Inflation Dynamics and an Extended New Keynesian Phillips Curve for China

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ABSTRACT: This paper shows that the error term in the stylized New Keynesian Phillips curve (NKPC) model for China is significantly serially correlated. We propose an extended NKPC model for China, which can be easily rationalized in terms of sticky-price setting of backward-looking firms. Empirical results show that further lags of inflation are needed in the hybrid specification of the NKPC in order to rule out serial correlation; forward-looking behavior has a relatively larger impact on inflation dynamics than backward-looking behavior; and conventional output measures remain valid inflation forces in the extended model. Open economy augmentations, nevertheless, indicate that neither exchange rate nor import prices exert a significant impact on inflation in China.

KEY WORDS: inflation dynamics, new Keynesian Phillips curve, serial correlation.

The empirical validity of the New Keynesian Phillips curve (NKPC) with rational expectations has attracted considerable attention from both policymakers and academic researchers. Because a completely forward-looking model often does not explain the high degree of persistence in inflation and in inflation’s response to monetary-policy shocks, the NKPC model has been extended from the pure forward-looking versions with solely rational expectations, as in Roberts (1995), to the recently developed hybrid versions with both expected and lagged inflation in the model as in Galí and Gertler (1999), Rudd and Whelan (2006), Sbordone (2005), and Zhang et al. (2008). The continually growing volume of literature concerning the NKPC modeling reflects how the understanding of inflation dynamics has progressed over time. It also indicates that the baseline trade-off depicted by the NKPC remains a useful component in monetary policy analysis after decades of investigation.

The current discussion on the NKPC often involves questions of whether inflation is a backward-looking or forward-looking process and whether output gap is a valid inflation-forcing variable (Vašíček 2011). The debate in the existing literature concentrates on estimation deficiencies such as weak identification and model specification bias in instrumental variables (IV) estimation or, more generally, the generalized method of moments (GMM) for the NKPC. Less attention, however, has been paid to the possible influence of serial correlation (and an extra error induced by rational inflation forecasts) in the GMM estimation for the stylized NKPC model (with a single backward lag and a one-period forward-looking term), as in the seminal work of Galí and Gertler (1999).

While Henry and Pagan (2004) and Zhang et al. (2008) have touched upon this issue, these studies have been largely dominated by the experiences in developed economies, presumably because this relationship originated from developed countries and standard macro models often work less well in developing countries. Nonetheless, most central
banks (from both developed and developing economies) assume, either explicitly or implicitly, the existence of the Phillips curve trade-off in their policy decisions (Fischer 1996), which indicates that the NKPC relationship is not a unique toolkit exclusively applied to developed economies. See Catik and Önder (2011), Önder (2004), and Saygili and Özdemir (2009) for discussions of inflation dynamics in emerging market economies.

In this paper, we examine the NKPC relationship for the Chinese economy, which, since the 1990s, has experienced a number of pronounced ups and downs in its business cycle associated with marked movements in inflation. This is shown in Figure 1, which depicts time series data for the real gross domestic product (GDP) (detrended by Hodrick–Prescott [HP] filter) and year-on-year growth rate of consumer price index (CPI) from the first quarter of 1992 to the last quarter of 2011 (i.e., 1992Q1–2011Q4). This association is attracting a small but growing number of studies to investigate different forms of the NKPC that link inflation with inflation expectations and the real output gap in China, notably by Funke (2006), Gerlach and Peng (2006), Mehrotra et al. (2007), and Scheibe and Vines (2005).

The work to date has generated some useful findings, but these findings have also raised some controversies about the NKPC modeling in China. One common problem in these studies, as in the studies for the developed economy, is the ignorance of serial correlation in the empirical IV estimations of the NKPC models for China. Although some earlier studies may have implicitly acknowledged the problem of serial correlation by allowing some extended backward view on inflation either in their regression models (e.g., Scheibe and Vines 2005) or in their instrumental variable sets (e.g., Funke 2006; Mehrotra et al. 2007), they have not fully (and explicitly) addressed a possible serial correlation problem (and its consequences) in estimating the NKPC models.

The presence of serial correlation in IV estimation casts significant doubts on the validity of the commonly used instrumental variables in the literature and the efficacy of the stylized specification for the NKPC. Surprisingly, despite its conspicuous importance, the issue of serial correlation has been under examined by the research community. In particular, a common practice in the literature involves using lagged dependent variables as instruments in the GMM estimation for the NKPC to solve the endogeneity problem, irrespective of the potential serial correlation problem this may induce. The possible presence of serial correlation is crucial for the choice of valid instruments for GMM estimation as all lags of the dependent variable are invalid instruments in the presence...
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of autoregressive serial correlation. Since lags of inflation are typically employed as instruments for estimation of the NKPC, the consistency of these estimates depends on the lack of such serial correlation.

In this paper, we reconsider the problem of estimating the NKPC for China, with a particular focus on the serial correlation problem in the empirical NKPC model. To achieve this objective, we first employ an instrumental variable (IV) projection approach to approximate inflation expectations—specifically, the projection of the realized future inflation on the underlying IV—and then estimate the NKPC model by the GMM. This method can effectively isolate the model-specification error from the composite error, which consists of both the specification error and a rational inflation-forecast error. This makes a serial correlation test for the specification disturbance now feasible and facilitates comparisons of statistical inference under different data-generating mechanisms.

To preview our empirical results, we find that the error term in the stylized NKPC model for China manifests significant serial correlation. In addition, even under the traditional setup assuming the absence of serial correlation, the standard errors of regression differ strikingly between the NKPC specifications with and without rational inflation-expectations error. One of the reasons for the presence of serial correlation is the inefficacy of lagged inflation dynamics in the stylized NKPC. Therefore, we propose an extended NKPC model by assuming that the “backward-looking” firms in the sticky-prices model set their prices based on an extended horizon of historical inflation.

Our empirical results reveal that this extended model is indeed free of serial correlation and additional lagged inflation is statistically significant. The results in the present research also suggest that the conventional output gap remains a valid inflation-driving variable in the extended NKPC. We also show that these findings are robust to open economy augmentations for the extended model when import price inflation or exchange rate is taken into account.

The Stylized NKPC and Empirical Controversies

Theoretical Discussion

With recent advances, the NKPC model with rational expectations has evolved from earlier models of sticky prices based on Calvo (1983), Rotemberg (1982), and Taylor (1980). Roberts (1995) shows that these models can be synthesized in a common formulation as

$$\pi_t = c_0 + \alpha_y E_t \pi_{t+1} + \alpha_y y_t + \eta_t,$$

where $c_0$ is a constant, $\pi_t$ denotes the rate of inflation, $E_t \pi_{t+1}$ is expected inflation for period $t+1$ given information available up to period $t$, $y_t$ denotes the real driving variable, and $\eta_t$ refers to the specification error. By construction, $\alpha_y$ in Equation (1) represents a subjective discount factor. Roberts (1995) sets the subjective discount factor to be one and refers to the equation as the New Keynesian Phillips curve.

Equation (1) suggests that the inflation process is purely forward looking, with current inflation a function of future inflation and current real driving variables. This model is theoretically appealing because it can be developed from the explicit and solid microeconomic foundations relating to the dynamic stochastic general equilibrium (DSGE) models. Unfortunately, model (1) implies that central banks can reduce inflation without cost, that is, $\pi_t$ can be moderated by adjusting the next period’s inflation expectations
without having to depress the real economy. This appears to be in stark contrast with the
costly disinflation experiences in both developed and developing economies over the
past few decades.

Consequently, in their very influential work, Galí and Gertler (1999) provide a theo-
retical structure which nests the sticky-prices model as a special case of a hybrid speci-
fication of the NKPC. The authors assert that the lack of inflation persistence implied
by Equation (1) can be resolved by employing a theoretically based real marginal cost
measure, namely, labor income share, as the driving force for inflation. Specifically, they
develop their theory by assuming an environment of monopolistically competitive firms
in which a fraction of the firms behave optimally in their price setting, as in Calvo’s
(1983) model, while the remaining firms follow a rule of thumb of backward-looking
price-setting behavior. Following a similar procedure, starting with Equation (1), the
hybrid specification of the NKPC can be obtained as

\[ \pi_t = c_0 + \alpha_f \pi_{t+1} + \alpha_y y_t + \eta_t. \]  

(2)

The distinct feature of Equation (2), compared with the earlier models in Fuhrer (1997),
Fuhrer and Moore (1995), and Roberts (1995), is that real marginal cost, rather than the
real output gap, is a valid real driving force for inflation.1 Using the GMM estimator, Galí
and Gertler (1999) also show that the specification of (2) with an appropriate amount of
forward-looking behavior captures U.S. inflation dynamics very well. The GMM estima-
tion procedure in Galí and Gertler can be summarized as follows: the authors approximate
the unobserved inflation expectations in Equation (2) by the corresponding realized future
inflation; that is, instead of estimating the stylized NKPC model (2), they estimate

\[ \pi_t = c_0 + \alpha_f \pi_{t+1} + \alpha_y y_t + u_t, \]  

(3)

where

\[ u_t = \eta_t - \alpha_f \pi_{t+1}, \]

which is induced by the rational expectations approximation, that is,

\[ E_t \pi_{t+1} = \pi_t - e_{t+1}. \]  

(4)

This standard approach has also been adopted by recent studies of the NKPC for China
(e.g., Funke 2006; Mehrotra et al. 2007). In terms of this method, the existing studies
assume that both \( \eta_t \) and \( e_{t+1} \) are white noise. In turn, they argue that Equation (2) can be
consistently estimated through Equation (3) by the GMM with relevant variables dated
\( t - 1 \) and earlier as instruments. A fundamental principle of rational expectations is that
the forecasting error \( e_{t+1} \) is assumed to be orthogonal to agents’ sets in forming their
expectations. This principle combined with the white noise assumption on \( \eta_t \) implies
that lagged values of inflation (and other relevant variables) are legitimate instruments
and the GMM estimator will yield consistent estimates for (2).

As suggested earlier, however, the potential problem of serial correlation may invali-
date the GMM estimates in the aforementioned studies. Specifically, if the specification
error \( \eta_t \) is serially correlated, while lagged values of the dependent variable (i.e., lagged
inflation) are included in the IV set (as in the existing literature), then the moment condi-
tions associated with lagged inflation are invalid. In effect, it is likely that lagged values
of the real driving variable are also correlated with \( \eta_t \) when this error term exhibits serial
correlation. As a consequence, the GMM estimates associated with the stylized NKPC
may be not only biased but also inconsistent.
In addition, even if the parameters in Equation (2) were consistently estimated via Equation (3) by the GMM, it does not imply that the inference based on (3) is necessarily valid. In particular, the volatility of the prediction error $e$ and its potential correlation with the specification error $\eta$ are likely to inflate (or deflate) the variance of the error term associated with the stylized model (2). Consequently, the variance of the disturbance in Equation (3) may differ substantively from that in the NKPC model (2).

These issues are crucial in the GMM estimation for the NKPC model, and yet they are underinvestigated in the literature. The current study, therefore, embarks on an investigation of serial correlation and the nature of these error terms based on the differing constructions of Equation (2) and (3). To this end, we approximate the unobserved inflation expectations in (2) by projecting realized future inflation (i.e., $\pi_{t+1}$) on the underlying IV set $Z$, that is

$$E_t \pi_{t+1} = P_Z \pi_{t+1},$$

(5)

where $P_Z = Z(Z'Z)^{-1}Z'$ is the projection matrix in terms of the IV set.

It follows that this procedure will yield precisely the same coefficient estimates as those obtained through the GMM estimation for (3), while the standard errors will be different since the former ignores uncertainty in the estimation of the projection matrix (Pagan 1984). In addition, to provide valid tests for serial correlation in the GMM estimation of the dynamic model with a lagged dependent variable, we employ the IV serial correlation test proposed by Godfrey (1994) under the null hypothesis of no serial correlation in the underlying GMM estimation. This instrumental variable test for serial correlation is implemented by adding appropriate lagged residuals from the initial estimation to the regressors of the underlying model and checking their joint significance by applying the Lagrange multiplier principle.

**Empirical Results of the Stylized NKPC for China**

Based on the foregoing construction, Table 1 summarizes the GMM (two-stage least-squares [2SLS]) estimation results of the stylized NKPC model, with S1 and S2 denoting standard errors corresponding to the specifications (2) and (3), respectively. Note that inflation rate is measured by the year-on-year growth rate of CPI (i.e., CPI inflation), and real output gap is obtained by HP-filtered real GDP. The details of the data series used in the empirical investigation are described in the Appendix. In the GMM estimation, the IV set includes four lags of inflation, two lags of the real output gap, and one lag of growth rate of monetary aggregate $M_2$ (denoted $\Delta M_2$). The IV set is selected to be consistent with the IV used in estimating the extended model later in this paper and is based on economic relevancies and IV diagnostic tests (i.e., IV serial correlation test, overidentification test, and weak-IV test); see the section Empirical Results of the Extended Model for more details.

The results show that the GMM point estimates on future inflation are generally higher than 0.53 while those on lagged inflation are smaller than 0.47, either with or without the restriction of convex combination on the forward- and backward-looking components (i.e., $\alpha_f + \alpha_b = 1$), indicating a slightly dominant role of forward-looking behavior. Moreover, coefficient estimates on the real output gap are positive, but none of the estimates are statistically significant. Essentially, it is the latter observation that leads to questions in the existing literature regarding the validity of the output gap as a driving force for inflation in the NKPC.
However, although the coefficient estimates in Table 1 seem to be against the output-gap version of the NKPC, the standard errors associated with the underlying coefficients in the NKPC model (2) differ substantively from those based on (3). This impression is also confirmed by comparing standard errors of regression (S.E.) between Equations (2) and (3), with the standard errors associated with the specification (2) uniformly being smaller than those pertaining to the specification (3). For instance, under the conventional construction (3), the standard error of regression is 1.285, while this estimate is 0.910 when the specification of model (2) is considered. The same scenario occurs when the restriction of \( \alpha_f + \alpha_y = 1 \) is imposed. Interestingly, however, the difference between S1 and S2 associated with the output gap appears less distinct, although it turns out to be immaterial since the GDP gap is statistically insignificant under either case.

In essence, the observed differences illustrated above are affected by the introduction of the rational prediction error \( e_{\eta_t+1} \). The potential influence of this disturbance can also be evaluated by comparing the standard errors of regression reported in Table 1, which implies that in practice the correlation between the forecasting error and the specification disturbance in the NKPC tends to be influentially large.

All of the above is based on the assumption that \( \eta_t \) in Equation (2) is white noise so that lagged values of inflation are legitimate instruments. However, the results of the Godfrey (1994) IV serial correlation tests (p-auto) for \( \eta_t \) in Table 1 suggest that in all the regressions, the null hypothesis of no serial correlation (up to 4 lags) can be decisively rejected at the 1 percent significance level. The presence of serial correlation in the stylized NKPC model casts doubt on the validity of lagged values of inflation (and possibly real variables) as instruments.

It may be noted that using quarterly data with year-on-year inflation figures may automatically increase serial correlation in the residuals of the NKPC model since the year-on-year growth rate of price index is effectively the dynamic sum of quarter-on-quarter inflation figures. In addition, out of the earlier China studies, Funke (2006), Gerlach and Peng (2006), and Mehrotra et al. (2007) all use annual data so that the amount of serial correlation in these papers may actually be less than that shown in Table 1. To explore the serial correlation issue with alternative inflation figures, we estimate the stylized hybrid NKPC by using annual data and quarter-on-quarter growth rate of inflation series.

### Table 1. GMM estimation results of the stylized NKPC for China: 1992Q1–2011Q4

<table>
<thead>
<tr>
<th>( y_t = \text{HPGAP} )</th>
<th>( \hat{\alpha}_f )</th>
<th>( \hat{\alpha}_b )</th>
<th>( \hat{\alpha}_y )</th>
<th>S.E.</th>
<th>p-auto</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 (0.014)</td>
<td>(0.017)</td>
<td>(0.163)</td>
<td>0.910</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>S2 (0.040)</td>
<td>(0.038)</td>
<td>(0.124)</td>
<td>1.285</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>( \alpha_f + \alpha_y = 1 )</td>
<td>0.532***</td>
<td>0.468***</td>
<td>0.206</td>
<td>0.907</td>
<td>0.000</td>
</tr>
<tr>
<td>S1 (0.018)</td>
<td>(0.018)</td>
<td>(0.136)</td>
<td>0.907</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>S2 (0.040)</td>
<td>(0.040)</td>
<td>(0.130)</td>
<td>1.269</td>
<td>0.000</td>
<td></td>
</tr>
</tbody>
</table>

Notes: S.E. is standard error of regression. Sample spans 1992Q1–2011Q4 prior to lag adjustment. S1 and S2 refer to Newey–West heteroskedasticity- and autocorrelation-consistent (HAC) standard errors (lag specified by auto-AIC with Bartlett kernel) associated with Equations (2) and (3), respectively. p-auto denotes p-value of IV serial correlation test of Godfrey (1994) under the null hypothesis of no serial correlation. *** Statistical significance at the 1 percent level.
(seasonally adjusted), respectively. The results (not reported here) suggest that the auto-
correlation problem is less severe than that in the model with year-on-year growth data
but still significantly exists in these models with alternative inflation figures.

Overall, the presence of serial correlation in the estimated residuals implies that the
assumption of white noise $\eta_t$ in the stylized NKPC model (2) is unlikely to hold. The
empirical finding of serial correlation may be unsurprising in that the theoretical deriv-
ation of the NKPC does not predict the absence of serial correlation in $\eta_t$. More crucially,
the stylized NKPC may be empirically insufficient to capture China’s inflation dynamics.
On theoretical grounds, if we interpret one period as being fairly short (say one quarter
in quarterly models), it is likely that agents who follow “the rule of thumb” of backward-
looking behavior may look at past inflation over more than one period. Therefore, we
develop and test an extended specification of the NKPC in the following section.

**Theoretical Framework of an Extended Model**

The previous section presented evidence that the error term in the stylized NKPC model
is serially correlated. Galí et al. (2001) also acknowledge that the independent and identi-
cally distributed (i.i.d.) assumption on $\eta_t$ may be too strong. The serial correlation may,
of course, come from different sources and so give rise to various implications. One
important implication of the serial correlation uncovered is that the stylized specification
is not sufficient to capture all of the U.S. inflation dynamics. Therefore, extending the
lagged inflation structure could be a rewarding innovation. More important, as we show
below, this extension can be derived from the microeconomic foundations of inflation
similar to the micro models used in the standard literature.

To be specific, we assume an economic environment similar to Calvo’s (1983) model,
in which firms are able to revise their prices in any given period with a fixed probability
$(1 - \theta)$. As in Galí and Gertler (1999), we also assume forward- and backward-looking
firms coexist in the economy with a proportion of $w$ and $(1 - w)$, respectively. Using
the regular assumptions in Calvo’s (1983) model and log-linear approximations, it is possible
to obtain the (natural log) aggregate price level as

$$p_t = \theta p_{t-1} + (1 - \theta)p^*_t,$$  \hspace{1cm} (6)

where $p^*_t$ is the new price set in period $t$. Let $p^f_t$ be the price set by forward-looking firms
and $p^b_t$ the price set by backward-looking firms at $t$. Then the new price (relative to the
aggregate price) can be expressed as a convex combination of $p^f_t$ and $p^b_t$, that is,

$$p^*_t = \omega p^f_t + (1 - \omega)p^b_t.$$  \hspace{1cm} (7)

Next, following the procedure in Woodford (2003), the pricing behavior of the forward-
looking firms can be written as

$$p^f_t = \theta \beta \sum_{s=0}^{\infty} (\theta \beta)^s E_t \pi_{t+s+1} + (1 - \theta \beta)^s E_t \zeta E_{t+s},$$ \hspace{1cm} (8)

where $\beta$ denotes a subjective discount factor, $\zeta$ is introduced by the procedure of log-
linearization (see Woodford for a discussion of economic implications of $\zeta$), and $y_t$ is
real output gap. Iterating Equation (8) gives

$$p^f_t = \theta \beta E_t p_{t+1} + (1 - \theta \beta) \zeta y_t + \theta \beta E_t p^f_{t+1},$$ \hspace{1cm} (9)
In Galí and Gertler (1999), the backward-looking firms are assumed to follow the rule of thumb of backward-looking behavior in their price setting. However, if we interpret one period as being fairly short (say one quarter in quarterly models), it is plausible to assume that the backward-looking firms adjust their pricing behavior by a weighted average of past (say one-year) inflation. Therefore, we assume that these firms’ pricing behavior follows

\[ p_t^B = p_{t-1}^* + p_{t-1} + \rho^*(L) \Delta \pi_{t-1}, \]  

(10)

where \( \rho^*(L) = \rho^* L + \rho^*_2 L^2 + \ldots + \rho^*_q L^q \) is a polynomial in lag operator which can be determined by information criteria and serial correlation test in empirical specification.

Note that subtracting \( p_t \) from both sides of Equation (6) gives

\[ p_t^* = \frac{\theta}{1 - \theta} \pi_t \]  

(11)

and iterating (7) one period ahead produces

\[ p_{t+1}^* = \omega p_{t+1}^E + (1 - \omega)p_{t+1}^B, \]  

(12)

which in turn gives

\[ p_{t+1}^E = \frac{1}{\omega} \left[ \frac{\theta}{1 - \theta} \pi_{t+1} - (1 - \omega)p_{t+1}^B \right]. \]  

(13)

In order to derive the last item in the square bracket of Equation (13) in terms of the inflation rate, lag (11) one period, subtract \( p_t \) from both sides of the resulting equation, and derive

\[ p_{t+1}^* - p_t = \frac{\theta}{1 - \theta} \pi_{t+1} - \pi_t. \]  

(14)

Substituting Equation (14) into (10) gives

\[ p_t^B - p_t = \frac{1}{1 - \theta} \pi_{t-1} + \rho^*(L) \Delta \pi_{t-1} - \pi_t. \]  

(15)

Now combining Equations (7), (10), (13), and (15) gives the extended model of the NKPC, that is,

\[ \pi_t = \alpha_f E_t p_{t+1} + \alpha_b \pi_{t+1} + \alpha_p (L) \Delta \pi_{t-1} + \alpha_y y_t + \eta_t, \]  

(16)

where \( \eta_t \) is a model specification error and other coefficients are combinations of structural parameters.

The specification of (16) is effectively a reparameterization of the standard NKPC and has two distinct advantages. First, the backward-looking coefficient, \( \alpha_b \), can be estimated with sufficient precision even if the individual coefficients on lagged inflation are imprecisely estimated due to possible multicollinearity between the lagged values. Second, the convex restriction of \( \alpha_f + \alpha_y = 1 \) can be easily imposed, which alleviates potential nonstationarity in the empirical regressions.

**Empirical Results of the Extended Model**

This section presents GMM (2SLS) estimation results for the extended NKPC model (16). The data used in our empirical studies are obtained from the National Bureau of Statistics.
of China spanning 1992Q1–2011Q4, dictated by data availability for real GDP. Inflation is measured by the year-on-year growth rate of CPI. To investigate the role of traditional output gap in the extended model, we concentrate on the HP-filtered real GDP (i.e., HPGAP). However, in the robustness analysis (see below), we also consider the real output gap derived from a fitted linear trend function of time (LDGAP), from Baxter and King’s (1999) fixed-length symmetric (BKGAP), and from Christiano and Fitzgerald’s (2003) fixed-length symmetric band-pass filters of the real GDP series (CFGAP). To facilitate our notations, we use LDGAP, BKGAP, and CFGAP, respectively, to denote the output-gap measures examined in the robustness analysis. As discussed below, GMM estimations of the extended NKPC model for China also involve monetary aggregate M2 (year-on-year growth rate, denoted \( \Delta M2 \)), which is obtained from the People’s Bank of China. All data series used in empirical work are assumed (and confirmed by conventional unit root tests) to be covariance stationary. More details of the data are presented in the Appendix.

Because the extended model, by design, is free of serial correlation in the empirical estimations, lagged inflations in the model are now valid instruments. In addition, the baseline IV set includes two lags of the output gap and one lag of \( \Delta M2 \), which is supported by both IV diagnostic tests (i.e., IV serial correlation test, overidentification test, and weak-IV test) and economic relevancies. First, because the real variable (y) in the regression is assumed to drive inflation, lagged values of y are expected to be valid instruments for the real variable in the current period and for future inflation. Second, the correlation between monetary growth and inflation can be understood in terms of the standard AS/LM (aggregate supply/liquidity and money) system which highlights the interactions between money and price. Note that unlike in the developed economies (such as the United States), quantity-based monetary instruments remain the main instruments of the central bank of China, as explicitly stated in the Monetary Policy Report published quarterly by the People’s Bank of China and shown in Burdekin and Siklos (2008) and Geiger (2008). Therefore, monetary growth, instead of interest rate, is used as IV for estimating the NKPC model for China. As such, the baseline IV set here appears to be reasonably conservative and sufficient in explaining the dynamics of the extended NKPC model for China.

**Baseline Results**

Using this construction, we summarize in Table 2 the key coefficient estimates of the extended model in conjunction with the statistics of our interest over the sample. In addition to the coefficient estimates of model (16), we also report results of the joint significance test on the extra lagged inflation from order two to the maximum lag \( (\tilde{\alpha}_1, L) \) and three IV diagnostic tests (IV serial correlation test, overidentification test, and weak-IV test).

Several interesting findings emerge from Table 2. First, the coefficient estimates of \( \tilde{\alpha}_1 \) show that the HPGAP obtains an intuitive (positive) sign and is statistically significant at 1 percent level in cases both with and without convex restriction. The magnitude of the estimates on the HPGAP is around 0.3–0.4, indicating that a 1 percent increase in the output gap will lead to a 0.3–0.4 percent rise in inflation, ceteris paribus. This is well in accord with the established economic theory as indicated, for example, in Roberts (1995). This result indicates that conventional measures of the output gap play a significant role in the NKPC when the model is properly extended and expectations are measured by the IV-projection method described previously.
Second, comparing the forward-looking and backward-looking inflation coefficients, forward-looking behavior slightly dominates backward-looking behavior over the underlying sample period. This finding indicates that inflation expectations play a slightly larger role than inflation inertia in China’s inflation-dynamic system. Nevertheless, both future inflation and lagged inflation are statistically significant at the conventional levels in all regressions. These findings hold in the imposition of the convex restriction $\alpha_f + \alpha_b = 1.2$.

Several additional issues associated with these results also merit discussion. First, and perhaps a more important finding in Table 2, is that serial correlation is generally absent (insignificant at a 5 percent level) in the extended model. The absence of serial correlation indicates that the extended NKPC model (16) is more plausible than the stylized specification (2) in explaining China’s inflation dynamics. Second, the joint tests on the extra inflation dynamics are significant in all the regressions at the 1 percent level (and typically much lower), as indicated by the $p$-values reported in the column headed $\hat{\alpha}_s(L)$, supporting the extension of the NKPC to incorporate additional lagged inflation terms. Third, $p$-values of the overidentifying-restrictions tests are larger than 10 percent in all cases, supporting the validity of the overidentifying-moment conditions used in the IV estimation. Fourth, Stock and Yogo’s (2005) weak-IV test results suggest that the IV set can be regarded as strong in all the regressions if the desired maximal bias of the IV estimator relative to ordinary least squares (OLS) is specified to be 15 percent.

To summarize the results reported in Table 2, we find that the extended NKPC model is relieved of the serial correlation problem and the conventional output gap is still a valid driving force for inflation. Additionally, the forward-looking behavior is (marginally) more dominant than the backward-looking behavior in the NKPC relationship for China. The results also affirm that richer dynamics than the stylized specification in the literature are warranted for modeling inflation dynamics of China over the period 1992–2011.

**Robustness**

To assess the robustness of these baseline findings, we perform three additional sensitivity exercises. In the first exercise, we reestimate the extended model by using alternative output-gap measures, namely LDGAP, BKGAP, and CFGAP, as mentioned previously. In the second and third exercises, we extend our model to an open-economy version by taking into account the exchange rate and import prices, respectively.
The results of the first exercise are reported in Table 3, which summarizes GMM estimation (2SLS) results for the extended NKPC by using the alternative real output-gap measures over the same sample period as above, namely 1992Q1–2011Q4. The results show that in most regressions, serial correlation is absent and extra values of lagged inflation are statistically significant at the 1 percent level. Also, forward-looking behavior is generally more dominant than inflation inertia in the underlying regressions.

In addition, Table 3 shows that all the measures of the output gap remain positive and significant at conventional levels of significance (except for the unrestricted regression involving LDGAP) with a slight moderation in magnitude of $\alpha_y$ for BKGAP. Interestingly, however, the results in Table 3 suggest that the coefficient estimates on LDGAP and CFGAP appear to be much smaller than those pertaining to HPGAP and BKGAP. Nonetheless, both LDGAP and CFGAP maintain their intuitive signs and statistical significance. For completeness, we also evaluate the IV diagnostic tests, and the corresponding results provide as consistent a scenario as those in Table 2.

Our second and third exercises are motivated by the fact that China is becoming a large open economy, and the closed-economy version of the baseline NKPC may be an inadequate account of open-economy considerations. In principle, there can be several channels (e.g., exchange rate pass-through and import prices pass-through channels) through which openness may influence domestic firms’ price-setting decisions via their impact on marginal production costs (Agénor and Bayraktar 2010). The open economy extension NKPC can be rationalized either by augmenting supply-side models of Calvo (1983) or by employing a more general framework of the dynamic stochastic general equilibrium (DSGE) model of Galí and Monacelli (2005).

Table 3. GMM (2SLS) estimation results of the extended NKPC using alternative output gap measures

<table>
<thead>
<tr>
<th></th>
<th>$\alpha_f$</th>
<th>$\alpha_b$</th>
<th>$\alpha_y$</th>
<th>$\alpha_y(L)$</th>
<th>$p$-auto</th>
<th>$p$-over</th>
<th>Weak IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDGAP</td>
<td>0.536***</td>
<td>0.463***</td>
<td>0.047</td>
<td>0.000</td>
<td>0.050</td>
<td>0.300</td>
<td>93.4</td>
</tr>
<tr>
<td></td>
<td>(0.036)</td>
<td>(0.026)</td>
<td>(0.037)</td>
<td>(0.037)</td>
<td>(0.037)</td>
<td>(0.037)</td>
<td></td>
</tr>
<tr>
<td>BKGAP</td>
<td>0.518***</td>
<td>0.474***</td>
<td>0.240***</td>
<td>0.000</td>
<td>0.014</td>
<td>0.756</td>
<td>360</td>
</tr>
<tr>
<td></td>
<td>(0.068)</td>
<td>(0.066)</td>
<td>(0.066)</td>
<td>(0.066)</td>
<td>(0.066)</td>
<td>(0.066)</td>
<td></td>
</tr>
<tr>
<td>CFGAP</td>
<td>0.514***</td>
<td>0.499***</td>
<td>0.070***</td>
<td>0.000</td>
<td>0.041</td>
<td>0.781</td>
<td>653</td>
</tr>
<tr>
<td></td>
<td>(0.025)</td>
<td>(0.020)</td>
<td>(0.024)</td>
<td>(0.024)</td>
<td>(0.024)</td>
<td>(0.024)</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Sample spans 1992Q1–2011Q4 prior to lag adjustment. *, **, and *** statistical significance at the 10 percent, 5 percent, and 1 percent levels, respectively.
change of the real exchange rate or import prices, rather than their levels (e.g., in Guender 2006), that appears in the open-economy version of the NKPC model. In practice, the rate of change of the underlying variables is more appealing than the levels as the former is $I(0)$ while the latter is $I(1)$, attested to by conventional unit root tests.

To take into account the potential impact of these two factors on domestic inflation, therefore, we augment model (16) by considering the possible influence of exchange rate and import prices on domestic inflation, respectively, that is,

$$
\pi_t = \alpha_f \pi_{t+1} + \alpha_y y_t + \alpha_p (L) \Delta \pi_{t-1} + \alpha_{ex} EX_t + \eta_t,
$$

(17)

and

$$
\pi_t = \alpha_f \pi_{t+1} + \alpha_y y_t + \alpha_p (L) \Delta \pi_{t-1} + \alpha_{im} IM_t + \eta_t,
$$

(18)

where $EX$ and $IM$ denote growth rates (year-on-year) of real effective exchange rate of the renminbi (RMB) and import price index, respectively. The raw data (quarterly frequency available) for the effective exchange rate are obtained from *International Financial Statistics*, and the data for the import price index are from the Global Economic Monitor of the World Bank.

Tables 4 and 5 present corresponding results for the augmented models (17) and (18), respectively. Since the different output-gap measures do not produce substantively different results, Tables 4 and 5 report only the estimation results based on HPGAP to save space. Table 4 shows that the empirical regressions of model (17) are substantially free of significant serial correlation problem and the extra inflation lags are statistically significant. In addition, the output gap remains a significant driving force for domestic inflation even when the effective exchange rate is incorporated into the NKPC model. The magnitude of the coefficient estimates on the output gap is also much similar to those reported in Table 2. Also similar to the results in Table 2, the forward-looking behavior is more dominant than the backward-looking behavior.

In addition, both Tables 4 and 5 suggest that the coefficient estimates on exchange rate and import price inflation are uniformly very small and statistically insignificant in all the regressions. This result indicates that the impact of exchange rate changes and import price changes on domestic inflation is trivial. A further implication from this finding is that neither appreciation nor depreciation of the renminbi (RMB) against world currencies will exert domestic inflationary pressure in China. Also, the import price inflation is rather an international supply shock, which is unlikely to affect domestic inflation in a significant way. Both Table 4 and Table 5, nonetheless, suggest that the baseline model of Equation (16) is sufficient in capturing features of China’s inflation dynamics between 1992 and 2011.

**Conclusions**

The GMM estimation for the stylized NKPC model is often criticized on the grounds that the approach may suffer from finite-sample problems, weak IV, or some identification problems. Very little attention has been paid to a potential serial correlation problem (and its fatal consequences on the GMM estimation) in the prototypical dynamic time series model. This paper explicitly addresses the serial correlation problem in the stylized NKPC for China’s inflation dynamics, which had hitherto been neglected. We propose an IV-projection approximation method for constructing inflation expectations, which avoids inducing an extra forecasting error into the baseline model. Our results show that
Table 4. IV estimation results of the extended NKPC with exchange rate

<table>
<thead>
<tr>
<th></th>
<th>$\tilde{\alpha}_f$</th>
<th>$\tilde{\alpha}_b$</th>
<th>$\tilde{\alpha}_r$</th>
<th>$\tilde{\alpha}_{ze}$</th>
<th>$\tilde{\alpha}_p(L)$</th>
<th>$p$-auto</th>
<th>$p$-over</th>
<th>Weak IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPGAP</td>
<td>0.569*** (0.044)</td>
<td>0.412*** (0.040)</td>
<td>0.434*** (0.138)</td>
<td>-0.009 (0.038)</td>
<td>0.000</td>
<td>0.044</td>
<td>0.549</td>
<td>3.39</td>
</tr>
<tr>
<td>$\alpha_f + \alpha_b = 1$</td>
<td>0.579*** (0.049)</td>
<td>0.421*** (0.049)</td>
<td>0.313*** (0.138)</td>
<td>-0.001 (0.021)</td>
<td>0.000</td>
<td>0.195</td>
<td>0.743</td>
<td>3.39</td>
</tr>
</tbody>
</table>

Notes: Sample spans 1992Q1–2011Q4 prior to lag adjustment. *, **, and *** statistical significance at the 10 percent, 5 percent, and 1 percent levels, respectively.
Table 5. IV estimation results of the extended NKPC with imported price inflation

<table>
<thead>
<tr>
<th>HPGAP</th>
<th>$\bar{a}_r$</th>
<th>$\bar{a}_b$</th>
<th>$\bar{a}_f$</th>
<th>$\bar{a}_{imp}$</th>
<th>$\bar{a}_{p(L)}$</th>
<th>$p$-auto</th>
<th>$p$-over</th>
<th>Weak IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_f + \alpha_b = 1$</td>
<td>0.575*** (0.068)</td>
<td>0.411*** (0.055)</td>
<td>0.396*** (0.017)</td>
<td>0.001</td>
<td>0.000</td>
<td>0.080</td>
<td>0.517</td>
<td>6.54</td>
</tr>
<tr>
<td>HPGAP</td>
<td>0.584*** (0.064)</td>
<td>0.416*** (0.064)</td>
<td>0.316*** (0.073)</td>
<td>0.003</td>
<td>0.000</td>
<td>0.309</td>
<td>0.748</td>
<td>6.54</td>
</tr>
</tbody>
</table>

Notes: Sample spans 1992Q1–2011Q4 prior to lag adjustment. *, **, and *** statistical significance at the 10 percent, 5 percent, and 1 percent levels, respectively.
the stylized specification of the NKPC is significantly serially correlated for the Chinese data. In addition, even under the i.i.d. assumption made in the literature regarding the structural and forecasting errors, the different constructions of inflation expectations may also give rise to a different inference.

These findings lead us to develop and estimate an extended model with richer lagged inflation dynamics for China. Our empirical results suggest that the extended model provides a good description of China’s inflation dynamics over the post-1990s period, with forward-looking behavior being relatively more important than backward-looking behavior in explaining inflation and with the conventional output gap as a valid real driving variable for inflation. These results indicate that the “output-gap–based” NKPC constitutes a valid and useful toolkit in understanding China’s inflation dynamics once serial correlation in the NKPC is properly accounted for. The finding also entails further investigation on the validity of the celebrated “marginal-cost–based” NKPC for China in the future work when the relevant data for marginal cost is available.

Moreover, in contrast to the studies relevant to a developed economy that find a significant role for exchange rate (or import prices) in explaining inflation dynamics, our results suggest that exchange rate and import prices have very little impact on China’s inflation dynamics. This may indicate that the standard channels for openness to affect the evolution of domestic inflation are not articulated fully in the Chinese economy. Alternatively, it may indicate that other factors representing openness may be worth considering. Recent research by Borio and Filardo (2007) has provided an important contribution in this direction, and further examinations of China’s inflation process may provide more compelling results, which may complement the present research.

Notes

1. Using a measure such as labor share to proxy marginal cost, however, is not attractive in the Chinese case due to data limitations, so the real output gap is used throughout this paper.

2. The convex restriction implies that the subjective discount factor in the microfoundations of the NKPC is one, which is often imposed in the literature. In our estimations, the null hypothesis of the convex restriction cannot be rejected at conventional levels.

3. For the estimations of Equations (17) and (18), the baseline IV set is modified by adding one lag of each of EX and IM, respectively.

4. The degree of China’s trade openness (i.e., total amount of imports and exports divided by nominal GDP), for example, grew from 35 percent in the 1990s to 54 percent in the 2000s, based on data published by China’s National Bureau of Statistics.

References


Appendix

This appendix describes the data series used in the empirical work, including CPI (Consumer Price Index) inflation, monetary aggregate (M2), real effective exchange rate, import price index, and real GDP. The data span the first quarter of 1992 to the last quarter of 2011. The year-on-year CPI inflation series was obtained from China’s National Bureau of Statistics (NBS). The monthly available data of the CPI series is transformed to quarterly frequency by using end-of-quarter observations as the corresponding quarterly values to avoid inducing serial correlation in the transformed data. Quarterly available data for M2 and real effective exchange rate over the underlying sample are obtained from International Financial Statistics (IFS), and quarterly available data for import price index is obtained from the Global Economic Monitor (GEM) of the World Bank.

Note that the quarterly data for real GDP are not directly available and are calculated by using the level of nominal GDP and the growth rate of real GDP published by China’s NBS for the period of 1992–2011 (with 1997 as the base year). The derived quarterly real GDP series based on this procedure appears to match the officially published annual data by the NBS very convincingly. Based on the derived real GDP level data, the output-gap measures used in the paper, namely, HPGAP, LDGAP, BKGAP, and CFGAP, are derived by a two-sided Hodrick–Prescott filtered log real GDP with penalty parameter 1600, the linear detrending method, Baxter and King’s (1999) fixed-length symmetric, and Christiano and Fitzgerald’s (2003) fixed-length symmetric band-pass filters of the real GDP series, respectively.