Endogenous Phillips Curve

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Abstract

Coming Soon

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1 Introduction

Inflation, as the long-time topic in macroeconomics, is affected by not only real variables such as GDP and unemployment but also people's expectation. Phillips curve, suggested by Phillips (1958), is the one of representative tool to express such a complicated relationship. Friedman (1968) added inflation expectation on the Phillips curve and it became a cornerstone in inflation literature. However, due to the measurement of inflation expectation and lack of theoretical background, the Phillips curve was blamed, though it has gotten more attention in the analysis of monetary policy's effectiveness or dynamics.

Despite of huge inflow and outflow of liquidity in money market since the global financial crisis, the behavior of inflation is in doubt. Krugman, in his New York Times' opinion, stated that we would be deep inflation by now if the theory worked. Therefore, the puzzle regarding the inflation is summarized in two-folds,according to Conti (2021). First one is that deflation was not severe during the turmoil by the global financial crisis. Gilchrist et al. (2017), and Coibion and Gorodnichenko (2015) pointed out the role of global and financial factors or the relevance of inflation expectations for th reason of missing deflation. On the othe hand, Yellen (2015), Conti (2015) pointed out de-anchoring in expectation and inflation was not severe after liquidity measures were implemented to cope with the turmoil. This view is called as "missing inflation".

This strand of the literature has been accompanied by a more specific debate, which also precedes the low-inflation period, on the usefulness of the Phillips curve for describing and forecasting inflation. In particular, a flattening of the Phillips curve since the early 1960s has been documented (Blanchard et al., 2015), whereas evidence of a more recent steepening after 2008–09 has been provided by Riggi and Venditti (2015). Such non-trivial shifts in the relation between inflation and economic activity, coupled with disappointing inflation dynamics in spite of the economic recovery, triggered investigation ofwhether the Phillips curve was "dead"[1] While these authors

[1]See Ball (2019), Hindrayanto et al. (2019), Hooper et al. (2020), Coibion and Gorodnichenko (2015), Laseen (2016), Bobeica (2019).

conclude that the Phillips curve is alive, higher inflation has still failed to materialize notwithstanding the strong improvement in economic dynamics and labour market outlook that characterized most of the advanced economies before the outbreak of Covid-19[2].

Whatever the view is called, in terms of Phillips curve, the link between changes in US inflation and the output gap(or unemployment gap) weakened in recent decades. Over roughly the same period, a positive link between the level of U.S. inflation and the output gap has emerged, reminiscent of the original 1958 version of the Phillips curve. As Yellen (2019) remarked, "The slope of the Phillips curve—a measure of the responsiveness of inflation to [economic] slack—has diminished very significantly since the 1960s", there comes up many hypothesis regarding the issue. Jørgenssen and Lansing (2021) summarized those hypotesis in five views. These include (1) structural changes in the economy that have reduced the inflationary pressure of gap variables, (2) the successful stabilizing effects of monetary policy in response to supply shocks that push inflation and the output gap in opposite directions, creating the statistical illusion of a declining gap coefficient, (3) vigilant monetary policy that has served to anchor people's inflation expectations, and hence inflation itself, to a value near 2%, (4) demographic shifts or other slow-moving forces that have contributed to mismeasurement of the gap variable, and (5) the existence of a nonlinear relationship between inflation and the gap variable, causing the gap coefficient to become smaller in magnitude when inflation is low or less volatile.

In this paper, we suspected whether the change of coefficients could be explained endogenously not by external factors to develop the universal Phillips curve which can be applied in any state. In this sense, we propose endogenous Phillips curve where the coefficient changes by the regime change. This model is robust to the choice of inflation measure, inflation expectation and natural rate of unemployment. Regime change is suitable to explain the change of relationship between inflation and unemployment slack since there has been dramatic change in inflation such as

[2]This favourable economic outlook was also the result of a period of extraordinary monetary stimulus:Yellen (2015) discusses the role of monetary policy in a low-inflation environment; Conti (2017) uses a Bayesian VAR model to study the conduct of the FED's monetary policy and its implications for the dynamics of US core inflation and wage growth.

Oil shock, the Great Moderation and the Great Recession. Those events ruined the accurate estimation of coefficients and by removing those effects, we can observe less volatile result. Though there must be external factors to make a change in the Phillips curve, we assume that the dynamics of inflation and unemployment slack can be explained endogenously.

Literature regarding the regime switching framework of Phillips curve has been studied by Amisano and Fagan (2013) who develop a time-varying transition probabilities Markov Switching model in which inflation is characterised by two regimes (high and low inflation). A smoothed measure of broad money growth has important leading indicator properties for switches between inflation regimes. Thus money growth provides an important early warning indicator for risks to price stability. Nalewaik (2016) develop regime switching Phillips curve focusing on wage and core PCE inflation. The key innovation is the addition to the models of fundamental driving variables like labor-market slack, and the evidence strongly suggests a non-linear effect of slack on wage growth and core PCE price inflation that becomes much larger after labor markets tighten beyond a certain point. Forbes et al. (2021) suggested nonlinear Philips curve, especially when the inflation is "low". The nonlinear curve is steep when output is above potential (slack is negative), but flat when output is below potential (slack is positive), so that further increases in economic slack have little effect on inflation. This finding is consistent with evidence of downward nominal wage and price rigidity.

Here are some key literature to keep the track regarding the Phillips curve . Ball (2014) examines the recent behavior of core inflation in the United States and specifies a simple Phillips curve based on the assumptions that inflation expectations are fully anchored at the Federal Reserve's target, and that labor-market slack is captured by the level of short-term unemployment and this equation explains inflation behavior since 2000. He also proposes a more general Phillips curve in which core inflation depends on short-term unemployment and on expected inflation as measured by the Survey of Professional Forecasters. This specification fits U.S. inflation since 1985. Benigno and Ricci (2008) told that the curve is virtually vertical for high inflation rates but becomes flatter as inflation declines. And macroeconomic volatil-

ity shifts the Phillips curve outward, implying that stabilization policies can play an important role in shaping the trade-off. Third, nominal wages tend to be endogenously rigid also upward, at low inflation. Fourth, when inflation decreases, volatility of unemployment increases whereas the volatility of inflation decreases. In Blanchard (2018), a small coefficient implies an attractive short-run tradeoff between inflation and unemployment. In the benchmark New Keynesian model, stabilizing inflation keeps the unemployment rate at the natural rate, and the natural rate in turn is the "constrained efficient rate," i.e., the best rate that can be achieved by policy. This proposition have been called as the "divine coincidence." The residual can be interpreted in two ways: First as capturing unobserved movements in the natural rate. If so, it implies large, high frequency movements in the natural rate. Or it can be interpreted as the result of misspecification, for example, the use of the wrong inflation series, or the wrong dynamic specification.

We explains

2 Model

2.1 Phillips curve

Gordon (1990) proposed the Phillips curve as follows

$$\pi_t = \alpha(L)\pi_{t-1} + \beta(L)D_t + \gamma(L)z_t + \nu_t \tag{1}$$

where D_t is an index of excess demand (normalized so that $D_i = 0$ indicates the absence of excess deman), z_t is a vector of supply shock variables (normalized so that $z_i = 0$ indicates an absence of supply shocks). Following Gordon (1990)' so-called Triangle model, we consider the following Phillips curve,

$$\pi_t = \mu + \alpha(L)\pi_{t-1} + \beta(L)u_{t-1} + \gamma(L)z_{t-1} + \nu_t \tag{2}$$

The triangle equations estimated in this paper use current and lagged values of the unemployment gap as a proxy for the excess demand parameter D_t, where the

unemployment gap is defined as the difference between the actual rate of unemployment and the natural rate, and the natural rate (or NAIRU) is allowed to vary over time.

The triangle approach differs from the NKPC approach by including long lags on the dependent variable, additional lags on the unemployment gap, and explicit variables to represent the supply shocks, namely the effect on inflation of changes in the relative price of food and energy, the change in the relative price of non-food non-oil imports, the eight-quarter change in the trend rate of productivity growth, and dummy variables for the effect of the 1971-74 Nixon-era price controls

Whereas, New Keynesian-type Phillips curve of Roberts (1995) and Gali and Gertler (1999) is as follows

$$\pi_t = E_t \pi_{t+1} + \lambda mc_t \tag{3}$$

where mc_t refers the exogenous structure to affect the Phillips curve. Blanchard (2015) proposed the specification of Phillips curve as follows, following Matheson and Stavrev (2013) for selected countries with time-varying approach,

$$\pi_t = \theta_t(u_t - u_t^*) + \lambda_t E_{t-1}(\pi_t) + (1 - \lambda_t)\pi_{t-1}^* + \mu_t \pi_{im,t} + \varepsilon_t \tag{4}$$

$E_{t-1}(\pi_t)$ is a long-term expectation, π_{t-1}^* is the average of the last four quarterly inflation rates, and $\pi_{im,t}$ is import price inflation relative to headline inflation. We develop the Phillips curve considering commonly used terms with labor market slack, expected inflation and exogenous variable to extract the optimal specification without macroeconomic theoretical background.

2.2 Endogenous Regime Switching version

In this section, we employ the endogenous regime switching that is developed by Chang et al. (2017) for the Phillips curve analysis in the U.S. The reason why we use the endogenous regime switching instead of the conventional Markov witching is that the endogenous regime switching model allows us to implement the current realization of the underlying time series. In the Markov switching one, the future transition

between low and high states is determined by the current state only, which is unrealistic. Furthermore, the endogenous model facilitates to identify an unobservable latent factor that characterize the regime between states. The factor can be used for interesting economic interpretation regarding the dynamics of the relationships between series. The transition probabilities estimated from the endogenous model determined by the current state and the underlying time series change over time, but the probabilities of the Markov switching model between two states is always constant. Furthermore, as shown in Chang et al. (2017), the Markov switching model is a subset of the endogenous regime switching model. That is, the endogenous regime switching model can be reduced to the conventional Markov switching model.

The following specification is used to investigate the relationship between in inflation rate and unemployment rate by adopting the endogenous regime switch model to provide useful information on the dynamics of the Phillips curve. This has led to the following specifications:
Backward-looking model

$$\pi_t = \mu + \beta(s_t)(ur_t - nur_t) + \gamma(s_t)E_t(\pi_{t-1}) + \sigma(s_t)\varepsilon_t \tag{5}$$

Forward-looking model

$$\pi_t = \mu + \beta(s_t)(ur_t - nur_t) + \delta(s_t)E_t(\pi_{t+1}) + \sigma(s_t)\varepsilon_t \tag{6}$$

where π_t indicates the quarterly inflation rate at t, $E[\pi_{t-1}]$ and $E[\pi_{t+1}]$ signify a four-period of average of lag and lead inflation rate. ur_t and nur_t denote the unemployment rate and the natural rate of unemployment, respectively.

In the model, the state process (s_t) is determined by the autoregressive latent factor ω_t and the threshold level τ . Specifically, the regime is switched by the state process $s_t = \mathbf{1}\{\omega_t \geq \tau\}$ where $\mathbf{1}\{.\}$.

The latent factor ω_t follows a first order autoregressive process as

$$\omega_t = \alpha\omega_{t-1} + \nu_t \tag{7}$$

for $t = 1, 2, \ldots$ with parameters $\alpha \in (-1.1]$ and *i.i.d.* standard normal innovation ν_t. A state dependent parameter $\theta_t \in \{\beta(s_t), \gamma(s_t), \delta(s_t), \sigma(s_t)\}$ can be described by

$$\theta_t = \theta(s_t) = \theta^l(1 - s_t) + \theta^h s_t \tag{8}$$

The regime with $\theta_t = \theta^l$ or $s_t = 0(\omega_t < \tau)$ is called as the low regime, while we call the high regime when $\theta_t = \theta^h$ or $s_t = 1(\omega_t \geq \tau)$.

The latent factor ω_t is assumed to be correlated with the previous shock. That is ε_t and ν_t are jointly *i.i.d.* as

$$\begin{pmatrix} \varepsilon_t \\ \nu_{t+1} \end{pmatrix} \sim N\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & \rho \\ \rho & 1 \end{pmatrix} \right) \tag{9}$$

When the correlation between two components ϵ_t and ν_{t+1} is not zero ($\rho \neq 0$), the latent factor ω_{t+1} is correlated with the observed inflation rate π_t. Current inflation rate π_t affects future transitions between states, as the latent factor ω_t determines the future states s_{t+1}. The zero correlation between ϵ_t and ν_{t+1} implies that potential transition between states is not affected by the current inflation rate π_t. Hence, an analysis of results by Chang et al. (2017) provides an insight that when $\rho = 0$ with $|\alpha| < 0$, the endogenous regime switching is general enough to include conventional Markov switching model.

Maximum likelihood estimation with modified Markov switching filter is considered for estimate the parameters present in the model.

2.3 Data

We employ four inflation measure which is widely used in inflation literature, headline CPI, PCE and core CPI and PCE. Natural rate of unemployment is obtained from Congressional Budget Office (CBO)'s measure. CBO officially has not reported the short term measure of natural rate of unemployment anymore but they already released the expected one up to 2030. CBO's natural rate of unemployment is the rate of unemployment arising from all sources except fluctuations in aggregate demand.

Estimates of potential GDP are based on the long-term natural rate.[3]

As an inflation expectation, we use the survey result of the Survey of Professional Forecasters (SPF) and the Livingston Survey (LS). SPF provides the forecast of CPI and PCE both up to 6 quarters ahead. LS provides the forecast of CPI only with 6 and 12 months ahead. Though LS surveys the forecast of the longer horizon such as 2, 3 and 10 years ahead, it seems too long horizons so that we do not used it.

We transform the price index into the four-quarter log change to avoid the high frequency noise in the monthly change. Then the available samples extends from the 1961Q1 to 2021Q3. Measurement of labor market slack is measured by the difference between the unemployment rate and the natural rate of unemployment rate, which is obtained from CBO. Note that the revision of the natural rate is made occasionally and it may affect the result, especially in forecasting literature as described in Nalewaik (2016).

As inflation proxy, we employ CPI all, Core CPI, PCE all, Core PCE and the natural rate of unemployment as the CBO's long-term natural, short-term natural and Livingston survey's natural rate. For backward looking specification, we use the average of the last four quarterly inflation. Whereas, for the forward looking specification, we use the Livingston survey for one-quarter ahead forecasting. Proxy for exogenous shock is the import price shock, following Nalewaik (2016). Forbes et al. (2021) used exchange rate, oil prices and global value chains. To describe the cost-push shock, we use the import price index.

Table 1 show the list of variables we used for estimating Phillips curve. Combining those we create 40 specifications with the survey of inflation expectation, and 8 with the average of previous inflation.

[3]CBO did not make explicit adjustments to the short-term natural rate for structural factors before the recent downturn. The short-term natural rate incorporates structural factors that are temporarily boosting the natural rate beginning in 2008. The short-term natural rate is used to gauge the amount of current and projected slack in labor markets, which is a key input into CBO's projections of inflation.

Table 1: List of Variables

No.	Section	Variables	Description
1	Inflation	CPI	Headline
2			Core
3		PCE	Headline
4			Core
5	Employment	Unemployment rate	Level
6		Natural Rate of unemployment	Long-term
7			Short-term
8	Inflation Expectation	Survey of Professional Forecasters	Mean of 1∼6 quarter ahead
9		Livingston Survey	Mean and Median (CPI only)
10	Exogenous	Import price index	Inflation of Import price

3 Result

Table 2 and 3 is the estimation result of Phillips curve we proposed as in equation 4. The former one follows the forward looking behavior so that we use the survey of predicted inflation from the Survey of Professional Forecasters and Livingston Survey as inflation expectation. Whereas, the latter table used the moving average of previous inflation as the inflation expectation so that it follows adaptive expectation.

With forward looking behavior, the parameters describing the relationship between the inflation and employment slack, β_l and β_u are estimated negatively. As the unemployment rate is getting above the natural rate of employment, there are stronger downward pressure on the inflation. The magnitude is harder in the upper regime significantly but it becomes insignificant in the lower state, in the model 1,2 and 4. δ is the coefficient for the inflation expectation and can be interpreted as the sensitivity for the inflation anchor. If the public have more confidence for the central bank to keep the inflation target, δ would be greater. In the upper state, the public shows stronger confidence for the inflation expectation with significance. However, the difference between two states are not much when we follows the adaptive expectation. γ, assessed the persistence of the past inflation and it is stronger in the lower state with significance in any specifications. λ represents the coefficient for

Table 2: Estimation of Philips Curve with forward looking CPI

	Model 1		Model 2		Model 3		Model 4	
Parameters	Estimates	St. Error	Estimates	St. Error	Estimates	St. Error	Estimates	St. Error
μ	0.003**	0.001	0.006**	0.003	0.001	0.001	0.006***	0.001
β_l	-0.028	0.031	0.034	0.393	-0.071**	0.034	-0.032	0.042
β_u	-0.497***	0.121	-0.473*	0.273	-0.544***	0.191	-0.687***	0.112
δ_l	0.421***	0.074	0.767	0.724	0.343***	0.104	0.780***	0.058
δ_u	0.840***	0.135	1.145**	0.502	0.764**	0.303	1.172***	0.062
γ_u	0.486***	0.072	-	-	0.684***	0.080	-	-
γ_l	0.277***	0.099	-	-	0.371*	0.193	-	-
λ_l	-0.031	0.020	-0.019	0.048	-	-	-	-
λ_u	0.068*	0.039	0.129*	0.068	-	-	-	-
σ_l	0.006***	0.000	0.005	0.009	0.007***	0.000	0.006***	0.000
σ_l	0.019***	0.002	0.017	0.029	0.026***	0.003	0.019***	0.002
α	0.994***	0.008	0.947***	0.123	0.982***	0.014	0.989***	0.010
τ	3.195*	1.762	1.023	1.519	4.798***	1.417	2.858	3.358
ρ	0.016	0.368	0.487	0.614	0.458	0.282	0.410	0.465
Likelihood	815.516		796.745		807.706		792.220	

* Notes: Inflation is measured by core CPI. Livingston Survey represents inflation expectation.

the exogenous variable. We employ import price inflation which proxies cost-push inflation. This effects are split depending on the state but is significant in the upper state where the import price inflation are positively related with the inflation. In summary, we can define the lower state as the stable one since the inflation responds less sensitively against the employment slack and inflation expectation, and it became more persistent and less sensitive against exogenous variable. However, in the lower state, the coefficient to the unanticipated shock, σ is greater than one in the upper state. It means that if the there is any shock which is not expected comes up, the economy may react greater than the other state. Without exogenous variable or lags of inflation, like in model 3 and 4, β and δ are robustly estimated.

With backward looking behavior where we employ the average of past four quarter inflation as the inflation expectation, most of parameters shows the similar result to the former case. Key takeaways is that β_l is estimated significantly in 3 out of 4 specifications, though it still shows less sensitivity against employment slack. And λs are estimated insignificantly in both models. It seems the past inflation may reflect

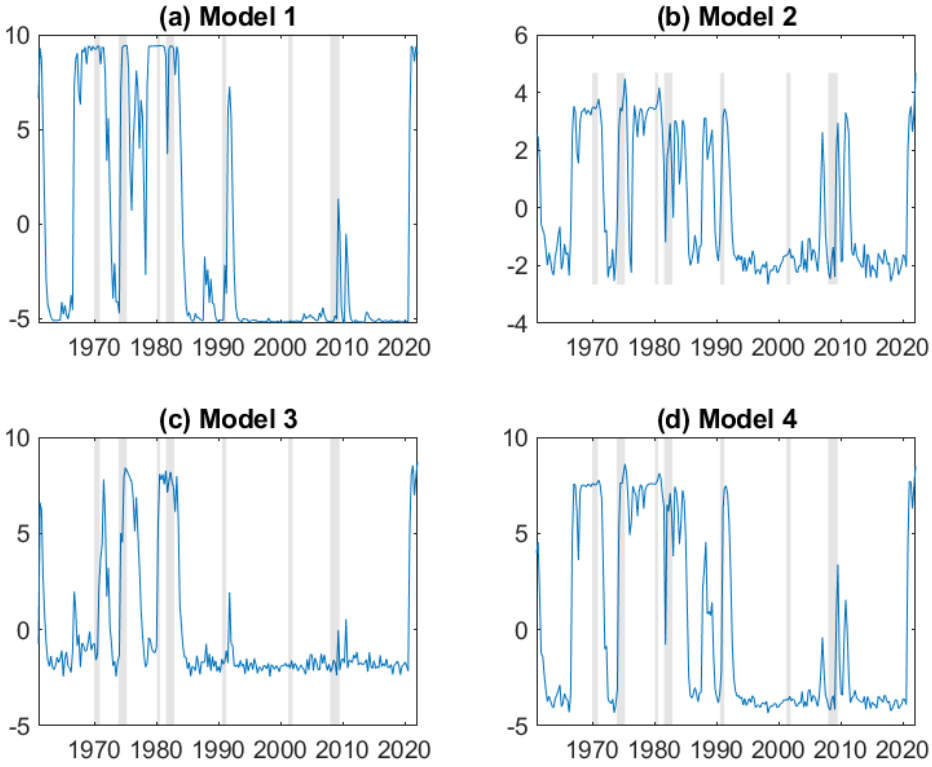
Table 3: Estimation of Philips Curve with backward looking CPI

	Model 1		Model 2		Model 3		Model 4	
Parameters	Estimates	St. Error	Estimates	St. Error	Estimates	St. Error	Estimates	St. Error
μ	0.001	0.001	0.003***	0.001	0.001	0.001	0.003*	0.002
β_l	-0.056*	0.031	-0.100***	0.033	-0.052	0.032	-0.095**	0.043
β_u	-0.433***	0.064	-0.458**	0.187	-0.466**	0.185	-0.522**	0.222
δ_l	0.513***	0.064	0.913***	0.034	0.515***	0.093	0.917***	0.083
δ_u	0.642***	0.096	0.969***	0.064	0.621***	0.198	0.998***	0.070
γ_u	0.471***	0.054	-	-	0.471***	0.093	-	-
γ_l	0.312***	0.088	-	-	0.357*	0.189	-	-
λ_l	-0.005	0.016	-0.007	0.016	-	-	-	-
λ_u	0.042	0.067	0.053	0.060	-	-	-	-
σ_l	0.007***	0.000	0.006***	0.000	0.007***	0.000	0.006***	0.000
σ_l	0.028***	0.003	0.026***	0.003	0.028***	0.003	0.026***	0.004
α	0.981***	0.011	0.984***	0.013	0.981***	0.015	0.983***	0.014
τ	5.193***	0.284	3.602*	2.055	5.152***	1.242	3.588*	1.927
ρ	0.698***	0.085	0.124	0.299	0.707***	0.204	0.150	0.303
Likelihood	807.874		801.857		807.684		801.421	

* Notes: Inflation is measured by core CPI. Inflation expectation follows adaptive expectation which is measured by the moving average of four quarter previous inflation rate.

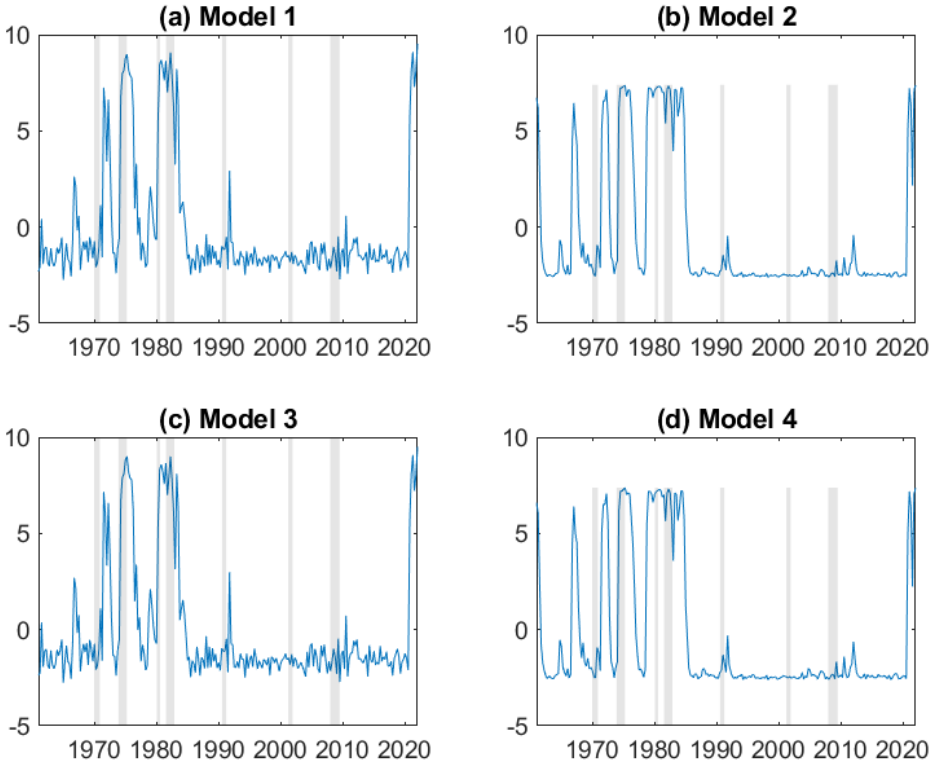
the changes in exogenous variable but it needs further investigation. In result, no matter of specification we used, our model shows the robust result.

Figure 1: Latent factor with inflation expectation



As we designed in equation (7), the latent factors follows AR(1) process and it turns out it has high persistence as it is shown in Table 2 and 3. Figure 1 and 2 shows the latent factor, s_t, which changes the regime of coefficient in our Phillips curve specification. Note that gray area in the figure represents NBER's recession periods. Two figures correspond to the estimation result in Table 2 and 3.

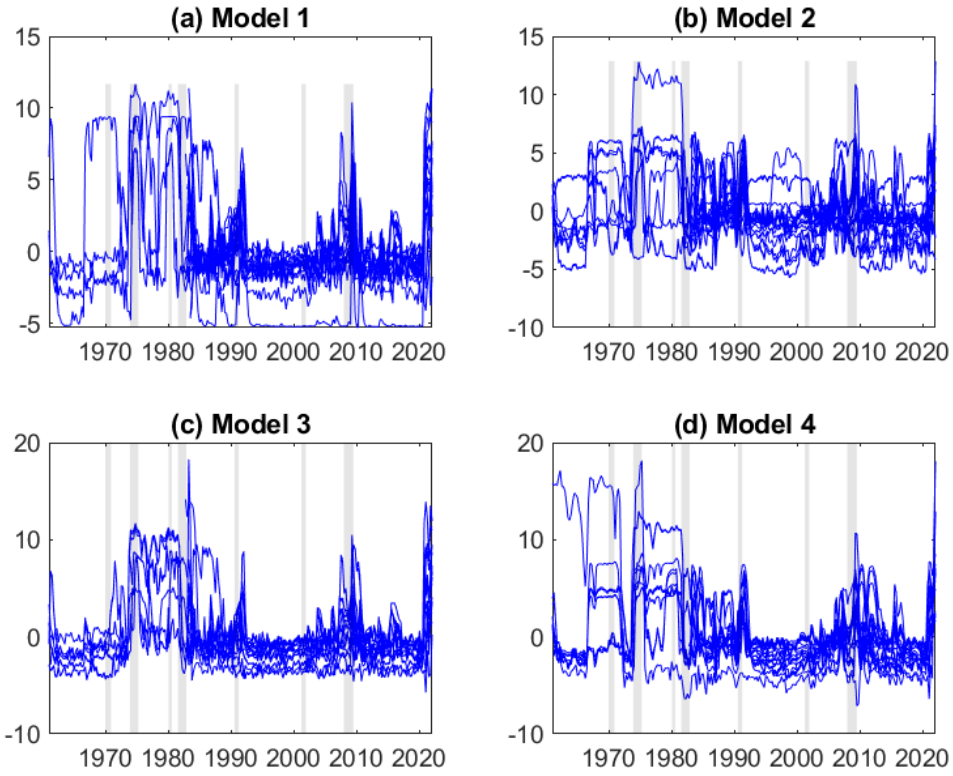
Figure 2: Latent factor with adaptive expectation



Latent factors are usually in the upper state when the economy is in the recession and it supports our interpretation about the estimation result. However, in the recession of the 21st century except current one caused by the pandemic, the state variable did not react as much as in 20th century, especially with backward looking behavior. From 1960s to 1990s, the latent factors of Phillips curve correspond well to the business cycle but only the downturn during the Great Recession is well captured after 2000s. More important thing is that all of models show the current latent factors are in the upper state where the inflation react to the labor market slack more sensitively. But the current state is quite different from the previous business cycle since the pandemic caused it. In labor market, there is not enough labor supply due to the quarantine by the pandemic even though there are over-demands. And this

affects the global value chain such as Chinese shutdown and shortage of shipment so that it creates cost-push inflation. We can expect the inflation reacts aggressively as the labor market slack enlarges.

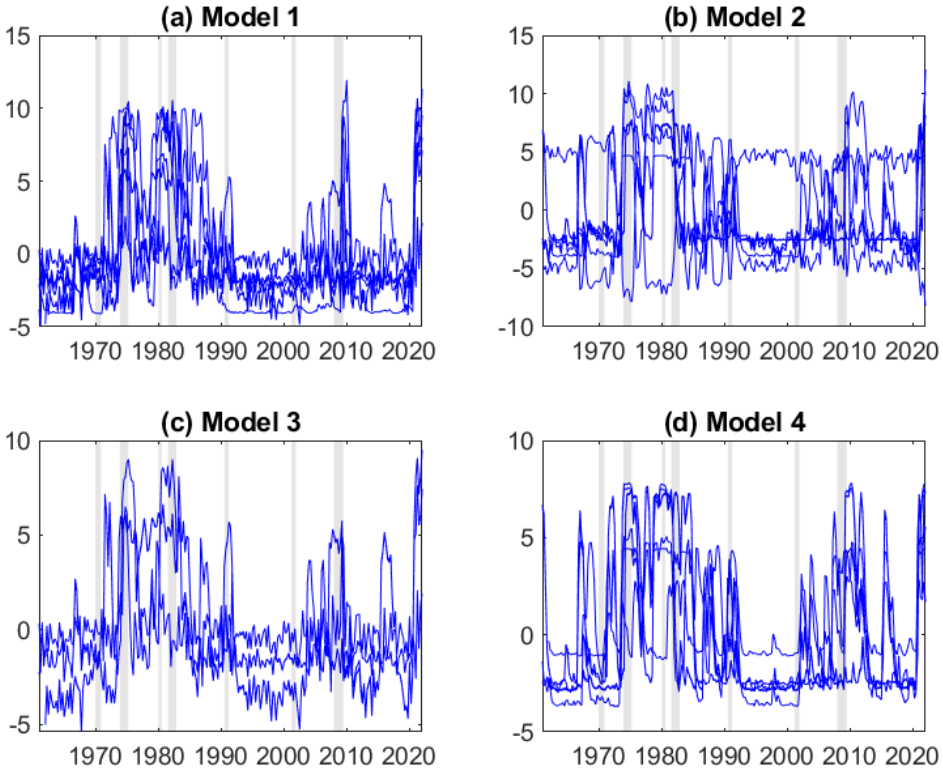
Figure 3: Overlapped Latent factors with inflation expectation



* Notes: Since the SPF is available after 1980, there is less models are estimated before then.

Since we construct the Phillips curve with various measure, we can test how well the list of different specification estimate the curve for robustness check. Figure 3 shows overlapped latent factors of all specification by models we estimate in Table 2. Figure 4 shows the result corresponding to the Table 3.

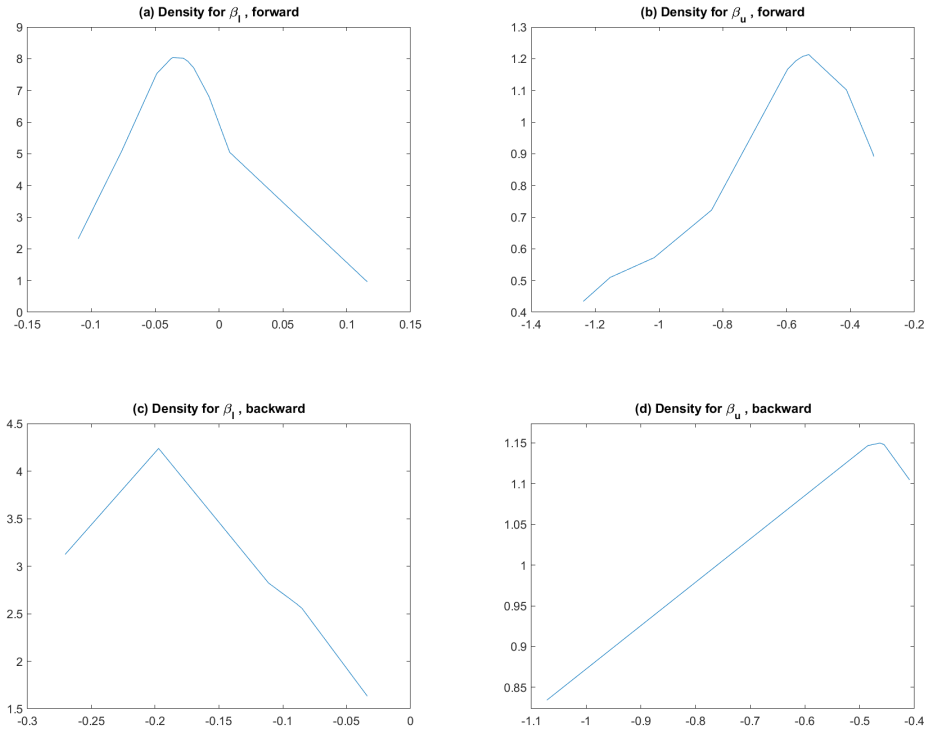
Figure 4: Overlapped Latent factors with inflation expectation



* Notes:

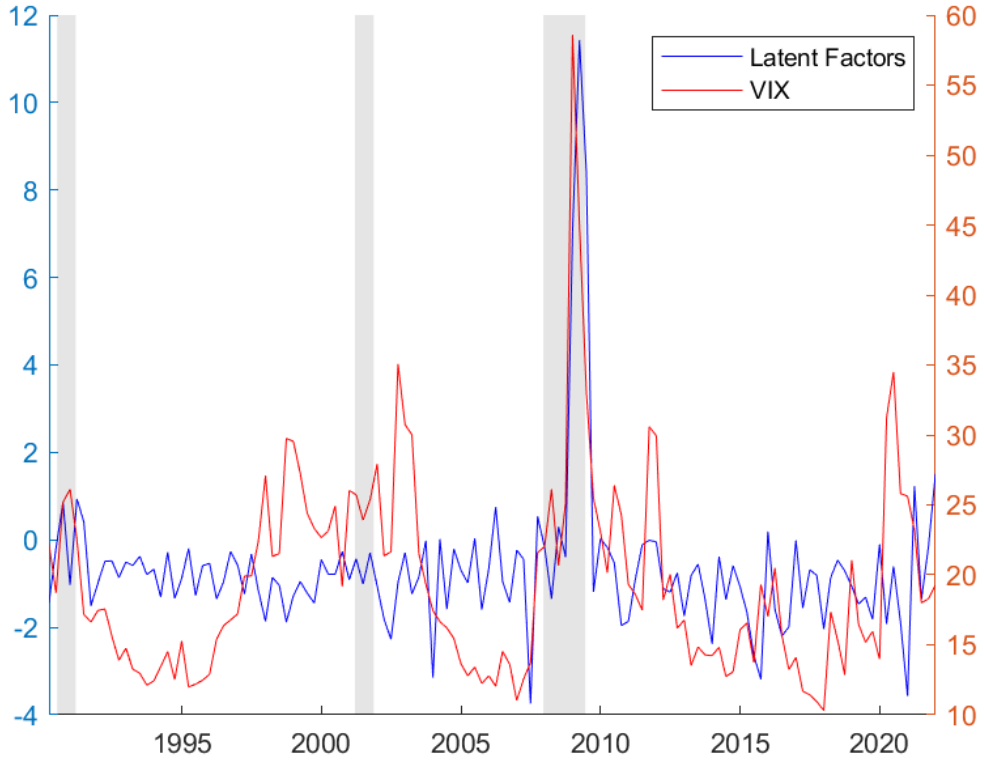
We observe the trend of β by seeing the density of β in various specification. Figure 5 depicts the density of β_l and β_u. In Panel (a), the distribution of β_l is skewed to left and the mode is in negative area but there are some cases with positive β_l which means that the inflation may react to labor market slack positively in the lower state. This may explain situation such as the Great Moderation. Whereas, β_u, as shown in the Panel (b), is skewed to the right but it is still in negative. This relationship could be stronger in some cases but the possibility is low. With backward looking perspective, we have similar result with the forward looking's.

Figure 5: Density of β over various specifications



The future work we expect is identifying the latent factors which cause the endogenous change in the Phillips curve. One possibility we found is VIX which is a real-time index that represents the market's expectations for the relative strength of near-term price changes of the stock. Once the daily VIX is transferred to the quarterly value(in average), we found there is correlation between them, as shown in Figure 6. Based on this, it is possible that the state of Phillips curve may depends on the volatility of the economy.

Figure 6: Correlation between VIX and the latent factor



* Notes:

4 Concluding Remarks

We propose the Phillips curve in the regime switching framework where the latent factor are endogenously estimated.

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