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An Evaluation of the Inflationary Pressure Associated with Short- and Long-term Unemployment

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Abstract

In the years following 2009, long-term unemployment has been very elevated while inflation has fallen only moderately, raising the question of whether the long-term unemployed exert less downward pressure on prices than the short-term unemployed, perhaps because such potential workers are disconnected from the labor market. However, empirical evidence is mixed. This analysis demonstrates that the typical approach, using national data, is incapable of discriminating the inflationary pressure exerted by short- and long-term unemployment because the series are highly correlated, making inference difficult given the short-span of data used in Phillips-curve estimation. However, application of more data, through the use of regional variation, can discriminate the independent influences of short- and long-term unemployment on price inflation. We present a model illustrating these issues and apply the model to data for U.S. metropolitan regions. We find that that short- and long-term unemployment exert equal downward pressure on price inflation.
JEL Classification Code: E3

1 Introduction

Five years after the end of the Great Recession, the rate of long-term unemployment in the United State has remained relatively elevated, while the rate of short-term unemployment has returned to a level close to historical norms. At the same time, inflation, while low, has not fallen as much as some observers expected in the aftermath of the Great Recession (e.g., Ball and Mazumder (2011)). [1] Moreover, theoretical considerations raise the possibility that short- and long-term unemployment exert different pressure on prices: For example, workers that are unemployed for long periods may become disconnected from the labor market (due, for example, to‘hysteresis-type effects) or ranking practices may imply that the recently unemployed are the “marginal” influence on wage pressures (e.g., Blanchard and Summers (1988), Layard, Nickells, and Jackman (1991) or Blanchard and Diamond (1994)). These considerations have raised the question of whether the long-term unemployed exert less downward pressure on prices. Such questions are highly relevant in policy discussions following the Great Recession (e.g., Economic Report of the President (2014), pages 81-83). However, empirical evidence, based on estimation of Phillips curves for U.S. national data, is mixed.

The standard approach using national inflation and unemployment data faces considerable empirical challenges. In particular, rates of short- and long-term unemployment are highly correlated in U.S. data, making inference difficult in short samples. (That is, the regressors suffer from the problem of “multicollinearity”.) We will illustrate that this empirical problem is very clear when estimating a simple Phillips curve in U.S. data, where coefficients on short- and long-term unemployment rates are very imprecisely estimated, but are jointly highly statistically significant.

However, these challenges can be overcome by bringing more data to bear on the question. As the recent policy debate does not have the luxury

[1] Some research has suggested that the degree of disinflation since the Great Recession has not been surprising, e.g., Del Negro, Giannoni, and Schorfheide (2013).

of waiting for more years of data to accumulate, we turn to an additional source of data: Regional variation.[2] Specifically, we consider the links between inflation and various measures of unemployment across U.S. regions (as well as with national rates of unemployment) over the last 30 years. This approach yields much more precise parameter estimates. We estimate the influence of short- and long-term unemployment on inflation rather precisely (compared to earlier studies) and find no evidence that long-term unemployment exerts less pressure on prices than short-term unemployment.

The next section presents information on U.S. (national) data and estimates national-level Phillips curves, illustrating the empirical challenges associated with discriminating between the effects on inflation of short- and long-term unemployment. Section 3 presents a model to highlight the small-sample issue and how regional variation may yield more precise parameter estimates. Section 4 presents the results using U.S. metropolitan area data and section 5 concludes.

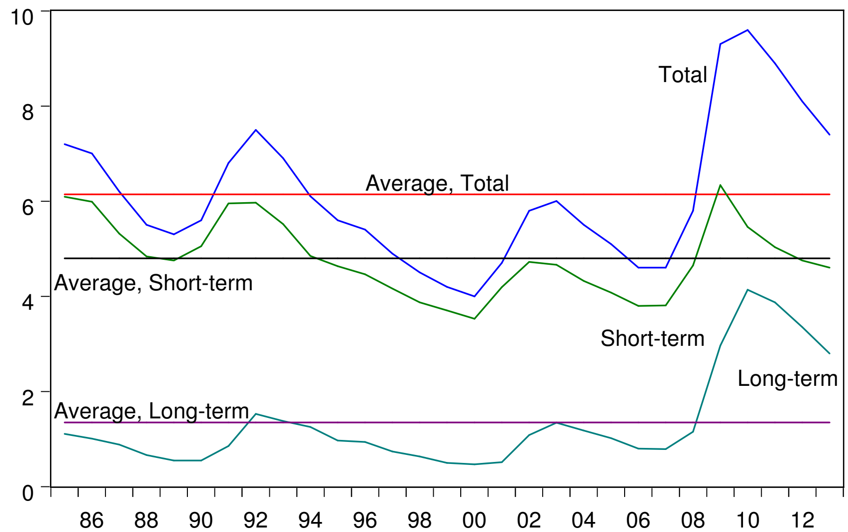
2 Aggregate Evidence for the United States

Figure 1 presents the evolution of the national unemployment rate, the rate of short-term unemployment, and the rate of long-term unemployment (where the cutoff between short- and long-term unemployment is set at 27 weeks); we focus on annual data. Short- and long-term unemployment are highly correlated. Since 2009, there has been some divergence. Notably, short-term unemployment fell to near its average level over this period by 2013, while long-term unemployment remained elevated.

To examine the inflationary pressure from unemployment rates, a simple

[2]Fitzgerald, Holtemeyer, and Nicolini (2013) recently estimated Phillips curves for U.S. regions and found that these specifications appear more stable over time than a national estimate. They propose a theoretical reason for their findings. The motivation herein is different – that is, this analysis focuses on the small sample problems associated with the high correlation between short- and long-term unemployment rates. Moreover, our model will allow regional and national unemployment factors to enter the Phillips curve (which seems reasonable for reasons outlined below), whereas Fitzgerald, Holtemeyer, and Nicolini (2013) consider only regional unemployment rates in their empirical models.

Figure 1: Total, Short-term, and Long-term Unemployment in the United States



Phillips curve is specified, in which inflation ($\Delta p(t)$) depends on its own lag and rates of unemployment (with the rates of total, short- and long-term unemployment denoted by $u(t)$, $u^s(t)$, $u^l(t)$, respectively):

$$\Delta p(t) = aE\Delta p(t) + \rho\Delta p(t-1) + \alpha^s u^s(t) + \alpha^l u^l(t) + e(t). \tag{1}$$

The basic motivation for the Phillips curves comes from the textbook "Expectations-augmented" approach: price inflation depends upon expected inflation, lagged inflation (e.g., inertia), and unemployment – with possibly distinct roles for short- and long-term unemployment, as explored in Ball and Mazumder (2011), Stock (2011), Gordon (2013), and Watson (2014).

We estimate this equation for the period from 1985 to 2013 and the more recent period from 1998 to 2013 using annual data. We focus on the recent period for estimation because of evidence that the nature of the Phillips curve was importantly different over this period, reflecting increased anchoring of inflation expectations (e.g., Williams (2006), Kiley (2007), and Boivin, Kiley, and Mishkin (2010)). In our empirical specification, we allow inflation expectations ($E\Delta p$) to be a function of a constant and the measure of expected inflation over the next 10 years from the Survey of Professional Forecasters for the 1985 to 2013 period. As the survey measure of expected inflation is essentially constant after 1998, expected inflation is proxied by the constant term in the 1998 to 2013 sample. We use the Consumer Price Index (excluding food and energy) as our price measure.

Results are reported in table 1. We consider a range of cases: The first two columns report the case using the total unemployment rate (i.e., $\alpha^s = \alpha^l$)); columns 3 and 4 report the case using only short-term unemployment ($\alpha^l = 0$), while columns 5 and 6 report the case using only long-term unemployment ($\alpha^s = 0$). Finally, the last two columns allow for separate influences from short- and long-term unemployment.

A few results are clear. First, some type of Phillips curve relationship is present in the data, as all of the specifications with only one measure of unemployment show statistically significant coefficients on the unemployment measure (with the reported standard errors yielding t-statistics around 3 in all cases). In addition, all of the equations fit quite similarly – as can be seen both in the similarity of coefficients and standard errors, and (more directly) in the R^2 statistics. Finally, consistent with Williams (2006), inertia is reduced in the most recent (1998-2013) period in each specification. Note that this finding suggests the focus on accelerationist specifications, in which the lag on inflation (or sum of lags) is restricted to enter with a coefficient of unity, is misplaced.

Several recent analyses have discussed the possible separate roles of short-term and long-term unemployment. Ball and Mazumder (2011) speculate that the differential behavior of short- and long-term unemployment after 2009 may allow for separate consideration of these factors as more data accumulate (and our model/Monte Carlo simulations in the next section will examine this conjecture). Building on this idea, Stock (2011), Gordon (2013), Watson (2014), and Linder, Peach, and Rich (2014) each estimate Phillips curves similar to those in the first four columns – that is, curves

Table 1: Estimates of Phillips Curve Using National Data

	Sample Period							
	1985-2013	1998-2013	1985-2013	1998-2013	1985-2013	1998-2013	1985-2013	1998-2013
Unemployment Measure	Total		Short		Long		Short and Long	
a	0.52		0.52		0.51		0.52	
	(0.23)		(0.22)		(0.23)		(0.23)	
ρ	0.50	0.14	0.61	0.35	0.44	0.04	0.59	0.15
	(0.17)	(0.21)	(0.17)	(0.12)	(0.19)	(0.16)	(0.23)	(0.18)
α^s	-0.11	-0.16	-0.28	-0.34	na	na	-0.24	-0.17
	(0.05)	(0.05)	(0.11)	(0.12)			(0.21)	(0.20)
α^l	-0.11	-0.16	na	na	-0.17	-0.24	-0.03	-0.14
	(0.05)	(0.05)			(0.08)	(0.08)	(0.15)	(0.15)
Wald test (p-value)								
$\alpha^s = 0, \alpha^l = 0$	0.03	0.01	0.02	0.01	0.04	0.01	0.05	0.01
Wald test (p-value)								
$\alpha^s = \alpha^l = 0$	na	na	na	na	na	na	0.54	0.92
R^2	0.69	0.57	0.69	0.53	0.68	0.54	0.69	0.57

1. Standard errors of coefficient estimates in parentheses under appropriate coefficient. Wald test (p-value) refers to the asymptotic χ^2 test.

with either total unemployment or short-term unemployment, but not both short-term and long-term unemployment. An important difference is that these previous analyses emphasize and "accelerationist" form of the Phillips curve, in which high unemployment results in continuously falling inflation; in contrast, our analysis builds on Williams (2006) and Kiley (2007), who document how anchored expectations since the Volcker disinflation imply that high levels of economic slack result in below average. but not continuously decelerating, inflation. (This distinction is important in evaluating the claims of "missing disinflation" that follow the approach of Ball and Mazumder (2011). For example, this is the evidence emphasized in Gordon (2013) or Linder, Peach, and Rich (2014) or Krueger, Cramer, and Cho (2014).)

The reason previous analyses have taken the approach of looking at either short- or long-term unemployment, but not both, is clear in the last two columns: The coefficients on short- and long-term unemployment are very imprecisely estimated when each measure is allowed to enter. However, these coefficients are jointly highly significant in the statistical sense (as indicated by the p-value associated with the Wald test for the exclusion of these variables). Finally, due to the lack of precision, the Wald test for the equality of the coefficients on short- and long-term unemployment cannot reject this hypothesis – but this result is hardly dispositive on the issue, as the balance of results points to problems distinguishing the roles of short- and long-term unemployment in inflationary pressure. The next section highlights these problems and a possible solution.

3 A Model to Guide the Analysis

We now provide an illustration of the problem and our approach to resolving these difficulties.

We start by observing, as in Fitzgerald, Holtemeyer, and Nicolini (2013), that the United States is composed of many regions, and it is plausible to consider Phillips curves at the regional level. On its face, this is not controversial – the world economy consists of many regions and economists estimates Phillips curves for individual regions, even across regions sharing a common currency (e.g., the Euro area). More fundamentally, labor markets may be somewhat localized, implying that regional labor market conditions may affect costs (and hence prices) within a region. In addition, non-traded goods and services may reflect resource utilization pressures within their regions. With these thoughts in mind, we suppose that price inflation in region i ($\Delta p(i,t)$) is a related to regional and national factors in much the same way as assumed above:

$$\begin{aligned}\Delta p(i,t) &= aE\Delta p(i,t) + \rho_1 \Delta p(i,t-1) + \rho_2 \Delta p(t-1) \\ &+\alpha_1^s u^s(i,t) + \alpha_1^l u^l(i,t) + +\alpha_2^s u^s(t) + \alpha_2^l u^l(t) + e^i(t).\end{aligned} \tag{2}$$

Note that, in principal, this equation allows for independent roles for regional and national factors (in expectations, in inertia, and in the role of labor market factors). We have assumed symmetry across regions.

To demonstrate the challenges that arise using national data, we use a Monte Carlo approach. Specifically, we parameterize equation 2, simulate data from this parameterization, and then estimate Phillips curves using national and regional data.

Our simulations assume symmetric regions. Focusing on the Phillips curve, we assume that inflation expectations are anchored (at a constant level), that inertia is local (with $\rho_1 = 0.5$ and $\rho_2 = 0$), and that short- and long-term unemployment enter the Phillips curve with equal coefficients and that these effects are local (with $\alpha_1^s = \alpha_1^l = 0.25$ and $\alpha_2^s = \alpha_2^l = 0$). Finally, we assume that the errors in the Phillips curve have a standard deviation of 1 and that the correlation between regions is 0.2.

For unemployment, we assume regional short- and long-term unemployment rates are the sum of a common and regional factor, both of which are auto-correlated. The common unemployment factor is an AR(2) process (where the coefficient on the first lag is 1.1 and that on the second is -0.5) whose innovation standard error is 0.4 percent. The regional factors for short-term and long-term unemployment are independent (within and across regions); this implies that the correlations between short- and long-term unemployment within and across regions are due to the common factor. The regional factors are AR(1) processes with a lag coefficient of 0.9 and an innovation standard error of 0.237.

(More details on the simulated model are provided in an appendix.)

This calibration roughly matches features of U.S. data for CPI inflation and unemployment across the regions we use in our empirical analysis. In particular, we examine 24 large metropolitan areas in the United States for which we could gather the Consumer Price Index and measures of unemployment over the 1985 to 2013 period.[3] Our panel of regions contains 24 regions over 29 years; however, there are missing observations for certain regions at the beginning and end of the time period under study, so our panel is unbalanced. An appendix presents more information on the data used in this study.

Table 2 presents some summary statistics for the U.S. data and from our parameterization of the model. The simulated data has the key characteristics to U.S. data. The volatility of inflation and unemployment measures is similar to that of the data, as are the autocorrelations. (Although national inflation is somewhat less auto-correlated in the simulated data than over the 1985-2013 sample, this reflects the fact that inflation was higher in the early half of this period, and the autocorrelation of inflation is much lower in recent years; our calibration balances these considerations.) Inflation is modestly correlated across metropolitan areas; unemployment measures are more strongly correlated across metropolitan regions.

Results for estimates of the effects of short- and long-term unemployment on inflation using simulated national data are reported in figure 2: This panel reports the empirical densities of coefficients on short- and long-term unemployment, along with those estimated when one imposes that the

[3]This is essentially the universe of metropolitan areas for which our price measure is available. Among the areas for which the CPI is available, we delete Tampa Bay and Phoenix because prices are only available for a subset of months during a year. We also exclude Anchorage, as changes in definition implied that it was not possible to construct (relatively) consistent measures of unemployment for that region.

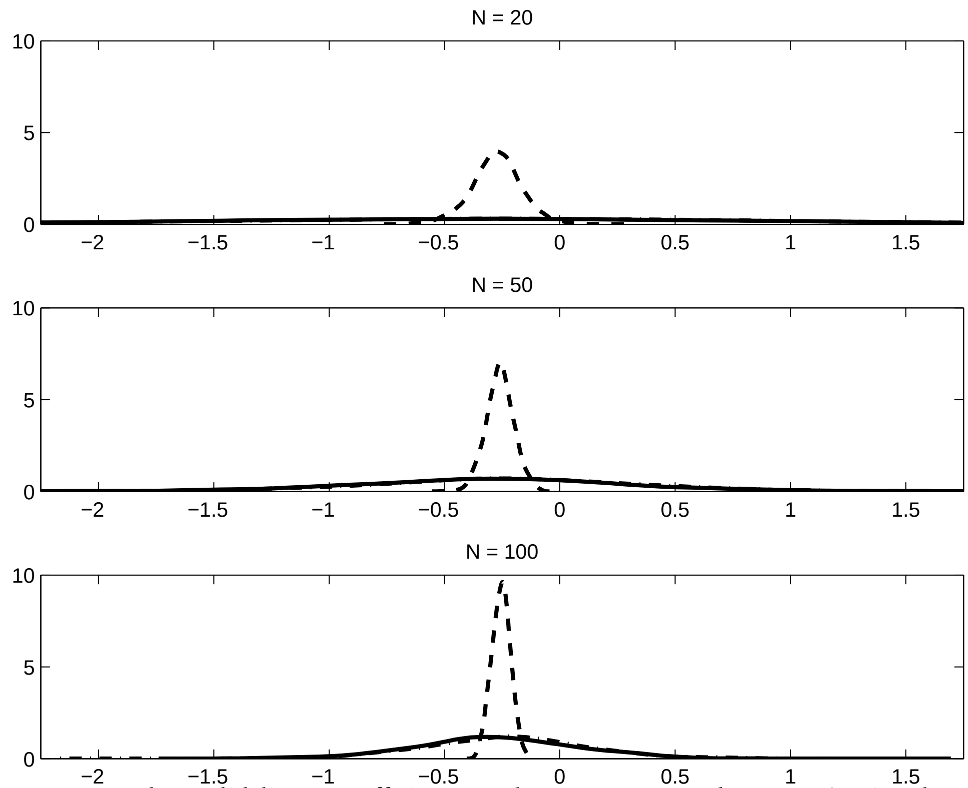
Table 2: Summary Statistics: U.S. (1985-2013) and Simulated Data

	Consumer Price Index (excluding food and energy)			
	Data		Simulated	
	National	Regional	National	Regional
Standard Deviation	1.1	1.3	0.8	1.3
Autocorrelation	0.9	0.7	0.7	0.6
Average pairwise Correlation across regions	0.3		0.3	
	Unemployment, Total			
	Data		Simulated	
	National	Regional	National	Regional
Standard Deviation	1.5	1.7	1.4	1.6
Autocorrelation	0.8	0.8	0.7	0.8
Average pairwise Correlation across regions	0.6		0.8	
	Unemployment, Short-term			
	Data		Simulated	
	National	Regional	National	Regional
Standard Deviation	0.8	1.0	0.7	0.9
Autocorrelation	0.7	0.7	0.7	0.8
Average pairwise Correlation across regions	0.5		0.6	
	Unemployment, Long-term			
	Data		Simulated	
	National	Regional	National	Regional
Standard Deviation	1.0	1.0	0.7	0.9
Autocorrelation	0.8	0.8	0.7	0.8
Average pairwise Correlation across regions	0.8		0.6	

1. Simulation: 100000 draws.

coefficients on these measures are equal (i.e., the total unemployment case). The top panel assumes a sample period of 20 years, the middle panel a sample period of 50 years, and the bottom panel a sample of 100 years. The thin blue (solid) and red (dashed) lines report the simulated density function for short- and long-term unemployment coefficients, respectively. (Note that these coefficients should be identical as the simulated data generating

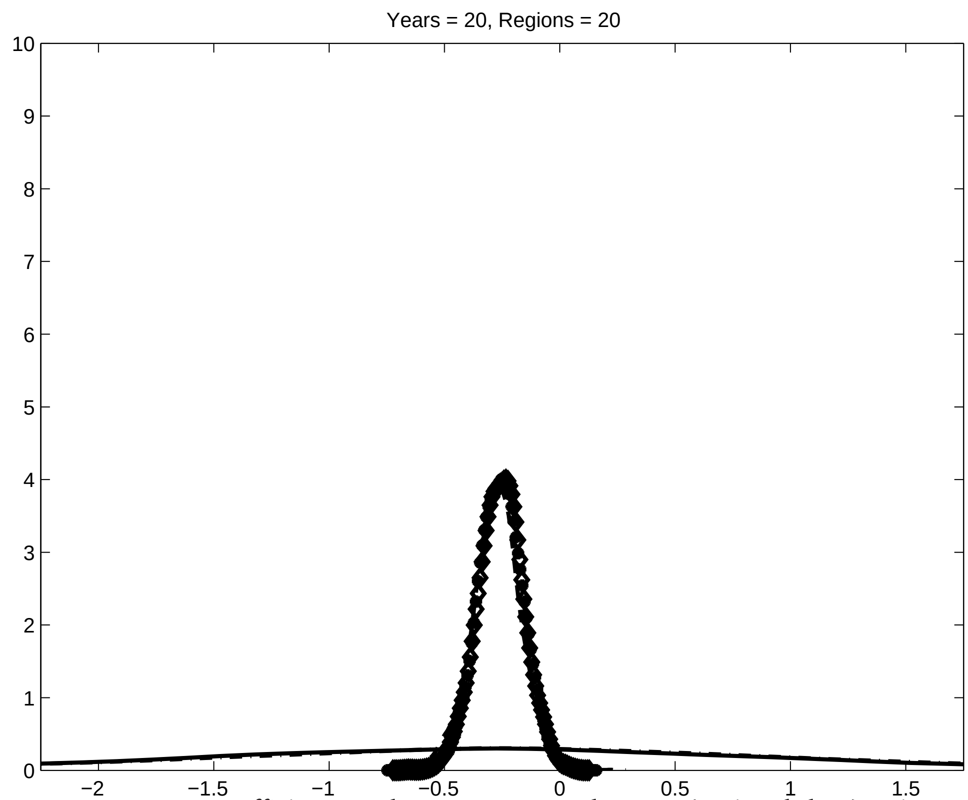
Figure 2: Simulated Densities of Coefficients on Unemployment, National Data



Note: Blue solid line: Coefficient on short-term unemployment (national data); Red dashed, dotted line: Coefficient on long-term unemployment (national data); Black dashed line: Coefficient on long-term unemployment (national data).

process is symmetric in these factors; the lines are very similar. indicating that our simulations are fairly accurate; the overlap of the lines makes it difficult to see the individual lines for coefficients on short- and long-term unemployment). The thin black (dashed) line reports the results for the national unemployment rate. Each coefficient is centered around 0.25, as it should be. The coefficients on short-term and long-term unemployment are very imprecisely estimated, even with 100 years of data (while the total unemployment measure estimates are more precisely estimated). Note that this result contradicts the conjecture of Ball and Mazumder (2013), who speculated that a few more years of data would provide clearer evidence of

Figure 3: Simulated Densities of Coefficients on Unemployment, Regional Data



Note: Stars: Coefficient on short-term unemployment(regional data); Diamonds: Coefficient on long-term unemployment (regional data); Solid line: Coefficient on short-term unemployment (national data); Dashed, dotted line: Coefficient on long-term unemployment (national data); Dashed line: Coefficient on total unemployment (national data).

the effects of short- and long-term unemployment on inflation. According to this analysis, a great deal more data would need to accumulate before precise estimates of the effects of short- and long-term unemployment could be estimated with any precision.

Figure 3 shows what happens when more data is brought to bear. In particular, this figure reports the results using 20 years of simulated data and exploiting the panel nature of the data (by using the 20 simulated regions). As shown by the stars and diamonds, the regional results are far more precise than the national-level results (repeated in the figure as lines). (Note that, because of the scale, it is difficult to see the lines illustrating the distribution of estimates based on national data; this visual effect illustrates the lack of precision using national data.) Our analysis suggests that a look at regional variation may help, and we turn to this data in the next section.

4 Results Using U.S. Metropolitan Data

We now turn to an empirical analysis of U.S. regional data. As mentioned before, We examine 24 large metropolitan areas for the United States.

We estimate equation 2 over two sample periods (as in our national estimates), 1985-2013 and 1998-2013. For the 1985-2013 sample, we proxy expected inflation with a region-specific intercept and the national measure of long-run expected inflation from the Survey of Professional forecasters used in our national regression; for the 1998-2013 sample, region fixed effects are used to proxy for expected inflation (because, as in the national regressions presented earlier, the survey measure of expected inflation is essentially constant over the 1998-2013 period). Note that these regional fixed effects will also account for regional differences in the average level of the measures of unemployment. (We do not impose any structure that would allow us to disentangle estimates of expected inflation and the natural rate of unemployment).[4] Finally, we also consider a specification with fixed time-period effects, which eliminates the ability of the specification to identify the coefficients on the national rates of the survey measure of inflation expectations, lagged inflation, and the unemployment measures, but controls for the possibility of omitted (time- varying) national factors.

Table 3 presents results. The first two columns repeat the results estimated using national data (reported previously in table 1). The middle columns present the estimates without time-period fixed effects, and the last two columns report results with the time-period fixed effects.

[4] In contrast, Fitzgerald, Holtemeyer, and Nicolini (2013) assume that there is a common national rate of expected inflation and use this assumption to identify the natural rate of unemployment implied by their regional estimates.

Table 3: Estimates of Phillips Curve Using Metropolitan Data

	Sample Period and Specification					
	National Data		Metropolitan Data			
	1985-2013	1998-2013	1985-2013	1998-2013	1985-2013	1998-2013
a	0.52		0.42		na	na
	(0.23)		(0.22)			
ρ_1			0.43	0.42	0.44	0.15
			(0.23)	(0.09)	(0.05)	(0.28)
ρ_2	0.59	0.15	0.25	-0.18	na	na
	(0.23)	(0.28)	(0.22)	(0.27)		
α_1^s			-0.21	-0.17	-0.22	-0.17
			(0.05)	(0.09)	(0.05)	(0.15)
α_1^l			-0.27	-0.29	-0.27	-0.14
			(0.07)	(0.09)	(0.07)	(0.15)
α_2^s	-0.24	-0.17	-0.14	-0.13	na	na
	(0.21)	(0.20)	(0.21)	(0.25)		
α_2^l	-0.03	-0.14	0.29	0.20	na	na
	(0.15)	(0.15)	(0.17)	(0.18)		
Wald test (p-value)						
$\alpha^s = 0, \alpha^l = 0$	0.05	0.01	0.00	0.00	0.00	0.00
Wald test (p-value)						
$\alpha^s = \alpha^l = 0$	0.54	0.92	0.28	0.54	0.57	0.46
Wald test (p-value)						
$\alpha_2^s = 0, \alpha_2^l = 0$			0.11	0.47	na	na
Regional fixed effects	No	No	Yes	Yes	Yes	Yes
Time-period fixed effects	No	No	No	No	Yes	Yes

1. Standard errors of coefficient estimates in parentheses under appropriate coefficient. Wald test (p-value) refers to the asymptotic χ^2 test. In cases where regional and national coefficients both enter, the Wald test refers to the sum of the regional and national coefficients.

Several results are apparent. First, the Phillips curve is very strong across metropolitan areas, with the null hypothesis of no Phillips curve ($\alpha_1^s = 0$, $\alpha_2^s = 0$, $\alpha_1^l = 0$, $\alpha_2^l = 0$) very strongly rejected. Second, the coefficients on metropolitan (local) unemployment rates are estimated precisely at around $-1/4$ (with, for example, t-statistics around 4 typical for α_1^s and α_1^l). Third, these local factors are much more important than the national rates of unemployment (where the Wald test does not reject the hypothesis that national unemployment rates should be excluded ($\alpha_2^s = 0$ and $\alpha_2^l = 0$), as reported in the last row containing Wald tests). Note this also implies that the last two columns with fixed regional and time-period effects (and therefore which control for national conditions not included) provide a good gauge of the effect of unemployment rates on inflation.

Finally, it is notable that the coefficients on local unemployment rates are precisely estimated and very similar, and the data do not reject the hypothesis that short- and long-term unemployment rates have similar effects on inflation. The national results on this issue were very imprecise because of the correlation between short- and long-term unemployment. As suggested by our model and simulation results, this difficulty can be overcome by examining regional data.

5 Conclusion

The elevated rate of long-term unemployment following the Great Recession has re-kindled interest in the question of whether long-term unemployment exerts similar effects on price inflation as short-term unemployment in the United States. Because short- and long-term unemployment rates are highly correlated in the United States, it has been difficult to answer this question.

We show, with a simple model and set of Monte Carlo exercises. that this difficulty is predictable given the sample sizes typically available using national data and that regional variation may help inference. We then exploit data on U.S. metropolitan regions to estimate the effects of short- and long-term unemployment on inflation. The results suggest that long-term unemployment has exerted similar downward pressure on inflation to that exerted by short-term unemployment in recent decades.

Finally, our analysis has highlighted how regional data can shed light on important questions facing the macroeconomy.[5]

[5]This finding has been a theme of recent research. For example, Fitzgerald, Holtemeyer, and Nicolini (2013) explore a different set of issues related to the Phillips curve using regional data. Nakamura and Steinsson (2011), among others, use regional data to examine the effects of fiscal stimulus.

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A National Data

We use the following data for the United States (sources in parentheses):

- The Consumer Price Index excluding food and energy (Bureau of Labor Statistics).
- The Civilian Unemployment Rate (Bureau of Labor Statistics).
- The Civilian Short-term Unemployment Rate (defined as unemployment spells of less than 27 weeks, computed from series on unemployment less than 27 weeks and series on the Civilian Labor Force) (Bureau of Labor Statistics) .
- The Civilian Short-term Unemployment Rate (equal to total minus short-term unemployment) (Bureau of Labor Statistics).
- Consumer Price Inflation Expected over the next 10 years (Survey of Professional Forecasters).

All data are annual (e.g., averages of underlying monthly or quarterly data).

B Metropolitan Area Data

We use the same CPI series for the metropolitan regions. We create metropolitan estimates of our unemployment series using the Current Population Survey. (In this case, short-term unemployment is defined as less than 27 weeks, as in the national data.)

The metropolitan areas we consider are New York-Northern New Jersey-Long Island, Philadelphia-Wilmington-Atlantic City,Boston-Brockton-Nashua, Pittsburgh, Chicago-Gary-Kenosha, Detroit-Ann Arbor-Flint, St. Louis, Cleveland-Akron, Minneapolis-St. Paul, Milwaukee-Racine, Cincinnati-Hamilton, Kansas City, Washington-Baltimore, Dallas-Fort Worth, Houston-Galveston-Brazoria, Atlanta, Miami-Fort Lauderdale, Los Angeles-Riverside-Orange County, San Francisco-Oakland-San Jose, Seattle-Tacoma-Bremerton, San Diego, Portland-Salem, Honolulu, and Denver-Boulder-Greeley.

C Simulated Model

The equations for the simulated model are presented in this appendix.

We assume 20 regions. Total unemployment in each region i is the sum of short- and long-term unemployment in each region ($u(i,t) = u^s(i,t) + u^l(i,t)$). The process for short-term unemployment reflects an aggregate ($a(t)$) and region specific ($r^s(i,t)$) factor,

$$u^s(i,t) = a(t) + r^s(i,t).$$

The aggregate and region specific factors are AR processes

$$a(t) = 1.1a(t-1) - .5a(t-2) + e(t)$$

$$r^s(i,t) = 0.9r^s(i,t-1) + v(i,t)$$

where $e(t)$ is i.i.d. $N(0, 0.4^2)$ and $v(i,t)$ is i.i.d. $N(0, 0.235^2)$ (and independent across regions i). The process for long-term unemployment is the same as that for short-term unemployment. (Note this calibration matches the data as described in table 2.)

The process for inflation is governed by a simple Phillips curve in each region

$$\Delta p(i,t) = 0.5\Delta p(i,t-1) - 0.25(u^s(i,t) + u^l(i,t)) + w(i,t)$$

where the vector $w(t) = [w(1,t), ..., w(20,t)]'$ is $N(0,\Sigma)$ where the diagonal elements of Σ equal 1 and the off-diagonal elements equal 0.2. This correlation structure implies that the correlation in inflation across regions reflects both the common (aggregate) impact of unemployment as well as other factors.