Re-estimate the Phillips curve in China

Shed "light" on the Phillips curve using panel data

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Abstract

This paper re-estimates the Chinese output-gap Phillips curve using panel data. Our estimated slopes range from 0.04 to 0.2 at the province level, which is one-tenth of those at the national level and 10 times those at the city level. The reason is that the variation in output becomes larger as we look into a more local level while the variation in the inflation remains small. We utilize the year fixed effect to absorb part of the inflation expectation formed upon national information, which accounts for 50% of the total expectation. We further use the night light data as a proxy for the output to estimate a "lumen gap Phillips curve" as a robust check, which generates similar results.

1 Introduction

There is a vast theoretical literature concerning Chinese economic issues based on New Keynesian models. Marked with nominal rigidity, New Keynesian models are increasingly popular in both academia and monetary policy practice in China. A typical New Keynesian model has the Phillips curve eq. (1)[1] as an integral equation, which is the ultimate source of the nominal rigidity, describing the relationship between inflation as a nominal variable and the output gap as a real one. Thus it's important to examine whether this curve exists in China to lay a solid base for these models. Moreover, figuring out the relationship between the output and inflation can help us better analyze the optimal

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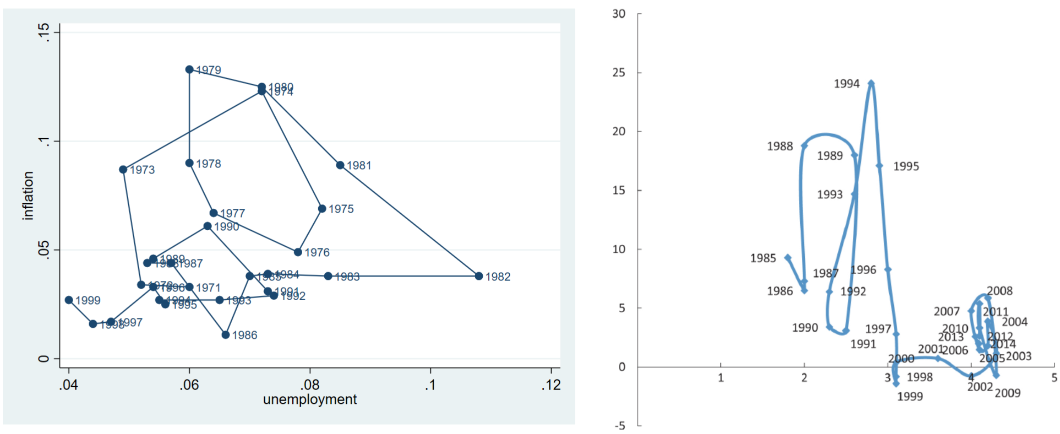
[1]Here $\tilde{y} \sim \tilde{MC}$, the surplus markup. Some papers describe NKPC as $\pi_t = \beta E_t \pi_{t+1} - \lambda \tilde{MC}_t$. The $\tilde{y}$ can also be substituted by the unemployment rate.

monetary policy and better evaluate the welfare implication of macro policies.

$$\pi_t = E_t \pi_{t+1} + \kappa \tilde{y}_t \tag{1}$$

While the existence of the Phillips curve in the United States is generally verified, Chinese data doesn't quite agree with the equation after the first look at the data. The "clockwise" pattern doesn't appear on the unemployment-inflation coordinate.[2] Much domestic research has proposed various models to accommodate the model with data. They generated quite different curves and interpretation. The earliest papers fail to verify the existence of the unemployment-inflation Phillips curve (Zhang [2003]), probably due to the low quality of the official unemployment data. Later papers focus on the output gap Phillips curve and the estimated slope varying from 0.08 (Chen [2008]) to 0.86 (Zheng and Guo [2013]). In general, there is little consensus on the magnitude of the slope. Some consensus has been reached on the importance of other building elements of the Phillips curve. For example, many papers (Bin [2011],Chen [2008], etc) found that the supply side shock also plays an important role in the formation of inflation. However, the magnitudes of these components also vary.



(a) US: Clockwise pattern

(b) China: No Clockwise pattern

Figure 1: The different patterns of inflation-unemployment dynamics of US and China

The expectation of inflation also plays a pivotal rule in the NKPC. Nevertheless, how to measure it remains an unsettled issue that arouses great academic attention. While many papers shed light on the identification of the inflation expectation in America (Lovell [1986],Coibion et al. [2018]). Existing literature pays little attention to gauging

[2]See fig. 1. Data source: https://www.thebalance.com/unemployment-rate-by-year-3305506.

inflation expectation in China. Among the papers measuring the Phillips curve, some papers try to proxy it with other measurements such as the survey inflation expectation. However, these structural models at the same time relax the structural assumption that the coefficient of the expectation term is exactly β. Some papers get an unrealistically large coefficient (such as 1.9-6.9 in Chen [2008]). Another prevailing approach is to take the lead inflation directly as the rational expectation of inflation while treating the error term as the expectation error. These papers usually don't take much effort to the rationality of their approach to proxy the inflation expectation. In fact, this approach avoids instead of solving the issue of measuring the expectation.

Among the vast literature measuring the Phillips curve in China, few of them utilize the cross-sectional variation of the panel data (except Bin [2011],Mehrotra et al. [2010]). Both papers relax the structural assumption on the coefficient of $\mathbb{E}[\pi]$, while leaving the other terms of the model still structured. They also directly use the lead realized inflation for the inflation expectation without much discussion. Besides, the data they used in their models was pre-recession. But it's not guaranteed that the previous result is still valid after 10 years. For example, the Phillips curve was "dead" but then again "alive" for several times in America. And the post-recession decade is featured with a flattening pattern of the Phillips curve. Moreover, China is on the trajectory of structural change, such as marketization, and has stepped into a new era of slower growth. Thus an updated measurement is meaningful given the dynamic nature of the Phillips curve and the rapidly changing structure of the Chinese economy.

This paper is aimed to look into three questions. First, I'll re-estimate the structured and unstructured Phillips curve using Chinese official panel data and see if there is some variance between these two settings (structural and nonstructural) or with the previous work. The reason for using the panel data is that the number of observations will be greatly amplified and we can utilize the year fixed effect. Second, I'll propose an expedient approach to handle the expectation term. Instead of looking for another proxy measurement, I resort to the year fixed effect to absorb part of the inflation expectation. The rationale for this strategy is based on the assumption that the expectation is formed upon the information that's only relevant locally as well as the nationally shared knowledge, which presumably contributes to a large portion of the total expectation. Last but not least, since the quality of the official data is often queried, I'll replicate the estimate using the night-light data as a proxy for the output as a robustness check.

fig. 2 scatters the output gap $\tilde{y}$ (proxied by night light) and inflation π of 9 randomly chosen provinces. As we can see, without any control, there seems to exist a Phillips curve for each province. Our empirical work will further examine the validity of this finding.

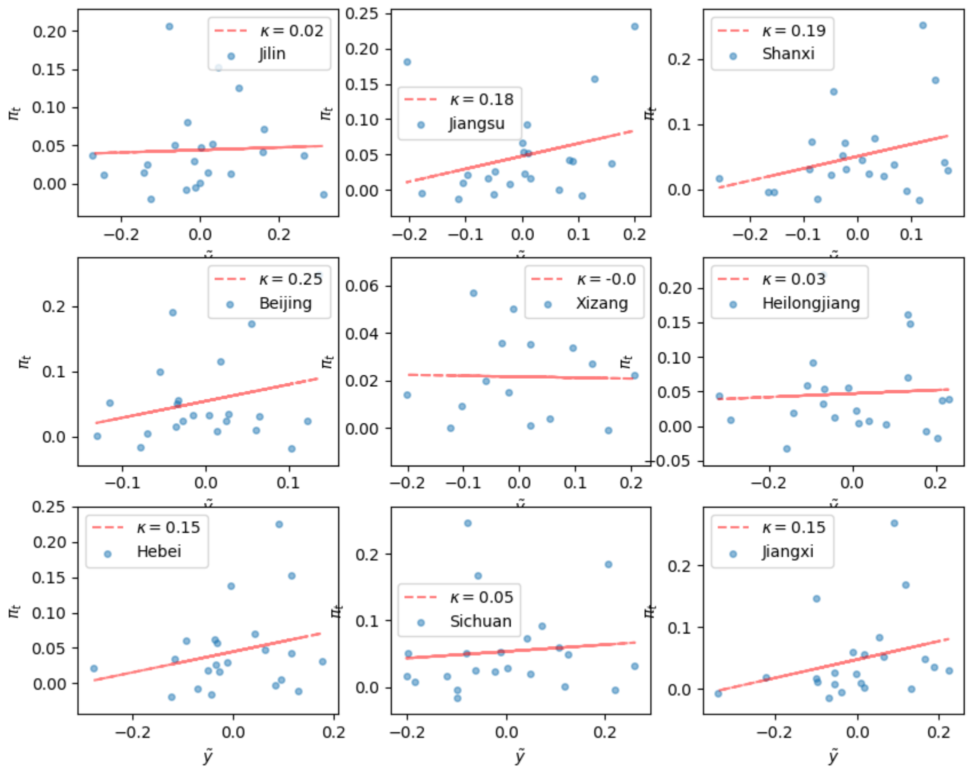


Figure 2: Phillips curves for 9 randomly chosen provinces

The rest of the paper will be organized as the following: In section II, I will summarize the existing literature measuring the Phillips curve both in China and other countries. In this part, I'll focus on the assumption and the empirical methodology of their models as well as the estimated results. Section III will discuss the source of our data and how the variables in the regression are constructed. A detailed explanation of the model and empirical strategy will also be presented in this section. Section IV will discuss the result of our estimates and their interpretation. Section V concludes and suggests some proposals for the future research.

2 Literature Review

Since the pioneering paper of Phillips [1958], the Phillips curve has become an integral feature of New Keynesian macro models. The early version of the Phillips curve simply described the trade-off between inflation(wage) and output(unemployment). Friedman first emphasizes the rule of expectation in the Phillips curve. He claims that output would only react to unanticipated monetary fluctuation. Based on adaptive expectation, Solow and Gordon et al. argues that the policy can utilize the unemployment-inflation trade-off even in the long run. This claim was dismissed during the "stagflation". Then came the "Lucas critique"(Lucas Jr) that individuals will form expectations rationally based on current information and any attempt to calibrate a Phillips curve from past is in vain.

Later on, the New-Keynesian Phillips curve (NKPC) based on full information rational expectation (FIRE) and sticky price (or wage) gradually prevailed. The most popular setting is the one in Calvo [1983], where only a portion of the firms can reset their price based on the expectation of future markups in each period. The resulting Phillips curve is eq. (1). However, the assumption that all the firms have rational expectations in setting their prices is not guaranteed in reality. An increasing list of the literature (such as Johnson et al. [1995]) suggests that the real world lies somewhere between fully rational and adaptive expectations. Galı and Gertler accommodates firms' adaptive expectation and generates the curve as $\pi_t = \lambda_f E_t\pi_{t+1} + \lambda_b\pi_{t-1} + \kappa\tilde{y}_t$[3]. In the real economy, inflation might be driven by the supply side price shock such as the inflation of fixed asset price or commodity (Gordon [1997]). The complete version of the Phillips curve should have the supply side price shock as the third building block, and thus becomes $\pi_t = \lambda_f E_t\pi_{t+1} + \lambda_b\pi_{t-1} + \kappa\tilde{y}_t + \gamma ss_t$.

There is a vast empirical literature offering supportive evidence to the existence of the Phillips curve in America. The first question is how to choose and construct the R.H.S. variable of eq. (1). Since the firm's mark up is unobservable, the output gap and unemployment rate are more desirable independent variables. The usual way to generate the output gap is to detrend the time series by a filter. [4]. Hodrick and Prescott [1997]

[3]This equation is also called the "hybrid NKPC". It becomes purely forward-looking if we drop π_{t-1} from the R.H.S, and purely backward if dropping $E_t\pi_{t+1}$

[4]Like band-pass(BK) filter(Baxter and King [1999]), CF filter(Christiano and Fitzgerald [2003]), and

suggests that the HP filter applies to most of the tasks. The second question is how to estimate the expectation term. A branch of papers tried to proxy the expectation using survey data(Coibion et al. [2018]). However, this approach is controversial and the expectation proxied by the microdata seems far from rational (Mankiw and Reis [2002]), which gives good reasons to incorporate the adaptive expectation into the model. Another branch of literature applies various econometric methods to estimate the curve. For example, Schorfheide [2008] uses least square estimate and get a set of $\hat{\kappa}$'s and $\hat{\lambda}$'s in different decades using various filters. [5]. The resulting κ range from 0 to 0.03 and λ ranges from 0 to 0.005, which is far below what the theory implies. Importantly, he shows that LS regression underestimates these parameters in that the markup shock $\tilde{\xi}_t$ is negatively correlated with output (attenuation bias). He also claims that lagged output and inflation are weak instruments because the lagged endogenous variable is uncorrelated with current output in equilibrium.[6] Using DSGE model, he redresses his estimate for κ of 0.1 and λ in [0.1,0.2]. The author also lists a range of DSGE based estimates in other literature. Those estimates vary from 0.001 (Cho and Moreno [2006]) to 4.15 (Canova [2009]). The divergent results suggest that the Phillips curve is dynamic in nature. But chances are that the models are yet complete or the empirical approaches are not robust enough.

Another prevailing method is the GMM estimate. GMM is a more general version of instrumental estimate. In estimating the Phillips curve, a usual strategy is to adopt the lagged endogenous variables as the instrumental variables. As we'll discuss later, this method is as popular as the DSGE estimate in Chinese literature. And we will also resort to GMM to implement an instrumental estimate. But another much simpler approach that we'll propose in Sector III is to use the year fixed effect to absorb part of the inflation expectation in the year fixed effect using panel data. Some literature has shed light on this approach. Ashenfelter et al. [1984] suggests that we can dispense with the effort to identify the supply shock and inflation expectation because they are largely shared across regions. He used the panel data from Canada, USA, and the UK and found that the Phillips curve was still there during the stagflation. DiNardo and

production function method.

[5]The models here are essentially $\pi_t = \beta E_t \pi_{t+1} + \kappa \tilde{y}_t + \tilde{\xi}_t$ or $\pi_t = \beta E_t \pi_{t+1} - \lambda \hat{MC}_t + \tilde{\xi}_t$

[6]The uninformativeness of the lagged variables as instruments is model-specific. This instrumental approach was nevertheless still widely used in academia and will also be used in this paper.

Moore [1999] follows Ashenfelter's work and construct an open-economy Phillips curve using panel data from 9 OECD countries. He estimates a coefficient of unemployment ranging from 0.3 to 0.6 for an unemployment-inflation model, which implies a κ of about 0.2 for an output-gap-inflation model. The estimates of both papers are larger than those mentioned earlier, suggesting that either the Phillips curve is steeper in a larger scope. Based on their work, it's a natural idea to extend this research to China.

There are many papers concerning Chinese Phillips curves. The early works discussed the external validity of the Phillips curve in China and brought about some variations from the mainstream model. For example, Li argues that since the rural and urban labor market are separated in China, an increase of labor demand from the urban industry will attract more peasant workers instead of lowering the urban unemployment rate, indicating a vertical Phillips curve. Zhang provides empirical evidence to this feature. But the validity of his result is compromised by the variation-lacking, suspect official unemployment data.

Most of the later works thus avoid using the unemployment rate and focus on the output-gap based Phillips curve. The first branch of them uses GMM. Chen found that κ lacks statistical significance but the coefficient of the lagged output gap is about 0.08(and significant), which is interpreted as the hysteresis of demand-side force. Zeng et al. [2006] also estimate some κ's from 0.26 to 0.52. Both papers choose lagged variables as instruments when conducting GMM. The second branch of papers simply adopts linear regression. Scheibe and Vines [2005] estimates a set of κ of a hybrid forward-looking NKPC in the magnitude of about 0.03. The third branch of works is based on structural models like DSGE and VAR. For example, Zheng and Guo [2013] build a small open economy model and estimate a κ of 0.86. Most of the estimates are higher than those of American Phillips curves.

A few papers estimate the Chinese Phillips curve from the panel data. Mehrotra et al. [2010] uses the annual data and estimates a κ of 0.006 for the hybrid NKPC without supply shock. The author also found the Phillips curve is dynamic across periods and provinces. Bin [2011] re-estimated the model and incorporated the external supply shock proxied by the interaction of the trade-dependency index and the CRB index[7]. The estimate of κ is 0.013 based on quarterly data. Both papers incorporate the lead inflation

[7] CRB is a price index of 22 economy-sensitive commodities composed by the Commodity Research Bureau.

π_{t+1} into the model and treat the error as expectation error. They also both rely on the GMM method instrumented by lagged endogenous variables. Therefore, they didn't utilize the year fixed effect to absorb inflation expectation and supply shocks[8]. No work has been done at the city level. And we'll further examine the existence of the Phillips curve in a more local scope.

However, researches using official data are prone to the query of authenticity. For example, Movshuk [2002] emphasizes the possibility that local governments may exaggerate the figure. Recently, night-light has become a popular proxy for local development (Michalopoulos and Papaioannou [2013]). And as an application in China, Kangning et al. uses this data to defend the authenticity of the Chinese official data by fitting the latter with the former. This paper will extend the estimate to a "night-light Phillips curve" as an innovation and a robustness check.

3 Description of Data and Model

3.1 Model and empirical strategy

This paper examines the existence of the Phillips curve in China using panel data. The model is to some extent structured, following the setting in [Galí, 2015, ch 5] in theory. Suppose that only a fraction θ of the firms can reset their prices in each period. The imperfect substitution of goods endows them with some monopoly power and thus positive markups. However, as the output fluctuates due to the demand-side shocks, the realized markup will vary. For example, when people become more patient, they will consume less and work less because leisure and consumption are substitutes. In equilibrium, the wage will fall. And with less labor in the industries, the increase in the marginal production further lower the cost and lift the markups for those firms that can reoptimize in this period. As a result, the reset price will be higher than that would be set without the shock.

This mechanism can be described by the following equation:

$$\pi_t = -\lambda \sum_{s=0}^{\infty} \beta^s E_t\{\hat{\mu}_{t+s}\}$$

[8]Though Mehrotra et al. mentioned this advantage in his literature review

Which is equivalent to

$$\pi_t = \beta E_t \pi_{t+1} - \lambda \hat{\mu}_t$$

or

$$\pi_t = \beta E_t \pi_{t+1} + \kappa \tilde{y}_t$$

where $\hat{\mu}_t$ is the "surplus markup", i.e. the gap between the realized markup and its natural counterpart. And $\tilde{y}$ is the "output gap" defined similarly.

The estimate will proceed in five steps. First, we estimate the κ in the baseline equation 2, based on a strong assumption that the model is strictly structured. We impose a discount factor β of 0.953, taking $\xi_{i,t}$ as an expectation error $E_t \pi_{t+1} - \pi_{t+1}$, and don't allow the constant term. However, the assumption that all the firms have rational expectations is not guaranteed in reality. An increasing list of the literature suggests that the real world lies somewhere between fully rational and adaptive expectations. Thus we'll relax our assumption to allow the firms' adaptive expectation (or backward expectation) by splitting the inflation into two terms as 3.

$$\pi_{i,t} = \beta \pi_{i,t+1} + \kappa \tilde{y}_t + \xi_{i,t} \tag{2}$$

$$\pi_{i,t} = \lambda_f \pi_{i,t+1} + \lambda_b \pi_{i,t+1} + \kappa \tilde{y}_t + \xi_{i,t}, \quad \lambda_f + \lambda_b = \beta \tag{3}$$

Second, we propose a convenient identification strategy for the inflation expectation term. This term is the integral element of the NKPC and is notoriously difficult to tackle. We propose that we can absorb the inflation expectation formed upon nationally shared information by adding a year fixed effect, and relax the constraint on λ_b and λ_f imposed by a structured model. We still keep the local lead inflation term to capture the information that's only prevailing or relevant locally. We also allow for local fixed effects in this model, which is hard to interpret under the structured model, but is reasonable since the model becomes non-structured with the year fixed effect. Moreover, our model assumes that all provinces share the same pattern of economic fluctuation to derive a general NKPC for the whole country. The local fixed effects can help us capture the heterogeneity among different provinces in a general sense.

Third, since supply shock is another elementary block of the NKPC, our model is prone to the endogeneity issues because the supply shock component in the residual is likely to be correlated with the independent variables. Thus we will incorporate the supply shock by adding a measurement of the domestic and external supply shock and make our model more complete as eq. (4). Next, on account of the endogeneity issue that ξ is correlated with the lead inflation as an expectation error(and possibly containing components that's correlated with other independent variables), I'll implement the IV estimate by GMM using lagged endogenous variables as instrumental variables, which is the conventional methodology in the existing literature. Finally, I'll redo the estimates using the output level proxied by the nightlight data, which is aimed to check whether the nightlight is a good proxy of output in the sense that it captures the fluctuation of the economy, or to examine whether the official data is genuine if we believe the nightlight data is more reliable.

$$\pi_{i,t} = \sum_s \beta^s year_t^s + \lambda_f \pi_{i,t+1} + \lambda_b \pi_{i,t+1} + \kappa \tilde{y}_t + \sum_n \eta^n X_i^n + \xi_{i,t} \tag{4}$$

$$\pi_{i,t} = \sum_s \beta^s year_t^s + \lambda_f \pi_{i,t+1} + \lambda_b \pi_{i,t+1} + \kappa \tilde{y}_t + \gamma ss_{i,t} + \sum_n \eta^n X_i^n + \xi_{i,t} \tag{5}$$

3.2 Data

We derive national and provincial nominal GDP, real GDP, GDP deflator, CPI, labor income share, and population from CEIC China Database. We also collected city-level GDP per capita, gross GDP, CPI, and population data from EPS China Database. In this level, our focus is limited to the cities in the 13 provinces with CPI records. The data above is collected in the marketizing period from 1980-2017 and the time windows vary between provinces. The night light data is the annual average stable, cloud-free light downloaded from the NOAA website, only available from 1992-2013. We choose 3 potential measures of supply shocks. We derive from CEIC the fixed assets price from 1990-2017 (panel) and the leaving-factory-PPI from 2000-2013 (panel). We also have the national level time series of the price of imported crude oil from 1989-2017, which will be manipulated into panel data by multiplying the "capital share" α, which is computed by $1 - \frac{laborincome}{GDP}$.

The data is processed as the following. We first deflate the local nominal output and divide them by the local population. Since the local GDP deflator data isn't available, we use the national GDP deflator instead. As the fig. 3 shows, the national GDP deflator lies among the local CPI's in most of the years. The reason why we're not deflating using local CPI is that the CPI will also enter the model as the dependent variable. Then we use HP filter[9] with $\lambda = 6.5$ to detrend the log real per capita output to generate the output gap $\tilde{y}$. Similarly, we take the mean of the lumen within one province to proxy the output. And we define the "effective lumen" as the average lumen divided by population density because a higher average lumen is likely to be caused by a denser population. Under the assumption that the lumen grows in proportion to the output, we let the log effective lumen to proxy the log output. Then we compute the "lumen gap" using the same filter as the counterpart of the output gap.

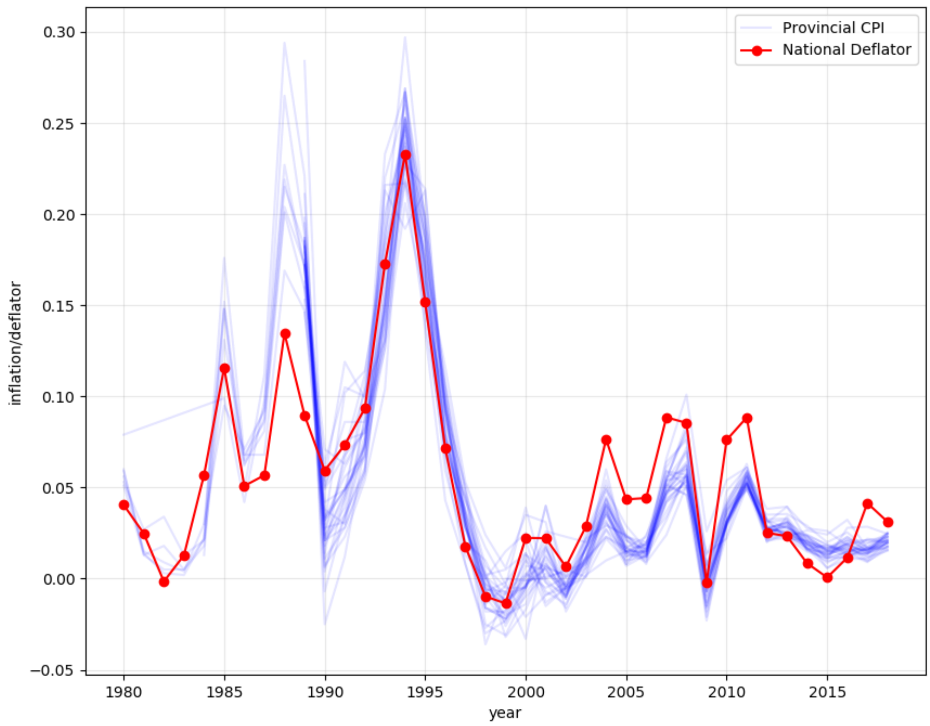


Figure 3: Provincial CPI and National GDP deflator

The supply shock is proxied by three potential measurements, which are the price index of fixed asset (panel), PPI (panel), price of imported crude oil (time series), and their interaction terms with the capital share α (panel). The fixed asset price and the PPI are two alternative measurements of the domestic supply shock, and the crude oil price multiplied by the capital share is the one for the external supply shock. We'll run

[9]Denote the natural output by τ, then $\{\tau_t\} = argmin_{\tau_t} \left[\sum_{t=1}^{T} (y_t - \tau_t)^2 + \lambda \sum_{t=2}^{T-1} \{(\tau_{t+1} - \tau_t) - (\tau_t - \tau_{t-1})\}^2\right]$

two regressions each with one of the domestic shocks and the external supply shock. The reason why we use the variables' interactions with capital share is that the larger the capital share, the more industrialized[10] one province is, and thus the more prone to the supply side's price shocks.

Table 1: Summary Statistics

	count	mean	median	sd	max	min
output gap $\tilde{y}$	682	0.00	0.00	0.02	0.13	-0.07
lumen gap $\tilde{y}\_light$	660	0.00	-0.00	0.12	0.31	-0.48
ln real GDP per capita	682	7.75	7.72	0.75	9.52	6.13
Population (million)	682	40.92	37.14	26.17	106.44	2.28
Population density (100/km^2)	660	3.89	2.68	5.19	37.08	0.02
Efficient lumen	660	-0.03	0.07	0.70	1.51	-2.04
Labor share	660	0.49	0.49	0.08	0.82	0.31
GDP deflator (last year=1)	682	0.06	0.04	0.06	0.23	-0.01
CPI	675	0.05	0.03	0.07	0.30	-0.04
Fixed asset price	638	0.05	0.03	0.07	0.39	-0.04
PPI	397	0.03	0.03	0.06	0.25	-0.15
PPI (purchase 1990=100)	682	263.61	234.00	68.60	379.30	121.10
price index of imported crude oil	651	353.74	217.36	239.99	810.78	116.77
Population (city 10,000)	544	495.36	416.85	275.33	1169.05	34.29
output gap $\tilde{y}$ (city)	3111	-0.00	0.01	0.13	0.60	-0.59
GDP per capita (city)	3095	24666.74	16320.20	24934.70	183544.00	736.00
CPI (city)	2757	0.03	0.02	0.04	0.27	-0.06

A summary of our data is shown in table 1.

4 Curve Estimates

In this section, we'll present the results of our estimates. We focus on whether there is significant evidence for the Phillips curve with a positive slope κ. What we care about further is the magnitude of the coefficients and their variation between different models and proxies of output. Moreover, we're interested in the role that the year fixed effect plays. First, it's designed to absorb the national component of the inflation expectation. Thus we expect λ_b and λ_f to shrink when we add the year fixed effect and relax the structural constraint on them. We can further calculate the attenuation of the sum of λ_f and λ_b and interpret it as the proportion of the total expectation that's shared

[10]The industries refer to the manufacturing and mining especially, which is more vulnerable to the price shocks and related with a higher capital share of income.

nationally. Second, the year fixed effect also captures the national component of local economic fluctuations. Therefore, κ would be expected to be lower upon introducing the year fixed effects because it then only captures the impact of local variation of the output gap on the inflation, while the year fixed effect captures that of the national comovement. Third, the year fixed effect also contains some components of the supply shock which was in the residual and presumably positively correlated with the output gap. Thus the coefficient κ may be even lower when the supply shocks are picked out from the residual. For the same reason, as we further add a more specific measurement of supply shock into the model, the κ may be further lower but closer to its real magnitude. We're also concerned about the potential difference when we proxy the output with the night-time lumen. An ideal result is that both models present similar evidence for the Phillips curve. But if the GDP regression is not as significant as the nightlight regression, we may conclude that either the official data is flawed and possibly trying to manipulate a "smooth" growth, or the nightlight is simply a better measurement of economic activity. If, on the contrary, the GDP regressions work but the nightlight data doesn't agree with the Phillips curve, it's capacity as a proxy for the output may be cast doubt on in the sense that it can't capture the important features of the economic fluctuations.

4.1 Baseline model

The structured baseline model suggests that the evidence is not strong enough to verify the existence of the Phillips curve. If we allow the firm to have adaptive expectation and impose the constraint that the proportion of these two kinds of firms sum up to one, we get an estimated κ of 0.2024 and λ_b of 0.426, which suggests that there exists a Phillips curve and about half of the firms have the adaptive expectation. This magnitude of κ is above much of the slopes of the Phillips curve estimated in America. But it lies in the range of the estimates for China based on the national time series data and those for other countries using panel data [11]. It's surprising that when we remove the constraint in column (3), all the coefficients only change slightly. Noticeably, the sum of these two coefficients is 0.9875, which is close to a reasonable discount factor. The reason why we need this regression is that we need a benchmark to calculate the proportion of the total

[11] For example, 0.08 for China by Chen [2008], 0.26-0.52 for China by Zeng et al. [2006], 0.2 for 9 OECD countries by DiNardo and Moore [1999], etc. The estimates for America are almost below 0.05, see the review in Schorfheide [2008].

expectation of inflation that's nationally shared. As the column(4) shows, when we add the year fixed effects, all the coefficients shrink. The sum of λ_f and λ_b is now 0.486, indicating that about half of the expectation is formed upon the national information. Now the κ reduces more than a half to 0.084 because the year fixed effect grasps part of the impact of the national business cycle on the local inflation rate. This significantly positive κ indicates that there exists a "regional" Phillips curve, as fig. 4 illustrates, that the inflation rate is higher in provinces with higher output gap in the same year.

Table 2: Provincial-level Baseline Regression

	(1) CNS	(2) CNS	(3) OLS	(4) FE	(5) FE	(6) FE	(7) GMM
output gap $\tilde{y}$	0.131	0.202*	0.201*	0.084*	0.004	0.039	0.061***
	(0.096)	(0.092)	(0.089)	(0.040)	(0.026)	(0.026)	(0.010)
F.CPI	0.953	0.527***	0.548***	0.275***	0.155^{+}	0.235**	0.622***
	(.)	(0.010)	(0.010)	(0.063)	(0.080)	(0.080)	(0.003)
L.CPI		0.426***	0.440***	0.211***	0.082	0.108^{+}	0.278***
		(0.010)	(0.011)	(0.056)	(0.086)	(0.062)	(0.003)
Fixed asset price					0.481***		1.037***
					(0.098)		(0.070)
α*fixed asset price					-0.761***		-1.115***
					(0.172)		(0.133)
α*crude oil price					0.063*	-0.024	-0.228***
					(0.027)	(0.059)	(0.002)
PPI						-0.011	
						(0.090)	
α*PPI						0.034	
						(0.161)	
Year_FE	No	No	No	Yes	Yes	Yes	No
Local_FE	No	No	No	Yes	Yes	Yes	No
Cluster	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Supply_shock	No	No	No	No	Yes	Yes	Yes
N	948	917	917	917	704	521	521

Standard errors in parentheses
$^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

As we incorporating the supply shocks into the model, the evidence for the Phillips curve becomes insignificant again no matter we use the fixed asset price or the PPI as the measurement of the domestic supply shock. The column(5) shows that the inflation of the fixed asset price has a strong impact on CPI, indicating that the supply shock is a strong driving force on Chinese goods' inflation by influencing the investment cost of the firms, and is probably stronger than the demand shocks. But it's also possible

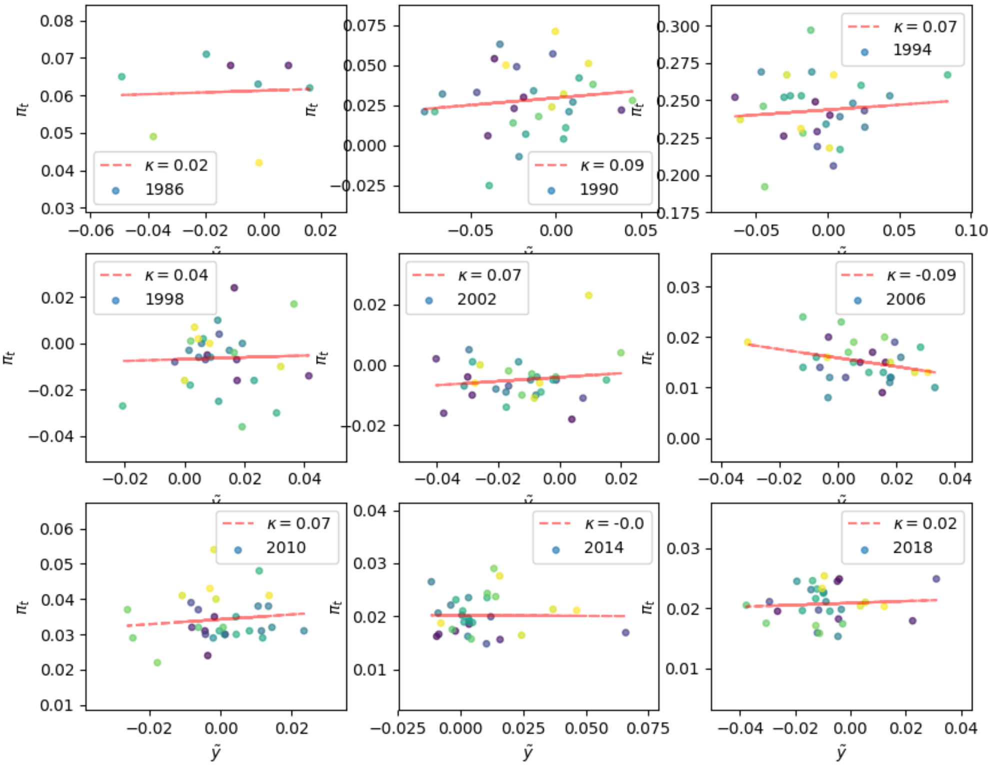


Figure 4: "Regional Phillips curve": provinces with higher output gap have higher inflation

that the fixed asset price is only a proxy for the output gap and absorb it's coefficient, thus rendering it insignificant. The external supply shock has only a slight impact on the current year's domestic inflation. For two provinces with a difference of 0.1 in α, 10% increase of the imported crude oil price only brings a difference of 0.06% in inflation. It's, however, hard to interpret why the province with a larger capital share is less sensitive to the fluctuation of the fixed asset price. When we use PPI as the domestic supply shock in column(6), all the coefficients become insignificant. The reason could be that the PPI also contains the price of the intermediate and ultimate goods, and thus isn't a good measurement of the supply shock. The last column reports the result of GMM estimate instrumented by the lagged one and two-period terms of the independent variables.[12] The result suggests strong evidence for the existence of the Phillips curve with a slope reducing to 0.06. The domestic supply shock's impact is even stronger than the previous regression, indicating that a one percent increase in the price of fixed asset will push the

[12]Hansen's J statistic is 29.97, p-value is 0.226 indicating no overidentification problem.

inflation up by 0.37 percent if the capital share is 0.6. The coefficient of the external supply shock is, however, at odds with our expectation. One possible reason is that oil prices alone can't represent all the imported raw material. Furthermore, the capital intensive provinces such as Inner Mongolia may rely less on the imported energy either because they are also rich in alternative natural resources or their economies are less open and trade-dependent.

As a summary, we observe fairly strong evidence form the panel data for the existence of the Phillips curve. When we incorporate the supply shock into our model, we find evidence that the domestic supply shock has an impact on inflation. However, the significance and magnitude of the slope wanes, while the GMM estimate provides evidence that the Phillips curve can accommodate the internal supply shock. Since the error term ξ is possibly correlated with the independent variables when interpreted, for example, as the expectation error, the GMM is more reliable in that it can tackle the endogeneity problem.

4.2 Nightlight Model

In this section, we proxy the output with "efficient lumen" defined as the average lumen divided by population density. We detrend the log efficient lumen by the HP filter and generate the "lumen gap" as the counterpart of the output gap. As shown in the summary table 1, the standard deviation of the "lumen gap" is 6 times higher than that of the output gap. Thus if we believe that the fluctuation in real output and the lumen are one-for-one, then the coefficients must be multiplied by 6 to compare it with the results in the previous section [13]. As table 3 shows, the estimates are similar when we use the "lumen gap" instead of output. But there are several differences worth noticing. First, the slope of the Phillips curve is generally higher than before. The coefficient 0.087 suggests a κ of 0.522. Second, adding year fixed effects turn all the coefficients mute, in contrast with the regression in the previous section. This suggests that a larger part of the movement

[13] However, there is no guarantee that the relationship is one for one. More generally, we assume the fluctuation in per capita real GDP is proportional to the fluctuation in the effective lumen. By OLS regression, one percent fluctuation in real per capita GDP corresponds to about 0.62 percents' fluctuation in the efficient lumen. Thus the coefficient should be multiplied by 10 instead of 6. Nevertheless, the long-run relationship doesn't necessarily reflect the short-run relative volatility. Thus the higher slope may not be a puzzle. In this case, if we believe there is only one valid Phillips curve, then we can instead calculate their relative volatility in the short run. The results in the tables suggest that one percent fluctuation in real per capita GDP corresponds to about 2.5 percents' fluctuation in the efficient lumen.

in the lumen might be shared nationally. And year fixed effect might absorb variations beyond the nationally shared expectation.

Table 3: Estimates based on nightlight-proxied output

	(1) CNS	(2) CNS	(3) OLS	(4) FE	(5) FE	(6) FE	(7) GMM
lumen gap	0.087***	0.077***	0.070***	-0.007	0.004	0.005	0.045***
	(0.014)	(0.010)	(0.010)	(0.010)	(0.006)	(0.007)	(0.007)
F.CPI	0.953	0.509***	0.599***	0.173	0.163+	0.150	0.615***
	(.)	(0.007)	(0.012)	(0.126)	(0.088)	(0.094)	(0.008)
L.CPI		0.444***	0.489***	0.142+	0.083	0.066	0.338***
		(0.007)	(0.006)	(0.080)	(0.091)	(0.079)	(0.008)
Fixed asset price					0.490***		0.983***
					(0.104)		(0.100)
α*fixed asset price					-0.769***		-1.007***
					(0.180)		(0.184)
α*crude oil price					0.074*	-0.017	-0.219***
					(0.033)	(0.076)	(0.003)
PPI						-0.044	
						(0.145)	
α*PPI						0.059	
						(0.250)	
Year_FE	No	No	No	Yes	Yes	Yes	No
Local_FE	No	No	No	Yes	Yes	Yes	No
Cluster	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Supply_shock	No	No	No	No	Yes	Yes	Yes
N	623	593	593	593	538	354	354

Standard errors in parentheses

$^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

To summarize, the result based on the output proxied by GDP or nightlight agrees with each other. Therefore, the nightlight is a valid proxy for the output, and the official GDP data are reliable in the sense that they all capture the fluctuating feature of the economic activity. The Phillips curve exists in China with all three building components, i.e. the expectation of inflation, demand shock, and supply shock. Year fixed effect can serve to absorb the nationally shared inflation expectation. It may also capture a portion of the supply shock and the comovement of local output, which might make the model prone to overcontrolling.

4.3 City Level Regional Phillips curve

We further look into the city level data to examine whether there is a Phillips curve at this level. The baseline structured model suggests strong evidence for the existence of the Phillips curve that's however even flatter than the provincial level Phillips curve. The coefficient dramatically shrinks when I incorporate the adaptive expectation into the model and relax the constraint on the coefficients. This result indicates that the Phillips curve in a more local scope may be flatter.

Table 4: Estimates of the City Level Regional Phillips Curve

	(1)	(2)	(3)	(4)
	CNS	CNS	OLS	FE
F.CPI (city)	0.953	0.503***	0.425***	0.132***
	(.)	(0.004)	(0.005)	(0.025)
L.CPI (city)		0.450***	0.436***	0.122***
		(0.004)	(0.005)	(0.023)
output gap $\tilde{y}$ (city)	0.039***	0.004*	0.008***	-0.004*
	(0.004)	(0.002)	(0.002)	(0.002)
Year_FE	No	No	No	Yes
Local_FE	No	No	No	Yes
Cluster	Yes	Yes	Yes	Yes
N	2572	2410	2410	2410

Standard errors in parentheses

$^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

To examine whether this conclusion is true, we scatter the output and inflation at both the national and provincial level of all the years in fig. 5. As one can see, the national Phillips curve has a slope of 1.86, more than 10 times steeper than the provincial Phillips curve. The reason is that the observations in the province-level are more dispersed than the national observations, which is the aggregate of all the provinces. While the output varies greatly across provinces in one year, the variance in inflation is not as high(which is also shown in fig. 3). Thus the observations are more dispersed in the horizontal axis (output gap). This leads to a lower estimated slope at the province level than the national level.

Similarly, one can imagine that the cities in one province have less variance in the inflation than the output because the price will probably converge due to the integrated market while the growth is not guaranteed to converge due to the inequality of local development. Thus chances are that the observations in the city level are more dispersed in the output dimension. And the resulting slope is therefore even lower.

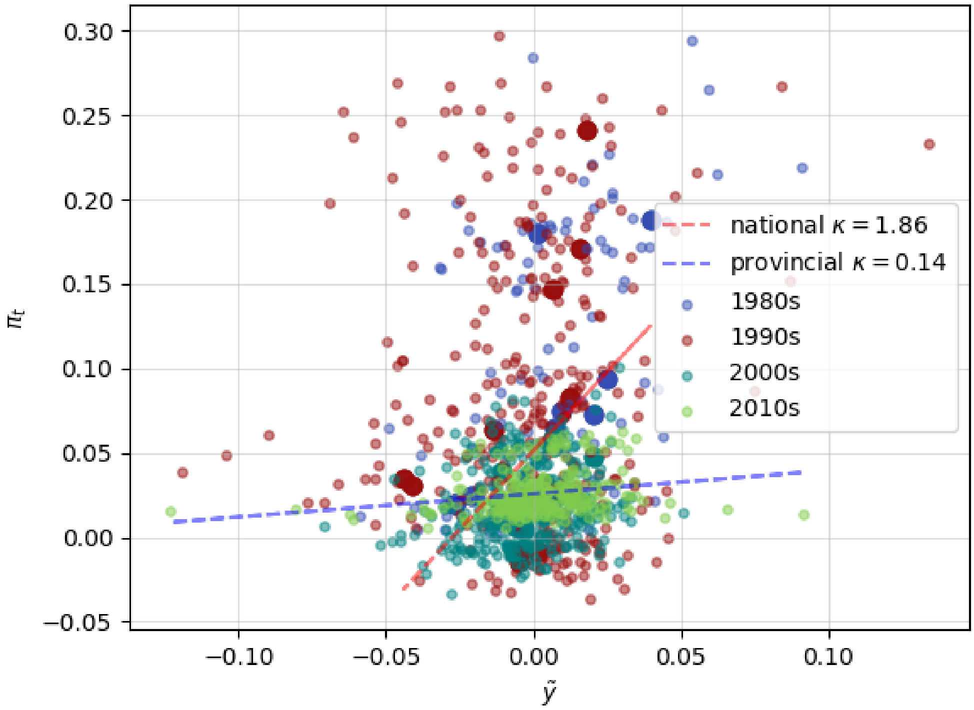


Figure 5: Provincial Phillips curve is flatter than the National Phillips curve

This feature of the panel estimate is worth noticing. In general, it's easier to observe a steeper Phillips curve at a more aggregate level. That may partly explain why the panel estimated mentioned above (DiNardo and Moore [1999] Ashenfelter et al. [1984]) get slope higher than most of the estimates in the United States.

Another unexpected difference in this level is that the coefficient κ goes significantly negative after controlling the year fixed effect. This result indicates a strong national co-movement in the output, i.e. the output gap is higher for most of the cities in the booming era but lower in the recession. As the local level variation on the inflation-output-gap coordinate (mainly the variation in inflation) is lower at the city level, the year fixed effect absorb not only a larger portion of the inflation expectation [14] but also a larger portion of the output gap's (surplus demand) impact on the inflation. Based on this analysis, a significantly negative coefficient of -0.004 is not a contradiction of the existence of the Phillips curve but only implies that the local variation is so little that the national level variation always dominates.

[14] As a by-product, we conclude that the nationally shared expectation contribute to 1-(0.132+0.122)/0.953=74% percent of the total inflation expectation.

5 Conclusion and Discussion

We state our major conclusions:

Conclusion 1: The Phillips curve does exist. The "regional level Phillips curve" also exists at least at the province level but may disappear as we look into the city level due to lack of local variation especially in inflation.

Conclusion 2: The year fixed effect can absorb the nationally shared inflation expectation but also absorb a large part of the output gap's impact on the inflation rate. That's because the comovement of the output was captured by the year fixed effect. At the province level, half of the expectation is formed upon national information. At the city level, the proportion increases to 74%.

Conclusion 3: The Phillips curve is robust to the output proxied by the nighttime "efficient lumen".

Other details are also worth summarizing. First, adaptive expectation is an important feature of Chinese Phillips curve. Second, as the column (2) and (3) in table 2 shows, the structured model and the unstructured model agree with each other's measurement of the proportion of the agents that have rational expectation. We find that about 55% of the agents have rational expectations. However, this result is prone to the correlation between the lead and the lagged inflation. Using GMM, we estimate that 62% of the agents have the rational expectation. The same instrumental estimate also gives the most conservative value of κ. Last but not least, the supply shock proxied by the fixed asset price plays an important rule in the formation of good inflation.

Several questions remain unsettled. First, it's hard to interpret the negative coefficient of the interaction term of α with the fixed asset price and the oil price. Chances are that the variation in α is not large enough, or the interpretation of α as the extent of industrialization and sensitivity to the supply shock is problematic. It's also probably because the price of the imported oil itself isn't representative of all the commodities. Second, it's hard to unify the estimate using GDP and the one with night light. The coefficient of the "lumen" gap is inconsistent with that of the output gap after being rescaled by the relative volatility of the lumen and the output. But since the results don't contradict each other, we can conduct further research using the GDP only and not necessarily go with both.

Like many other papers estimating the Phillips curve, this paper only provides one approach in estimating the curve and suggests a range for the slope but isn't able to generate an invariant estimate in all the regressions. Further work could try to investigate in more detail the changes of the Phillips curve's slope in different levels (beyond the country, national, provincial). It's also meaningful to decompose the year fixed effect into several components such as the nationally shared inflation expectation, the comovement of output and supply shock, which might require more instrumental variables and a more structural approach.

References

O. Ashenfelter et al. Macroeconomic analyses and microeconomic analyses of labor supply. In *Carnegie-Rochester Conference Series on Public Policy*, volume 21, pages 117–156. Elsevier, 1984.

M. Baxter and R. G. King. Measuring business cycles: approximate band-pass filters for economic time series. *Review of economics and statistics*, 81(4):575–593, 1999.

L. Y. S. Bin. The re-estimation of output gap-based phillips curve under open economy condition: Based on the provincial quarterly dynamic panel data [j]. *Journal of Financial Research*, 10, 2011.

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

F. Canova. What explains the great moderation in the us? a structural analysis. *Journal of the European Economic Association*, 7(4):697–721, 2009.

X. Chen. Research on new keynesian phillips curve in china. *Economic Research Journal*, 12:50–64, 2008.

S. Cho and A. Moreno. A small-sample study of the new-keynesian macro model. *Journal of Money, Credit, and Banking*, 38(6):1461–1481, 2006.

L. J. Christiano and T. J. Fitzgerald. The band pass filter. *international economic review*, 44(2):435–465, 2003.

O. Coibion, Y. Gorodnichenko, and R. Kamdar. The formation of expectations, inflation, and the phillips curve. *Journal of Economic Literature*, 56(4):1447–91, 2018.

J. DiNardo and M. P. Moore. The phillips curve is back? using panel data to analyze the relationship between unemployment and inflation in an open economy. Technical report, National Bureau of Economic Research, 1999.

M. Friedman. The role of monetary policy. *The American Economic Review*, 58(1):1–17, 1968.

J. Galí. *Monetary policy, inflation, and the business cycle: an introduction to the new Keynesian framework and its applications*. Princeton University Press, 2015.

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

R. J. Gordon. The time-varying nairu and its implications for economic policy. *Journal of economic Perspectives*, 11(1):11–32, 1997.

R. J. Gordon, R. Solow, G. Perry, and R. Gordon. The recent acceleration of inflation and its lessons for the future. *Brookings Papers on Economic Activity*, 1970(1):8–47, 1970.

R. J. Hodrick and E. C. Prescott. Postwar us business cycles: an empirical investigation. *Journal of Money, credit, and Banking*, pages 1–16, 1997.

M. D. Johnson, E. W. Anderson, and C. Fornell. Rational and Adaptive Performance Expectations in a Customer Satisfaction Framework. *Journal of Consumer Research*, 21(4):695–707, 03 1995. ISSN 0093-5301. doi: 10.1086/209428. URL https://doi.org/10.1086/209428.

X. Kangning, C. Fenglong, and L. Xiuyan. The truth of china economic growth: evidence from global night-time light data. *Econ. Res. J*, 9:17–29, 2015.

Li. Chinese phillips curve and oken's law under dual economy circumstance. *The Journal of World Economy*, 28(8):51–59, 2005.

M. C. Lovell. Tests of the rational expectations hypothesis. *The American Economic Review*, 76(1):110–124, 1986.

R. E. Lucas Jr. Econometric policy evaluation: A critique. In *Carnegie-Rochester conference series on public policy*, volume 1, pages 19–46. North-Holland, 1976.

N. G. Mankiw and R. Reis. Sticky information versus sticky prices: a proposal to replace the new keynesian phillips curve. *The Quarterly Journal of Economics*, 117(4):1295–1328, 2002.

A. Mehrotra, T. Peltonen, and A. S. Rivera. Modelling inflation in china—a regional perspective. *China Economic Review*, 21(2):237–255, 2010.

S. Michalopoulos and E. Papaioannou. National institutions and subnational development in africa. *The Quarterly journal of economics*, 129(1):151–213, 2013.

O. Movshuk. The reliability of china's growth figures: A survey of recent statistical controversies. *The Journal of Econometric Study of Northeast Asia*, 4(1):31–45, 2002.

A. W. Phillips. The relation between unemployment and the rate of change of money wage rates in the united kingdom, 1861–1957 1. *economica*, 25(100):283–299, 1958.

J. Scheibe and D. Vines. A phillips curve for china. 2005.

F. Schorfheide. Dsge model-based estimation of the new keynesian phillips curve. *FRB Richmond Economic Quarterly*, 94(4):397–433, 2008.

R. M. Solow. *Price expectations and the behavior of the price level: lectures given in the University of Manchester*. Manchester University Press, 1969.

L. Zeng, J. Xu, and G. Tang. An open economy new keynesian hybrid phillips curve of china. *The Journal of Quantitative and Technical Economics*, 23(3):76–84, 2006.

Zhang. Empirical research on the phillips curve of china from 1979 t0 2000. *Management Science*, (2):78–82, 2003.

T. Zheng and H. Guo. Estimating a small open economy dsge model with indeterminacy: Evidence from china. *Economic Modelling*, 31:642–652, 2013.