paper 2011-008.

Zhang, C. and Clovis, J. (2010), 'The New Keynesian Phillips Curve of rational expectations: A serial correlation extension', *Journal of Applied Economics* **13**(1), 159–179.

Zhang, C., Osborn, D. R. and Kim, D. H. (2008), 'The New Keynesian Phillips Curve: From Sticky Inflation to Sticky Prices', *Journal of Money, Credit and Banking* **40**(4), 667–699.

Zhang, C., Osborn, D. R. and Kim, D. H. (2009), 'Observed Inflation Forecasts and the New Keynesian Phillips Curve', *Oxford Bulletin of Economics and Statistics* **71**(3), 375–398.