Lecture 8: Phillips curve estimation

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Simple Theory

- Simple theory with Calvo pricing assumption implies:

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

  where

$$\lambda = \frac{(1-\theta)(1-\beta\theta)}{\theta}$$

  and $1-\theta$ is frequency of price change, β subjective discount factor

- Theory implies that mc_t is the appropriate "forcing variable" in the Phillips curve

- Yet most empirical work uses simple measures of the output gap such as detrended output

Gali-Gertler 99

Motivation:

- Is New Keynesian (Calvo) Phillips curve consistent with observed inflation persistence?
  - Implies disinflations can be costless
  - In practice, it seems disinflations are costly (Ball 94, 95)
    (Imperfect credibility could explain this)
- Do we need "sticky inflation" models or adaptive expectations?
- With quarterly data, hard to get statistically significant effect of real activity on inflation, when using output gap

Simple Theory

- Under certain assumptions:

$$mc_t = \kappa x_t$$

  where $x_t = y_t - y_t^n$ denotes the output gap

- Maybe Phillips curve estimation doesn't work because:
  - These assumptions don't hold in reality
  - Output gap is mismeasured

New Keynesian vs. Old Keynesian

- With rational expectations, NK Phillips curve can be written as

$$\pi_{t+1} - \pi_t = -\lambda\kappa x_t + \epsilon_{t+1}$$

where $\epsilon_{t+1} = \pi_{t+1} - E_t\pi_{t+1}$, and assuming $\beta = 1$.

- Traditional Phillips curve with adaptive expectations:

$$\pi_t = E_{t-1}\pi_t + \lambda\kappa x_t$$

$$\pi_t - \pi_{t-1} = \lambda\kappa x_t$$

where we are assuming $E_{t-1}\pi_t = \pi_{t-1}$

- Notice the difference in the sign on the output gap term!!
(and difference in timing of inflation change)

New Keynesian vs. Old Keynesian

$$\pi_{t+1} - \pi_t = -\lambda\kappa x_t + \epsilon_{t+1}$$

- NK Phillips curve implies tight labor market should lead inflation to fall!!
- Theoretical logic:
  - Inflation is a jump variable in this model
  - When output gaps are expected, inflation should jump up and start falling

$$\pi_t = \lambda\kappa \sum_{k=0}^{\infty} \beta^k E_t x_{t+k}$$

- I.e., inflation should lead output gap according to NK Phillips curve (Fuhrer-Moore 95)

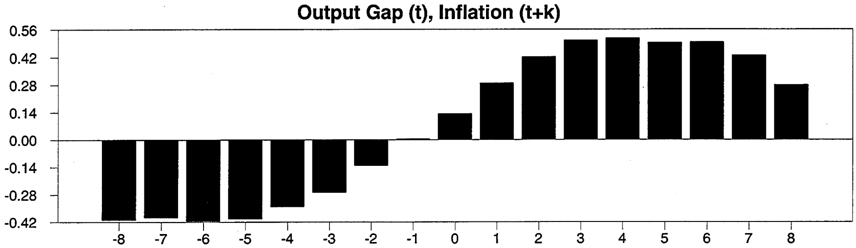
New Keynesian vs. Old Keynesian

- Simple estimation using quadratically detrended log GDP yields:

$$\pi_{t+1} - \pi_t = 0.081 x_t + \epsilon_{t+1}$$

- Output gap term has “wrong sign” (from NK perspective)

Output Gap Leads Inflation



Source: Gali and Gertler (1999) – Output gap measure as detrended output using HP-filter.
Sample period 1960Q1-1997Q4. Current output gap positively correlated with *future* inflation.

Marginal Cost as Opposed to Output Gap

- One reaction: NK Phillips curve is empirically unrealistic.
  - Perhaps some sluggishness messes up this jump business
  - Perhaps information frictions play a role (yield $E_{t-1}\pi_t$)
- Gali-Gertler argue:
  - Use of output gap is the problem
  - Output gap measured with error
  - Marginal costs tends to lag output gap
- Gali-Gertler propose to estimate Phillips curve using marginal cost as forcing variable

Measuring Marginal Cost

- But marginal costs are unobservable as well!!
- Gali-Gertler make following assumptions:
  - Production function: $Y_t = A_t K_t^{\alpha_k} N_t^{\alpha_n}$
  - Labor is hired on a spot market at constant wage
- Marginal cost:

$$MC_t = \frac{W_t/P_t}{\partial Y_t/\partial N_t} = \frac{W_t/P_t}{\alpha_n Y_t/N_t} = \frac{1}{\alpha_n}\frac{W_t N_t}{P_t Y_t} = \frac{S_t}{\alpha_n}$$

  proportional to labor share (average cost)

- In logs, we get:

$$mc_t = s_t$$

Measuring Marginal Cost

- Assumptions that Gali-Gertler make to derive this are strong assumptions!!
- Worker-firm relationship often long-term relationship
  - Not clear that current wage is a good proxy for marginal cost
  - May just be an installment payment on a long-term contract
  - Suppose workers performs well at time t:
    - Wage may not reflect this at time t
    - Rather worker may expect a raise / promotion in the future
  - Firms may insure workers (labor hoarding)
- Wages at a given point in time complicated by overtime
  - Marginal wage may not be the same as average wage

Supply Shocks

- Gali-Gertler estimate

$$\pi_t = \beta E_t \pi_{t+1} + \lambda s_t$$

- Advantage of using measure of marginal costs:
  - Supply shocks should be reflected in marginal costs

Expectations of Inflations

- What do Gali-Gertler do about expectations of inflation?
- They assume rational expectations
- Under this assumption, Phillips curve can be written

$$\pi_t = \beta\pi_{t+1} + \lambda s_t + \epsilon_{t+1}$$

  where $\epsilon_{t+1} = \beta E_t \pi_{t+1} - \beta\pi_{t+1}$ (i.i.d.)
- They furthermore take structural model super seriously in assuming that there is **no other error term** than this expectations error
- This strong structural assumption allows them to use lagged variables as instruments (any variable dated at time *t* or earlier)

Empirical Specification

- Maintained assumptions:

$$\pi_t - \beta\pi_{t+1} - \lambda s_t = \epsilon_{t+1}$$

  where ϵ_{t+1} is an i.i.d. expectations error and therefore uncorrelated with variables at time t or earlier

- Implies:

$$E_t\{(\pi_t - \beta\pi_{t+1} - \lambda s_t)z_t\} = 0$$

  where z_t is in the time t information set of agents

Empirical Specification

- Gali-Gertler use GMM with these orthogonality conditions

$$E_t\{(\pi_t - \beta\pi_{t+1} - \lambda s_t)z_t\} = 0$$

- Sample period: 1960Q1-1997Q4
- Instruments: Four lags of inflation, labor income share, output gap, long-short interest rate spread, wage inflation, and commodity price inflation (24 instruments)

Why IV and not OLS?

$$\pi_t = \beta\pi_{t+1} + \lambda s_t + \epsilon_{t+1}$$

- Under maintained assumption that error term is i.i.d. expectation error dated at time $t+1$, instrument only needed to estimate β
- More generally, other omitted variables (or cost push shocks) enter the equation and are dated at time t (i.e., affect π_t):
$$\pi_t = \beta\pi_{t+1} + \lambda s_t + \eta_t$$
- In this case, both β and λ potentially biased

Empirical Concerns

- Is ϵ_{t+1} really just an i.i.d. expectations error?
  - If assumptions needed for $mc_t = s_t$ don't hold, it's not
  - If expectations are not rational, it is not
- If it is not, then instruments may be invalid
  - Slow moving omitted variables correlated with past stuff
- 24 instruments raises concerns about many-weak instruments
  - Many/Weak instruments issue is an overfitting issue in small samples
  - Using 24 relatively weak instruments may lead to substantial overfitting

Reduced Form Results

- Estimation with labor share:

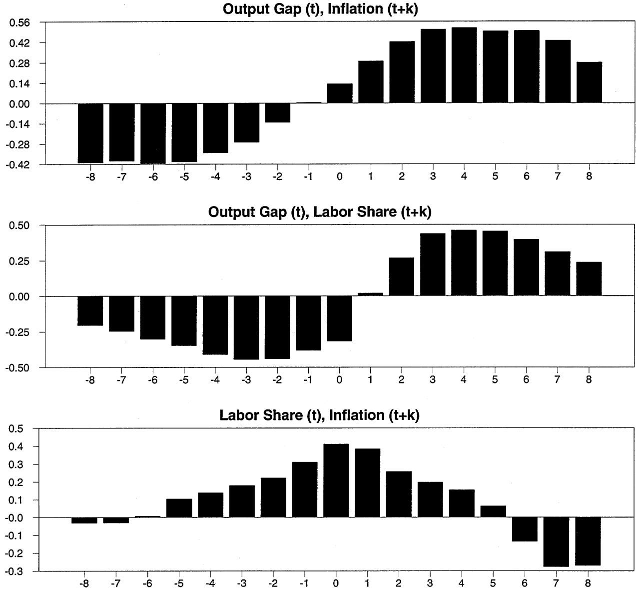
$$\pi_t = \underset{(0.012)}{0.023}\, s_t + \underset{(0.045)}{0.942}\, E_t \pi_{t+1}$$

  - Coefficients have “correct sign” and “sensible” magnitude

- Estimation with output gap (HP-filtered GDP):

$$\pi_t = -\underset{(0.005)}{0.016}\, s_t + \underset{(0.030)}{0.988}\, E_t \pi_{t+1}$$

  - Coefficient on output gap has “wrong sign”



Source: Gali and Gertler (1999) – Output gap measure as detrended output using HP-filter.
Sample period 1960Q1-1997Q4.

Output Gap vs. Labor Share

- Output gap leads inflation in contradiction to theory
- Labor share strongly correlated with inflation contemporaneously
- Labor share lags output gap
- Lag in response of labor share explains why it does better in Phillips curve estimation

Table 1
Estimates of the new Phillips curve

	θ	β	λ
GDP deflator			
(1)	0.829	0.926	0.047
	(0.013)	(0.024)	(0.008)
(2)	0.884	0.941	0.021
	(0.020)	(0.018)	(0.007)
Restricted β			
(1)	0.829	1.000	0.035
	(0.016)		(0.007)
(2)	0.915	1.000	0.007
	(0.035)		(0.006)
NFB deflator			
(1)	0.836	0.957	0.038
	(0.015)	(0.018)	(0.008)
(2)	0.884	0.967	0.018
	(0.023)	(0.016)	(0.008)

Notes: This table reports GMM estimates of the structural parameters of Eq. (15). Rows (1) and (2) correspond to the two specifications of the orthogonality conditions found in Eqs. (18) and (19) in the text, respectively. Estimates are based on quarterly data and cover the sample period 1960:1–1997:4. Instruments used include four lags of inflation, labor income share, long-short interest rate spread, output gap, wage inflation, and commodity price inflation. A 12-lag Newey–West estimate of the covariance matrix was used. Standard errors are shown in brackets.

Source: Gali and Gertler (1999) – Two normalizations of moment conditions.

Structural Estimates

Comparison vs. ex ante views:

- “Sensible” estimates for β
- Estimates of θ on the high end
  - Imply price rigidity of 5-6 quarters

Inflation Inertia

- Does NK Phillips curve account for inflation inertia?
- Gali-Gertler estimate specification with fraction of rule-of-thumb agents
- Rule-of-thumb agents set

$$p_t^b = \bar{p}_{t-1}^* + \pi_{t-1}$$

- This yields

$$\pi_t = \lambda mc_t + \gamma_f E_t \pi_{t+1} + \gamma_b \pi_{t-1}$$

where

$$\lambda = \frac{(1-\omega)(1-\theta)(1-\beta\theta)}{\theta+\omega[1-\theta(1-\beta)]}$$

$$\gamma_f = \frac{\beta\theta}{\theta+\omega[1-\theta(1-\beta)]} \qquad \gamma_b = \frac{\omega}{\theta+\omega[1-\theta(1-\beta)]}$$

and ω denotes the fraction of rule-of-thump agents

Table 2
Estimates of the new hybrid Phillips curve

	ω	θ	β	γ_b	γ_f	λ
GDP deflator						
(1)	0.265	0.808	0.885	0.252	0.682	0.037
	(0.031)	(0.015)	(0.030)	(0.023)	(0.020)	(0.007)
(2)	0.486	0.834	0.909	0.378	0.591	0.015
	(0.040)	(0.020)	(0.031)	(0.020)	(0.016)	(0.004)
Restricted β						
(1)	0.244	0.803	1.000	0.233	0.766	0.027
	(0.030)	(0.017)		(0.023)	(0.015)	(0.005)
(2)	0.522	0.838	1.000	0.383	0.616	0.009
	(0.043)	(0.027)		(0.020)	(0.016)	(0.003)
NFB deflator						
(1)	0.077	0.830	0.949	0.085	0.871	0.036
	(0.030)	(0.016)	(0.019)	(0.031)	(0.018)	(0.008)
(2)	0.239	0.866	0.957	0.218	0.755	0.015
	(0.043)	(0.025)	(0.021)	(0.031)	(0.016)	(0.006)

Notes: This table reports GMM estimates of parameters of Eq. (26). Rows (1) and (2) correspond to the two specifications of the orthogonality conditions found in Eqs. (27) and (28) in the text, respectively. Estimates are based on quarterly data and cover the sample period 1960:1–1997:4. Instruments used include four lags of inflation, labor income share, long-short interest rate spread, output gap, wage inflation, and commodity price inflation. A 12-lag Newey–West estimate of the covariance matrix was used. Standard errors are shown in brackets.

Source: Gali and Gertler (1999) – Two normalizations of moment conditions.

Estimation of Hybrid Phillips Curve

- Estimate of ω statistically significant
  - Normalization 1 yields: $\omega = 0.265(0.031)$
  - Normalization 2 yields: $\omega = 0.486(0.040)$
- A quarter to half of agents are rule-of-thumb
- Gali-Gertler conclusion:
  - Forward-looking behavior more important than backward-looking behavior
- Estimates of β on the low side at around 0.9

Critiques of Gali-Gertler

- Subsequent work has found Gali-Gertler's results to be highly sensitive to instruments used, vintage of data, model specification
- Mavroeidis-Plagborg-Moller-Stock 14 argue fundamental problem is weak instruments
  - Inflation is notoriously difficult to forecast
  - Lagged variables weak instruments for future inflation
- More recent literature has used many fewer instruments to avoid many-instruments problem

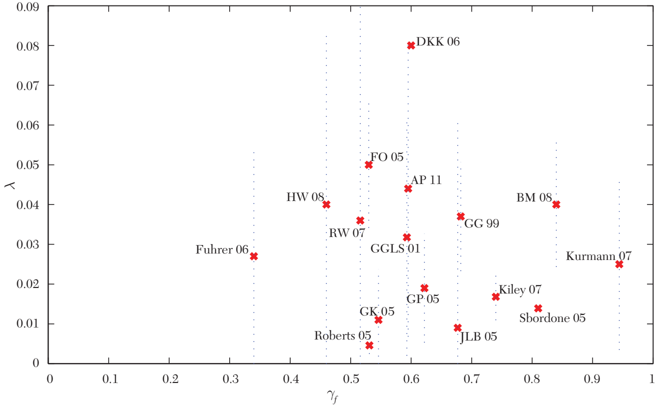


Figure 3. Point Estimates Reported in the Literature

Notes: Point estimates of λ (vertical axis) and γ_f (horizontal axis) reported in the literature. Only estimates that use U.S. data and the labor share as forcing variable are plotted. For some papers the semistructural point estimates have been imputed from point estimates of deeper parameters. The dotted blue lines indicate 95 percent confidence intervals for λ where available. We include papers with readily available estimates and more than twenty-five Google Scholar citations as of mid-September 2012: Galí and Gertler (1999); Galí, Gertler, and López-Salido (2001); Fuhrer and Olivei (2005); Gagnon and Khan (2005); Guay and Pelgrin (2005); Henzel and Wollmershäuser (2008); Jondeau and Le Bihan (2005); Roberts (2005); Sbordone (2005); Dufour, Khalaf, and Kichian (2006); Fuhrer (2006); Kiley (2007); Kurmann (2007); Rudd and Whelan (2007); Brissimis and Magginas (2008); and Adam and Padula (2011).

Source: Mavroeidis, Plagborg-Moller, Stock (2014)

Sensitivity to Data Vintage

- Rudd-Whelan 07 emphasize sensitivity to data vintage
- Mavroeidis-Plagborg-Moller-Stock 14 run Gali-Gertler 99 hybrid specification with Gali-Gertler-Lopez-Salido 01 instruments on Gali-Gertler 99 sample period for two data vintages
  - Roughly replicate Gali-Gertler 99 results for 2008 data vintage
  - With 2012 data vintage, slope of Phillips curve 30% smaller and insignificant

TABLE 3
Baseline GIV Estimates Using Different Data Vintages

Data vintage	Const.	λ	γ_f	γ_b	Hansen test
1998	0.041	0.026	0.615	0.340	5.263
	(0.030)	(0.013)	(0.057)	(0.058)	[0.628]
2012	–0.049	0.018	0.719	0.240	9.816
	(0.040)	(0.012)	(0.099)	(0.095)	[0.199]

Notes: Comparison of GIV estimates of the hybrid NKPC based on 1998 and 2012 vintages of data. The estimation sample is 1970q1 to 1998q1. Inflation: GDP deflator. Labor share: NFB. Instruments: four lags of inflation and two lags of the labor share, wage inflation, and quadratically-detrended output. Estimation method: CUE GMM. Weight matrix: Newey and West (1987) with automatic lag truncation (4 lags). Standard errors in parentheses and p-values in square brackets.

Source: Mavroeidis, Plagborg-Moller, Stock (2014)

Mavroeidis, Plagborg-Moller, Stock 14

- Run huge number of different a priori reasonable specifications with a common dataset
- Main findings:
  - Large amount of specification uncertainty
  - Large amount of sampling uncertainty
- Both conclusions due to weakness of identification

TABLE 4
NKPC SPECIFICATION COMBINATIONS

Specification settings	Options
Inflation (π_t)	GDP deflator, CPI, chained GDP def., GNP def., chained GNP def., NFB GDP def., PCE, core PCE, core CPI, filtered GDP def. gap, smoothed GDP def. gap, filt. CPI gap, sm. CPI gap, SPF-based CPI gap, filt. core CPI gap, sm. core CPI gap, filt. PCE gap, sm. PCE gap, filt. core PCE gap, sm. core PCE gap
Labor share (ls)	NFB, NFB coint. relation, HP filtered NFB gap, Baxter-King filt. NFB gap, linearly detrended NFB gap, quadratically detrended NFB gap, real-time NFB HP gap, real-time NFB BK gap, real-time NFB lin. detr. gap, real-time NFB quadr. detr. gap
Output gap (ygap)	CBO, HP filt., BK filt., lin. detr., quadr. detr., real-time HP filt., real-time BK filt., real-time lin. detr., real-time quadr. detr.
Reduced form	Unrestricted, VAR
Survey forecasts ($\pi^s_{t\|\tau}$)	SPF CPI, SPF GDP def., GB GDP def.
Expectations	π_{t+1} (endogenous), $\pi^s_{t+1\|t}$ (endog.), $\pi^s_{t+1\|t}$ (exogenous) $\pi^s_{t+1\|t-1}$ (endog.), $\pi^s_{t+1\|t-1}$ (exog.)
Instruments	GG: 4 lags of π_t, ls, ygap, 10y–90d yield spread, wage infl., commodity price infl. GGLS: 4 lags of π_t and 2 lags of ls, ygap, wage infl. small: 4 lags of π_t and 3 lags of forcing variable exact: 1 extra lag of each endog. regr. (just-identified) RT: 2 real-time lags of GDP def. inflation, Δls, ygap survey: 2 lags of 1-quarter SPF/GB forecasts, forcing variable Extra regressors (e.g., oil) added to instruments (if endog., use 2 lags)
Inflation lags	0 lags (pure NKPC), 1 lag, 4 lags
Parameter restrictions	No restrictions, $\gamma(1) = \gamma_f$ (inflation coefficients sum to 1) With $\gamma(1) = \gamma_f$, use lags of $\Delta\pi_t$ instead of π_t as instruments
Oil shocks	None, log change of WTI spot price divided by GDP def.
Interest rate	None, 90-day Treasury rate
Sample	Full available, 1960–1997, 1968–2005, 1968–2008, 1971–2008, 1981–2008, 1984–end of sample
GMM estimator	2-step, CUE

Notes: List of the specification options that we consider when estimating the NKPC (9). The efficient GMM weight matrix is computed using the Newey and West (1987) heteroskedasticity and autocorrelation consistent estimator with automatic lag truncation, except for VAR specifications, which use the White (1980) heteroskedasticity consistent estimator.

Source: Mavroeidis, Plagborg-Moller, Stock (2014)

Specification Uncertainty

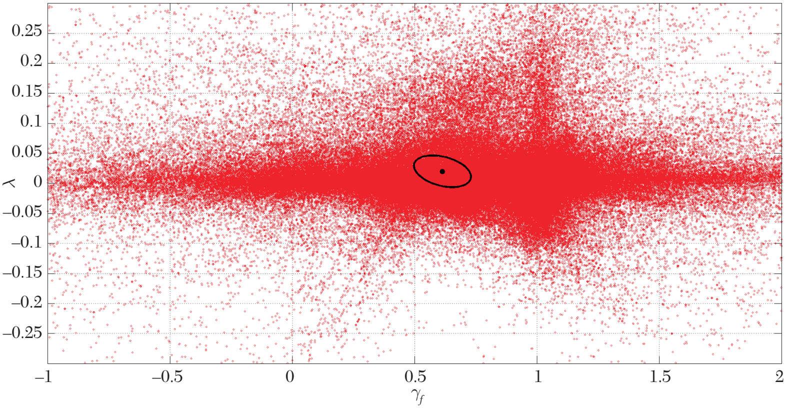


Figure 4. Point Estimates: Labor Share Specifications

Notes: Point estimates of λ, γ_f from the various specifications listed in table 4 that use the labor share as forcing variable, excluding real-time and survey instrument sets. The black dot and ellipse represent the point estimate and 90 percent joint Wald condence set from the 1998 vintage results in table 3.

Source: Mavroeidis, Plagborg-Moller, Stock (2014)

Specification Uncertainty

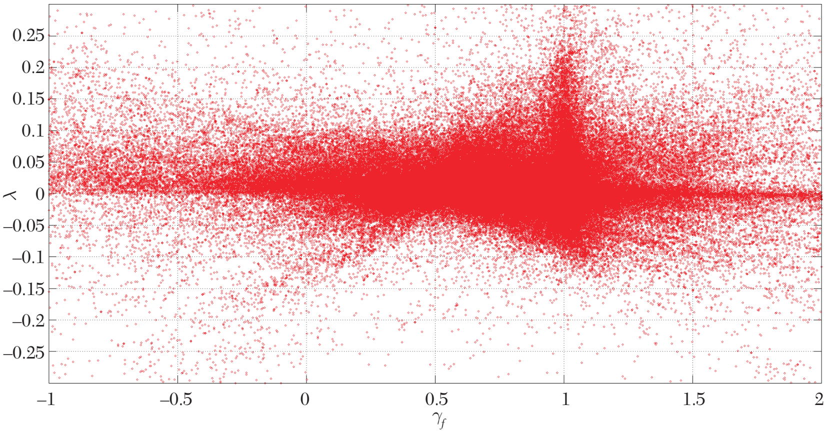


Figure 5. Point Estimates: Output Gap Specifications

Notes: Point estimates of λ, γ_f from the various specifications listed in table 4 that use the output gap as forcing variable, excluding real-time and survey instrument sets.

Source: Mavroeidis, Plagborg-Moller, Stock (2014)

Mavroeidis, Plagborg-Moller, Stock 14

Overall conclusion:

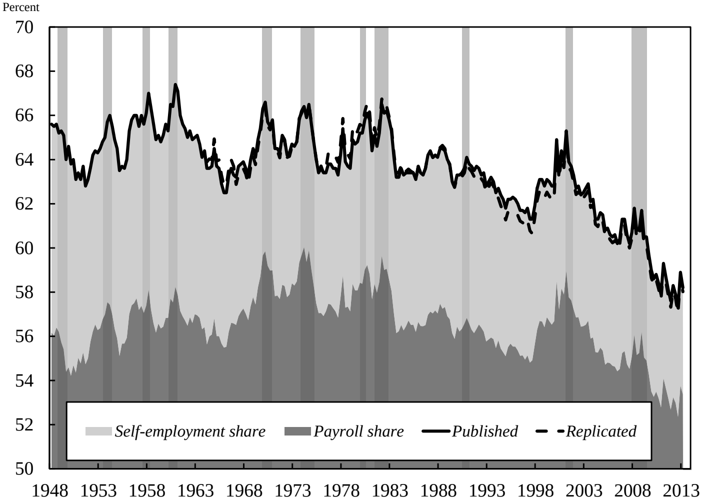
“Literature has reached a limit on how much can be learned about the New Keynesian Phillips curve from aggregate macroeconomic time series.”

“New identification approaches and new datasets are needed to reach an empirical consensus.”

Recent Behavior of the Labor Share

- Since about 2000, labor share has been trending downward
- If labor share is a good measure of marginal costs, downward trend should create massive deflationary pressure
  (Coibion-Gorodichenko 15)
- Doesn’t seem to line up with the evolution of inflation

Figure 1. Labor share, payroll share, and replicated labor share in U.S. nonfarm business sector.



Source: Bureau of Labor Statistics, Bureau of Economic Analysis, and authors' calculations

Source: Elsby, Hobijn, Sahin (2014)

Starting here, the slides follow closely Hazell, Herreño, Nakamura, Steinsson (2022)

Phillips Curve

New Keynesian formalization:

$$\pi_t = \beta E_t \pi_{t+1} - \kappa(u_t - u_t^n) + \nu_t$$

Drivers of inflation:

- Expected inflation: $E_t \pi_{t+1}$
- Measure of “output gap”: $u_t - u_t^n$
- Cost-push shocks: ν_t

Object of interest: Slope coefficient κ

- How much does an increase in “demand” affect inflation

Conventional Wisdom

- Volcker disinflation:
  - Tight policy -> high unemployment -> lower inflation
  - Substantial slope of the Phillips curve
- Since 1990:
  - Muted response of inflation to unemployment
  - Great Recession: missing disinflation
  - Late 2010s and 1990s: missing rise in inflation
- Phillips curve is getting flatter or hibernating
  - Perhaps an important flaw in the Keynesian model

Conventional Wisdom

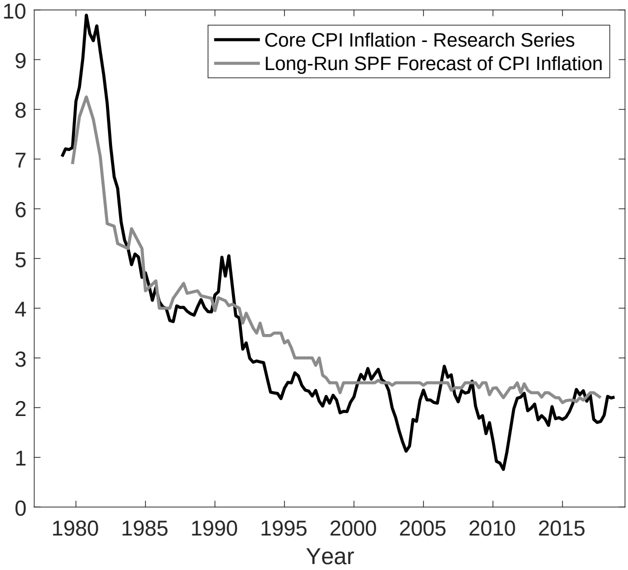
- Assume adaptive expectations: $\beta E_t \pi_{t+1} = \pi_{t-1}$
- In this case,
$$\pi_t = \beta E_t \pi_{t+1} - \kappa(u_t - u_t^n) + \nu_t$$
becomes
$$\Delta\pi_t = -\kappa(u_t - u_t^n) + \nu_t,$$
- Stock and Watson (2019):
  - $\Delta\pi_t$: Annual change in 12-month core PCE inflation
  - $u_t - u_t^n$: CBO unemployment gap
  - Refer to κ as “Phillips correlation”

Flattening Phillips Curve

Alternative Explanation

- Volcker disinflation:
  - Sharp regime shift
  - Rapid fall in long-run inflation expectations
  - Rapid fall in inflation
- Since 1990:
  - Long-run inflation expectations have become anchored
  - Consequently, inflation has become more stable
- Apparent “flattening” of Phillips curve due to anchoring of inflationary expectations (Bernanke, 2007; Mishkin, 2007)

Long-Run Inflation Expectations



Can We Tell These Stories Apart?

- Extremely difficult using aggregate evidence
  - Results based on survey or adaptive expectations are very sensitive to details of specification (e.g., which expectation variable)
  - Results based on structural rational expectations specifications also very sensitive to details (partly due to a weak instruments problem)

- Mavroeidis, Plagborg-Moller, Stock 14:

  [T]he Literature has reached a limit on how much can be learned about the New Keynesian Phillips curve from aggregate macroeconomic time series. New identification approaches and new datasets are needed to reach an empirical consensus.

Identification Challenges

- Inflation expectations may covary with unemployment
  - For example: Imperfectly credible regime change
  - Literature seeks to control for inflation expectations
    but this is difficult in practice
- Supply shocks (u_t^n and ν_t)
  - Lead to positive comovement between inflation and unemployment (stagflation)
  - Good monetary policy compounds with by counteracting demand variation, leaving only supply variation
    (Fitzgerald-Nicolini, 2014, McLeay-Tenreyro 2019)

Can Cross-Sectional Data Help?

- Recent literature estimates “regional Phillips curves”
  - Fitzgerald-Nicolini 14; Kiley 15; Babb-Detmeister 17; McLeay-Tenreyro 19; Hooper-Mishkin-Sufi 19; Fitzgerald-Jones-Kulish-Nicolini 20; Beraja-Hurst-Ospina 19 (wages), Hazell-Herreno-Nakamura-Steinsson 21.
- Major advantages:
  - Fixed effects soak up variation in (common) long-run inflation expectations
  - Fixed effects soak up aggregate supply shocks
  - Shift-share instruments can be used to deal with regional supply shocks
- New challenge:
  - How is the slope of the regional Phillips curve related to the slope of the aggregate Phillips curve?

The Role of the Long-Run Inflation Target

- Let's understand better the central role of long-run inflation expectations:

$$\pi_t = \beta E_t \pi_{t+1} - \kappa(u_t - u_t^n) + \nu_t$$

- Solve forward:

$$\pi_t = -\kappa E_t \sum_{j=0}^{\infty} \beta^j u_{t+j} + \omega_t$$

where $\omega_t = E_t \sum_{j=0}^{\infty} \beta^j (\kappa u_{t+j}^n + \nu_{t+j})$.

- Looks like long-run inflation expectation vanishes due to discounting
- This is an illusion!

The Role of the Long-Run Inflation Target

- Useful to decompose u_{t+j} into permanent and transitory component:

$$\pi_t = -\kappa E_t \sum_{j=0}^{\infty} \beta^j u_{t+j} + \omega_t$$

  becomes

$$\pi_t = -\kappa E_t \sum_{j=0}^{\infty} \beta^j \tilde{u}_{t+j} + \frac{\kappa}{1-\beta} E_t u_{t+\infty} + \omega_t$$

  where $\tilde{u}_t \equiv u_t - E_t u_{t+\infty}$
- Since $\frac{\kappa}{1-\beta} E_t u_{t+\infty} = E_t \pi_{t+\infty}$, we have

$$\pi_t = -\kappa E_t \sum_{j=0}^{\infty} \beta^j \tilde{u}_{t+j} + E_t \pi_{t+\infty} + \omega_t$$

  (Same result with $\beta = 1$)

The Role of the Long-Run Inflation Target

$$\pi_t = -\kappa E_t \sum_{j=0}^{\infty} \beta^j \tilde{u}_{t+j} + E_t \pi_{t+\infty} + \omega_t$$

- Long-run inflation target actually major determinant of current inflation
- Has a coefficient of one!!
- Current inflation moves one-for-one with beliefs about long-run inflation target
- In contrast, κ may be very small

The Role of the Long-Run Inflation Target

- To simplify, one can assume that $\tilde{u}_t$ follows an AR(1)
- This implies $E_t \tilde{u}_{t+j} = \rho_u^j \tilde{u}_t$

$$\pi_t = -\kappa E_t \sum_{j=0}^{\infty} \beta^j \tilde{u}_{t+j} + E_t \pi_{t+\infty} + \omega_t$$

becomes

$$\pi_t = -\psi \tilde{u}_t + E_t \pi_{t+\infty} + \omega_t$$

where $\psi = \kappa / (1 - \beta \rho_u)$.

The Role of the Long-Run Inflation Target

$$\pi_t = -\psi \tilde{u}_t + E_t \pi_{t+\infty} + \omega_t$$

- Variation in inflation may be dominated by variation in $E_t \pi_{t+\infty}$
- Variation in inflation may be **completely unrelated** to variation in $\tilde{u}_t$
- Worse still, correlation between $E_t \pi_{t+\infty}$ and $\tilde{u}_t$ potentially a source of severe omitted variables bias

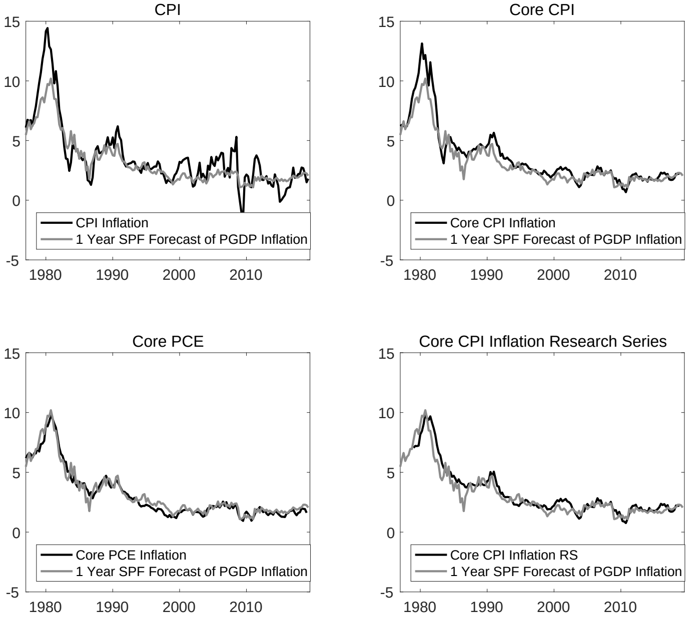
How Different Are π_t and $E_t\pi_{t+1}$?

$$\pi_t = \beta E_t\pi_{t+1} - \kappa(u_t - u_t^n) + \nu_t$$

- This is approximately (if $\beta \approx 1$):

$$\pi_t - E_t\pi_{t+1} \approx -\kappa(u_t - u_t^n) + \nu_t$$

- So, standard analysis aims to explain $\pi_t - E_t\pi_{t+1}$
- But how much is there to explain?
- Let's look at the difference between π_t and $E_t\pi_{t+1}$ in the data


CPI
CPI Inflation
1 Year SPF Forecast of PGDP Inflation
Core CPI
Core CPI Inflation
1 Year SPF Forecast of PGDP Inflation
Core PCE
Core PCE Inflation
1 Year SPF Forecast of PGDP Inflation
Core CPI Inflation Research Series
Core CPI Inflation RS
1 Year SPF Forecast of PGDP Inflation
15
10
5
0
-5
1980
1990
2000
2010

$\pi_t \approx E_t\pi_{t+1}$

$$\pi_t - E_t\pi_{t+1} \approx -\kappa(u_t - u_t^n) + \nu_t$$

- Inflation gap for core inflation is small throughout
  (for core using modern methods)
- Consistent with a flat Phillips curve

However:

- Relies heavily on exact timing of New Keynesian Phillips curve
  (Also subject to other concerns regarding aggregate Phillips curve estimation)

A Model of the Regional Phillips Curve

- Two regions: Home and Foreign
- Tradeable and non-tradeable sector in each region
- No labor mobility between regions
- Perfect labor mobility between sectors within region
- Monetary union

Households and Firms

- Households:
  - Consume and supply labor
  - Nested CES demand over varieties of traded and non-traded goods
  - GHH preferences
- Firms:
  - Linear production function in labor
  - Calvo (1983) type price rigidity

Phillips Curves

- Regional Phillips Curve for Non-Tradeables:

$$\pi^N_{Ht} = \beta E_t \pi^N_{H,t+1} - \kappa \hat{u}_{Ht} - \lambda \hat{p}^N_{Ht} + \nu^N_{Ht}$$

- Aggregate Phillips Curve:

$$\pi_t = \beta E_t \pi_{t+1} - \kappa \hat{u}_t + \nu_t$$

  where $\hat{u}_{Ht} = -\hat{n}_{Ht}$ and $\hat{u}_t = -\hat{n}_t$

- Important result: Same slope κ
  - This is true for non-tradeable regional Phillips curve
  - Not for overall regional Phillips curve (traded goods priced nationally)
  - Relies on GHH preferences

Regional Phillips Curve for Non-Tradeables

$$\pi^N_{Ht} = \beta E_t \pi^N_{H,t+1} - \kappa \hat{u}_{Ht} - \lambda \hat{p}^N_{Ht} + \nu^N_{Ht}$$

- Extra term: $\lambda \hat{p}^N_{Ht}$. Theoretically important!
- Common critique:
  - Even in multi-region RBC model, regional demand shock would result in an increase in relative price of local goods
- Extra term implies that this model nests multi-region RBC model
- If prices were flexible, λ would be large
- Empirically, λ estimated to be small

Regional Phillips Curve Solved Forward

- Let's solve the regional Phillips curve forward:

$$\pi^N_{Ht} = -\kappa E_t \sum_{j=0}^{\infty} \beta^j \tilde{u}_{H,t+j} - \lambda E_t \sum_{j=0}^{\infty} \beta^j \hat{p}^N_{H,t+j} + E_t \pi_{t+\infty} + \omega^N_{Ht},$$

- Long-run inflation expectations are constant across regions and can be replaced with time and state fixed effects:

$$\pi^N_{Ht} = -\kappa E_t \sum_{j=0}^{\infty} \beta^j \tilde{u}_{H,t+j} - \lambda E_t \sum_{j=0}^{\infty} \beta^j \hat{p}^N_{H,t+j} + \alpha_i + \gamma_t + \omega^N_{Ht},$$

- Panel specification "differences out" long-run inflation expectations

Common Across Regions?

$$\pi_{Ht}^{N} = -\kappa E_t \sum_{j=0}^{\infty} \beta^j \tilde{u}_{H,t+j} - \lambda E_t \sum_{j=0}^{\infty} \beta^j \hat{p}_{H,t+j}^{N} + E_t \pi_{t+\infty} + \omega_{Ht}^{N},$$

- Can't long-run inflation expectation differ across regions?
  - Prices are rising in New York relative to Kansas
  - Balassa-Samuelson effects
- Constant differences captured by state fixed effects
- Non-constant differences in **long-run** inflation expectations will be in error term
  - Small part of total variation (arguably)
  - A concern if correlated with instruments

Interpretation of Slope Coefficient

- Regional Phillips curve:

$$\pi_{Ht}^{N} = -\kappa E_t \sum_{j=0}^{\infty} \beta^j \tilde{u}_{H,t+j} - \lambda E_t \sum_{j=0}^{\infty} \beta^j \hat{p}_{H,t+j}^{N} + \alpha_i + \gamma_t + \omega_{Ht}^{N},$$

- Suppose we assume that $\tilde{u}_{Ht}$ and $\hat{p}_{Ht}^{N}$ follow AR(1) processes:

$$\pi_{Ht}^{N} = -\psi \tilde{u}_{Ht} - \delta \hat{p}_{Ht}^{N} + \alpha_i + \gamma_t + \omega_{Ht}^{N} \tag{1}$$

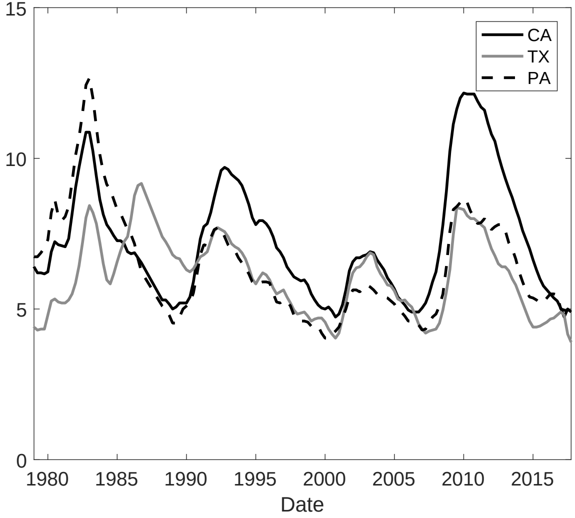
$$\text{where} \qquad \psi = \frac{\kappa}{1 - \beta\rho_u} \qquad \text{and} \qquad \delta = \frac{\lambda}{1 - \beta\rho_{pN}}$$

- Equation (1) similar to typical regional empirical specification
- But κ and ψ are not the same!
  - ψ potentially much larger than κ since $\tilde{u}_{Ht}$ is persistent
  - Prior regional Phillips curve literature estimates ψ not κ.
  - Helps explain large slope estimates in this literature

Data

- New state-level inflation indexes (Hazell-Herreno-Nakamura-Steinsson 21)
  - Sample period 1978 - 2018, quarterly
  - Based on BLS CPI micro data
  - Free of cross-state imputations
  - Separate indexes for tradeables vs. non-tradeables
- Analyze housing separately
- Measure of slack: State unemployment rates
- Tradeable demand spillover instrument:
  - State-industry employment shares
  - 2-digit SIC for 1975-2000
  - 3-digit NAICS from 1990-2018

Regional Business Cycles



Phillips Curve Slope

- Regional Phillips curve from model:

$$\pi_{it}^N = \alpha_i + \gamma_t - \kappa E_t \sum_{j=0}^{\infty} \beta^j u_{i,t+j} - \lambda E_t \sum_{j=0}^{\infty} \beta^j \hat{p}_{i,t+j}^N + \omega_{it}$$

- Reduced form equation similar to prior literature:

$$\pi_{it}^N = \alpha_i + \gamma_t - \psi u_{i,t-4} - \delta p_{i,t-4}^N + \varepsilon_{it}$$

- HHNS present estimates of both κ and ψ

Estimation of κ

$$\pi_{it}^N = \alpha_i + \gamma_t - \kappa E_t \sum_{j=0}^{\infty} \beta^j u_{i,t+j} - \lambda E_t \sum_{j=0}^{\infty} \beta^j \hat{p}_{i,t+j}^N + \omega_{it}$$

- Replace expectations with realized values and expectation error and truncate the infinite sums:

$$\pi_{it}^N = \alpha_i + \gamma_t - \kappa \sum_{j=0}^{T} \beta^j u_{i,t+j} - \lambda \sum_{j=0}^{T} \beta^j \hat{p}_{i,t+j}^N + \omega_{it} + \eta_{it}$$

  where η_{it} is an expectations error (and truncation error)

- κ can now be estimated using an IV regression (i.e., GMM)

- Calibrate $\beta = 0.99$

Identification

Two Approaches:

- Use lagged unemployment and relative prices as instruments
  - Unemployment may reflect supply shocks
  - Time fixed effects capture national supply shocks
  - Identifying assumption: No relative change in restaurant technology in Texas vs. Illinois when Texas experiences a recession relative to Illinois
- Tradeable demand instrument

Tradeable Demand Spillover Instrument

$$\text{Tradable Demand}_{i,t} = \sum_{x \in T} \bar{S}_{x,i} \times \Delta \log S_{-i,x,t}$$

- $\bar{S}_{x,i}$: Average employment share of industry x in state i over time
- $\log S_{-i,x,t}$: National employment share of industry x at time t
- Identifying assumption: supply shocks not simultaneously correlated with **both** shifts $\Delta \log S_{-i,x,t}$ **and** shares $\bar{S}_{x,i}$
- Intuition:
  - Oil boom increases labor demand and wages in Texas
  - “Demand shock” for Texan restaurants
  - Oil boom does not differentially affect production technology for restaurants in Texas

Estimation of ψ

$$\pi_{it}^{N} = \alpha_i + \gamma_t - \psi u_{i,t-4} - \delta p_{i,t-4}^{N} + \varepsilon_{it}$$

Same two approaches:

- OLS
- Instrument for $u_{i,t-4}$ with tradeable demand instrument

Estimates

Full Sample

	No State Effects	No Time Effects	Lagged u IV	Tradeable Demand IV
	(1)	(2)	(3)	(4)
ψ	-0.103	0.017	0.112	0.339
	(0.036)	(0.027)	(0.057)	(0.126)
κ	-0.0037	0.0003	0.0062	0.0062
	(0.0013)	(0.0019)	(0.0028)	(0.0025)
State Effects		✓	✓	✓
Time Effects			✓	✓

Has the Phillips Curve Flattened?

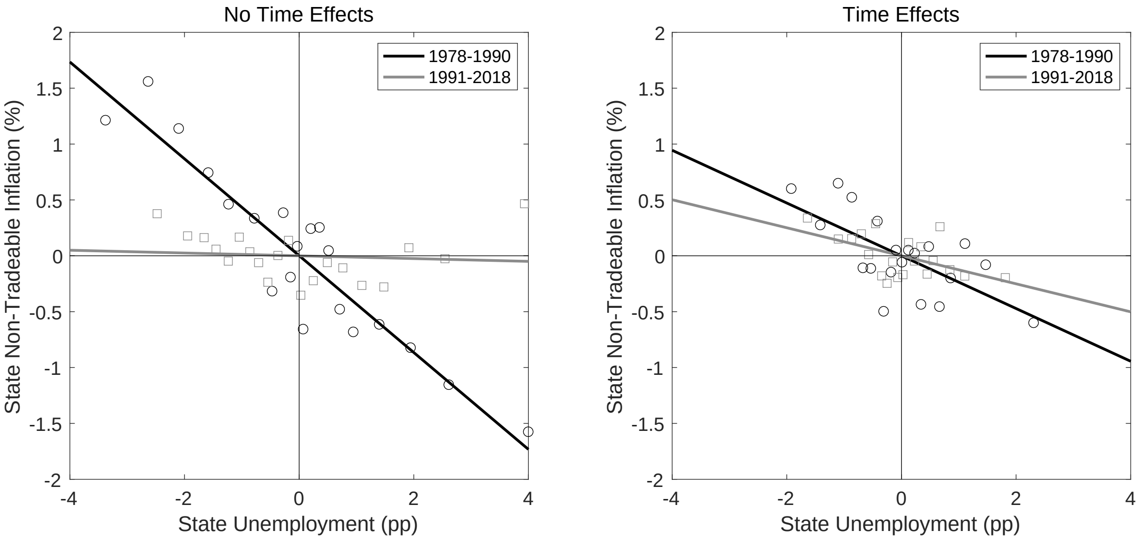
	Lagged u IV No Time Fixed Effects		Lagged u IV Time Fixed Effects		Tradeable Demand IV Time Fixed Effects	
	Pre-1990 (1)	Post-1990 (2)	Pre-1990 (3)	Post-1990 (4)	Pre-1990 (5)	Post-1990 (6)
ψ	0.449	0.009				
	(0.063)	(0.025)				
κ	0.0278	0.0002				
	(0.0025)	(0.0017)				

All specifications include state fixed effects

Has the Phillips Curve Flattened?

	Lagged u IV No Time Fixed Effects		Lagged u IV Time Fixed Effects		Tradeable Demand IV Time Fixed Effects	
	Pre-1990 (1)	Post-1990 (2)	Pre-1990 (3)	Post-1990 (4)	Pre-1990 (5)	Post-1990 (6)
ψ	0.449	0.009	0.198	0.090	0.422	0.332
	(0.063)	(0.025)	(0.113)	(0.057)	(0.232)	(0.157)
κ	0.0278	0.0002	0.0107	0.0050	0.0109	0.0055
	(0.0025)	(0.0017)	(0.0080)	(0.0038)	(0.0048)	(0.0029)

All specifications include state fixed effects



Scatterplots—Non-Tradeable Inflation and Unemployment

Main Conclusions

- Slope of Phillips curve small
  - $\kappa = 0.0062$ implies that even a 5 percentage point increase in unemployment decreases inflation by only 2 percentage points
    (if inflation expectations remain unchanged)
- Apparent "flattening" mainly due to anchoring of expectations
  - No time fixed effects: Factor >100 flattening
  - With time fixed effects: Factor 2 flattening
  - Interpretation: Time fixed effects absorb movements in long-run inflation expectations

HHNS Estimates Compared to Prior Work

	κ
Gali (2008)	0.085
Rotemberg and Woodford (1997)	0.019
Nakamura and Steinsson (2014)	0.0077
Our Estimate	
Full Sample IV Estimate	0.0062

Note: HHNS adjust prior estimates by the elasticity of output with respect to employment in the model in these papers. For Nakamura and Steinsson (2014), HHNS use the calibration with GHH preferences.

Missing Disinflation?

- Can HHNS's cross-section estimate of κ explain aggregate time-series fluctuations in inflation?
- Many have argued:
  - Missing disinflation during Great Recession
  - Missing reinflation during late 2010s and late 1990s
- Are cross-sectional estimates of Phillips curve steeper than time-series estimates?

Aggregate Implication

- Plot RHS and LHS of

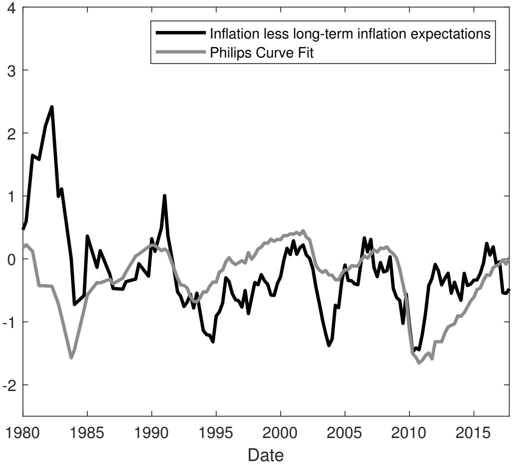
$$\pi_t - E_t \pi_{t+\infty} = -\kappa \zeta \tilde{u}_t + \omega_t$$

  assuming no supply shocks $\omega_t = 0$

- Scaling factor: $\zeta = 6.16$ (s.e. 1.80)

$$\sum_{j=0}^{T} \beta^j \tilde{u}_{t+j} = \zeta \tilde{u}_t + \alpha + \epsilon_t.$$

- Aggregate includes housing
  - Estimate aggregate Phillips curve for shelter
  - Data from American Community Survey for 2001-2017
  - $\kappa = 0.0243$ (s.e. 0.0053)
  - About four time larger than for non-shelter



Aggregate Phillips Curve

Has Phillips Curve “Broken Down” Recently?

- Post-1990: Predictions fit data reasonably well
  - Essentially no missing disinflation or missing reinflation
- Pre-1990: Data deviates substantially from predictions
  - Actual inflation gap much higher than predicted
  - Natural Explanation: Adverse supply shocks
- Opposite of conventional wisdom

The Elephant in the Room

- Key determinant of inflation: $E_t \pi_{t+\infty}$
- But how does the monetary authority change $E_t \pi_{t+\infty}$
  - Fundamentally hard!!
  - How does it convince people that what it says is credible?
  - Answering this is not a strong suit of economists (need more research)
- Sometimes beliefs do change rapidly
  (e.g., Volcker disinflation, ends of hyperinflations)

How Does One Change Long-Run Beliefs?

- Volcker tightened policy dramatically
  - Caused massive recession
  - Didn’t get fired
- Perhaps this was crucial in changing beliefs about long-run monetary regime
- Fundamentally different from view that inflation fell due to steep Phillips curve