Time Dependence in Okun's Law at the State Level

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Abstract

I apply an anelastic version of Okun's law at the state level within the United States. By accounting for time dependence, this model improves the original version of Okun's law by reflecting how changes in output do not result in changes in unemployment instantaneously. Ultimately, I find that the anelastic form of Okun's law yields results that are statistically significant while coming from a process that fits the observed lag and reflects the underlying macroeconomic theory.

1 Introduction

Although economists support the negative relationship between output and unemployment that is presented by Okun's law at large, there is much less support among economists regarding just how accurately Okun's law is able to capture this economic relationship. The original form of Okun's law implies that changes in output gaps result in changes in unemployment gaps instantaneously; however, data suggests otherwise. Rather than observing Okun's law instantaneously, we observe that there is usually a lag for one variable (say, the unemployment gap) to catch up to what the other variable (say, the output gap) says it should be. This is why economists observe the original form of Okun's law to be more accurate in the long run rather than in the short run.

To address this issue, my paper advocates for an improved version of Okun's law that accounts for such time dependence by doing the following: First, I review the extant literature that makes the case for why an anelastic version of Okun's law is necessary. Next, I explicitly state how the anelastic form of Okun's law is different from the original form. Then, I analyze each form of Okun's law at the U.S. state level. Lastly, I discuss our results which come from a process that fits the observed lag while reflecting the underlying macroeconomic theory.

2 Literature Review

Before delving into an adapted anelastic version of Okun's law, it is critical to understand why such a version is necessary in the first place. To do so, we must see how economists have been commonly applying Okun's law so far in its original version. One research paper that represents this is "Does One Law Fit All? Cross-Country Evidence on Okun's Law" by Ball et al. In this paper, Ball et al. compare how Okun's law performs in economies that are developing compared to those that are advanced. On the whole, they find that the Okun coefficient "which measures the short-run responsiveness of labor markets to output fluctuations. . . is about half as large in developing as advanced countries" Ball et al. (2019).

To calculate these Okun coefficients, Ball et al. use data from the International Monetary Fund's World Economic Outlook on the unemployment rate, employment, labor force, and real gross domestic product (GDP). They, then, use the Hodrick-Prescott (HP) filter to find respective trend values. In discussing their findings, Ball et al. point out that "there is considerable heterogeneity across countries . . . [in] the fit of Okun's Law" that they have "limited success in explaining" Ball et al. (2019). Although the authors lightly suggest that inconsistent indices of overall labor and inconsistent product market flexibility may be responsible for the varying success that they have in having country data fit the model, one can only wonder if the explanation perhaps lies in the model itself with room for improvement.

In addition to application at the country-level, there are applications at the state-level that rely on the original version of Okun's law too. Some specific examples include: "The Measurement and Determination of Okun's Law: Evidence from State Economies" by Blackley; "Regional Tests of Okun's Law" by Freeman; and, "A state-level analysis of Okun's law" by Guisinger et al. According to Blackley, his paper "makes the initial attempt to measure Okun's Law for each of the 26 largest states in the U.S. for the 1970-86 time period" Blackley (1991). By calculating his generalized least squares (GLS) estimates by using annual unemployment rate data from the U.S. Department of Labor and annual output data from the Department of Commerce, Blackley finds that "on average the results are generally consistent with estimates for the national economy" Blackley (1991). While discussing the econometric specification of Okun's law though, Blackley acknowledges how "there is general agreement [among economists] that unemployment does not respond fully to output changes in the short run" with "most national studies [that use] quarterly data [specify] one or more lags" Blackley (1991). To deal with this issue, Blackley assumes it away by claiming that "labor market adjustments are likely to occur within the current time period when using annual data" Blackley (1991) just like other economists have done. Soon after, Blackley also admits that he takes on this assumption because he is limited by the number of available observations in his work. Back in 1991, when Blackely's paper was published, due to the limited data, making such an assumption may have been acceptable; but now, after about thirty years, with more data and technology available, it is imperative for us to reconsider and potentially improve this approach.

Advancing from Blackley, Freeman's paper utilizes the Baxter and King bandpass filter, which is "a recent development in trend-cycle decomposition of economic time series" that helps smooth business cycle fluctuations, "to measure the Okun coefficient using U.S. national and regional data" Freeman (2000). In his study, Freeman considers the U.S. as a whole as well as its eight regional economies which have been defined by the Bureau of Economic Analysis. Describing his motivation, Freeman touches on how applying Okun's law at a regional level "is apparently new, and has the potential to uncover geographic differences" Freeman (2000) in how labor markets respond to output changes. Though, by calculating ordinary least squares (OLS) estimates for Okun's coefficients with filtered quarterly and annual data, Freeman finds that interregional differences in how unemployment reacts to output are not significant and that pooled estimates of regional data are consistent with the national estimates that are obtained from aggregate data. Like Freeman, in my paper, I take advantage of using a filter to smooth data.

Further developing ideas from Blackley and Freeman, Guisinger et al. “estimate Okun’s coefficients separately for each U.S. state [by] using an unobserved components framework” Guisinger et al. (2018) with “the annual [gross state product (GSP)] and the annual average of the unemployment rate from 1977 to 2012” Guisinger et al. (2018). After observing differences among each states’ Okun’s coefficients, they further investigate which factors are responsible for this. In doing so, Guisinger et al. conclude that “indicators of more flexible labor markets (higher levels of education achievement in the population, lower rate of unionization, and a higher share of non-manufacturing employment) are important determinants” Guisinger et al. (2018) for the heterogeneity that is seen among states’ Okun’s coefficients. In contrast to papers like Freeman’s which do not show significant differences between state-level and national-level Okun’s coefficients, Guisinger et al. argue that such differences should not be taken lightly. The heterogeneity matters because it reflects how “the relationship between output and the unemployment rate [vary] across states and [show] some regional patterns” regarding the underlying determinants. Subsequently, Guisinger et al. mention that “state-level heterogeneity in Okun’s coefficients could increase social and political tension,” especially as “considerable differences remain in in terms of demographic characteristics of the labor force and industrial composition” Guisinger et al. (2018). When it comes to my paper and the Okun’s coefficients that I calculate, if heterogeneity is present among the states, then it is probably further representation of the findings of Guisinger et al.

In reviewing applications of Okun’s law at both the country-level and state-level, it is critical for one to notice the implicit assumption that is often made: instantaneous elasticity. Returning to the original form of Okun’s law, the classic equation suggests that any changes in output immediately impact unemployment. This, however, is far from what we observe in reality. A couple of papers that examine this are “Okun’s law and anelastic relaxation in economics” by Hawkins and “Okun Loops and Anelastic Relaxation in the G7” by Hawkins and Li.

Hawkins explains that there are currently three popular forms of Okun’s law: gap, difference, and dynamic. Although gap-form applications have exhibited that output propels unemployment, and although both difference-form applications and dynamic-form applications have shown that instantaneous responses between output and unemployment do not occur, none of these forms manage to decently reflect the observed patterns while having a sound theoretical foundation. Next, Hawkins describes three formal assumptions that underly each form of Okun’s law: (i) each output gap level has a different unemployment gap at equilibrium, as well as the other way around; (ii) when output changes, enough time must pass in order for the unemployment to reach its equilibrium expectation; and, (iii) there is a linear relationship between the output gap and the unemployment gap. Eventually, Hawkins derives an anelastic form of Okun’s law that unites the gap, difference, and dynamic forms of it (as explicitly expressed later in my paper). All in all, Hawkins’ anelastic form of Okun’s law, “describes well the relationship between output and unemployment in the U.S., . . . [links] macroeconomic output-unemployment dynamics to the microeconomic responses to spatial differences in socioeconomic variables, ... [and] provides a natural way of interpreting time-dependence of changes in unemployment to changes in output as economic internal friction" Hawkins (2014).

Working with Li, Hawkins builds on his previous work to demonstrate that "Okun loops – loop deviations from Okun's law – are an expected outcome of extending Okun's law to allow for observed time dependence in the response of unemployment to a change in output, and are an example of anelastic relaxation in economics" Hawkins and Li (2021). Using the unemployment time series and the natural logarithm of the real output time series data from the Organization for Economic Co-operation and Development (OECD) for the U.S. and G7 countries, Hawkins and Li run the Hodrick-Prescott (HP) filter to use the cyclic component as the unemployment and output gaps. After fitting their discrete form of the anelastic form of Okun's law, they find each parameter to be "strongly significant" Hawkins and Li (2021) which means that their model describes the macroeconomic dynamics well. Then, Hawkins and Li visualize the Okun loops presented in their results, noting that Okun loops are most noticeable during recessions because that is when an economy "experiences the largest dynamic range of the output gap" Hawkins and Li (2021). After observing such "statistically significant and operationally parsimonious representation of output-unemployment dynamics" through their anelastic version of Okun's Law, in addition to successfully identifying Okun loops throughout time in G7 countries as well as the U.S. after WWII, with confidence, Hawkins and Li believe that "Okun loops are a common feature across economies" Hawkins and Li (2021).

Having been inspired by this new anelastic version of Okun's law that Hawkins has established and that he and Li have observed success with, in my paper I explore the application of it at the state level in the United States for the first time.

3 Okun's Law With and Without Anelasticity

Okun's law in its original form (Okun, 1962)

$$\tilde{u} = J\tilde{y} \, , \tag{1}$$

relates the unemployment gap $\tilde{u}$ to the unemployment gap $\tilde{y}$ by the constant J; the unemployment gap being the difference between the observed unemployment rate and the natural rate of unemployment and the output gap being the percent deviation of observed real gross domestic product (real GDP) from potential real GDP.

The anelastic form of Okun's law for a standard anelastic economy is given by Hawkins (2014)

$$\tau \frac{d\tilde{u}}{dt} + \tilde{u} = \tau J_U \frac{d\tilde{y}}{dt} + J_R \tilde{y} \, , \tag{2}$$

where J_U represents the instantaneous portion of the response of the unemployment gap to a change in the output gap, J_R represents the steady-state to which the unemployment gap will evolve, and τ is the relaxation time of the evolution from the instantaneous response to the steady state. In steady state this expression reduces to the original form of Okun's law $\tilde{u} = J_R \tilde{y}$.

4 Methodology

4.1 Data

To apply Hawkins' anelastic version of Okun's law at the state-level in the United States, for each state as well as the District of Columbia, I use Federal Reserve Economic Data - State Data's (FRED-SD's) quarterly time series data for the unemployment rate and nominal quarterly gross state product from January 2005 to April 2020. Since I am conducting an empirical analysis at the state-level in the U.S., utilizing FRED-SD, one of the most credible macroeconomic databases built for researchers to carry out such economic work, seems to be appropriate. When it comes to using the Federal Reserve Economic Data (FRED) database, it is especially useful how observations within its datasets are updated live, its datasets are available to the public, and that its data is already cleaned.

4.2 Fitting Process

Naturally, to fit the anelastic version of Okun's law, my extension of Hawkins' work uses the same process that he does. More particularly, the fitting process that Hawkins and Li use in their application of the anelastic form of Okun's law on G7 countries is the same one that I use on U.S. states and the District of Columbia. So, like them, for unemployment and output gaps, I use the cyclic component that comes from running the Hodrick-Prescott (HP) filter on both the unemployment rate time series data and the natural logarithm of the nominal gross state product time series data. While running this filter, I use a smoothing parameter of 1600.

5 Analysis

5.1 Okun's Law: Original Form

My empirical examination of Okun's law in the United States begins with a fit of Eq. (1)

Table 1: Okun's coefficient using Eq. (1).

State	J	adj-R^2	State	J	adj-R^2
AL	-0.822^{***} (0.090)	0.762	MT	-0.234^{***} (0.027)	0.615
AK	-0.040^{*} (0.017)	0.257	NE	-0.138^{**} (0.045)	0.313
AZ	-0.381^{***} (0.032)	0.885	NV	-0.367^{***} (0.054)	0.495
AR	-0.186^{***} (0.035)	0.320	NH	-0.150^{***} (0.034)	0.097
CA	-0.476^{***} (0.042)	0.820	NJ	-0.467^{***} (0.107)	0.516
CO	-0.397^{***} (0.047)	0.676	NM	-0.328^{**} (0.107)	0.424
CT	-0.214^{***} (0.033)	0.436	NY	0.005^{*} (0.107)	-0.024
DE	-0.068^{*} (0.033)	0.035	NC	-0.523^{***} (0.100)	0.559
FL	-0.448^{***} (0.074)	0.625	ND	-0.035^{***} (0.010)	0.472
GA	-0.613^{***} (0.068)	0.735	OH	-0.539^{***} (0.057)	0.738
HI	-0.399^{***} (0.065)	0.645	OK	-0.140^{***} (0.025)	0.680
ID	-0.439^{***} (0.086)	0.556	OR	-0.479^{***} (0.096)	0.601
IL	-0.605^{***} (0.054)	0.747	PA	-0.462^{***} (0.037)	0.656
IN	-0.442^{***} (0.055)	0.611	RI	-0.300^{***} (0.080)	0.190
IA	-0.181^{***} (0.041)	0.454	SC	-0.623^{***} (0.113)	0.628
KS	-0.191^{***} (0.041)	0.560	SD	-0.121^{**} (0.041)	0.338
KY	-0.499^{***} (0.080)	0.491	TN	-0.532^{***} (0.124)	0.463
LA	0.050^{*} (0.073)	-0.015	TX	-0.198^{***} (0.033)	0.594
ME	-0.266^{*} (0.161)	0.129	UT	-0.348^{***} (0.054)	0.631
MD	-0.145^{*} (0.154)	0.009	VT	-0.124^{*} (0.112)	0.079
MA	-0.437^{***} (0.096)	0.523	VA	-0.414^{*} (0.184)	0.133
MI	-0.454^{***} (0.071)	0.568	WA	-0.435^{***} (0.078)	0.618
MN	-0.388^{***} (0.039)	0.672	WV	-0.302^{*} (0.140)	0.191
MS	-0.343^{***} (0.054)	0.508	WI	-0.460^{***} (0.093)	0.368
MO	-0.307^{***} (0.091)	0.115	WY	-0.124^{***} (0.022)	0.691
			DC	-0.187^{*} (0.209)	0.041

The superscripts *, **, and *** indicate the p-value inequalities $p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.001$, respectively. Newey-West robust standard errors are shown in parentheses.

Looking at my results in Table 1, for most states, fitting the original form of Okun's law seems to work. Notably, the three states with the highest absolute values of Okun coefficients are Alabama, South Carolina, and Georgia and the three states with the lowest absolute values of Okun's coefficients are South Dakota, Nebraska, and Montana. There are, however, a small handful states for which fitting the original form of Okun's law does not seem to work because their Okun coefficients either have the incorrect sign (are positive) or are inadequately significant (have a significance level of 0.05 or less); namely, these states are Alaska, Delaware, Louisiana, Maine, Maryland, New York, Vermont, Virginia, and West Virginia as well as the District of Columbia.

In comparing my results to the previous research of Blackley, Freeman, and Guisinger et al., there are some intriguing similarities and differences. When it comes to which states have the highest and lowest absolute values of Okun coefficients, Blackley agrees that Alabama and South Carolina have the highest ones, but he believes that Louisiana, Minnesota, and Florida have the lowest ones. According to Guisinger et al., the states with the highest Okun coefficients are North Dakota, Washington, and Georgia and the states with the lowest Okun coefficients are Louisiana, Rhode Island, and Alabama. Interestingly, like Guisinger et al., Georgia has the third highest Okun coefficient in my results; but, disagreeing with both my and Blackley's result of Alabama having the highest Okun coefficient, Guisinger et al. report Alabama to have the third lowest Okun coefficient. Moreoever, in Freeman's study which reports Okun coefficients for the eight regional economies defined by the Bureau of Economic Analysis, the region that had the highest Okun coefficients was the Plains (Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, and South Dakota) and the regions that had the lowest Okun coefficient was the Far West (Alaska, California, Hawaii, Nevada, Oregon, and Washington). Perhaps consistent with Freeman, Guisinger et al. report that North Dakota is the state with the highest absolute value Okun coefficient because, as mentioned, North Dakota is part of the Plains region which is the region that Freeman reported to have the highest absolute value coefficient. However, Guisinger et al.'s results are perhaps inconsistent with Freeman too, because while Guisinger et al. report Washington to have one of the highest absolute value Okun coefficients, Washington is part of the Far West which is the region that Freeman reported to have the lowest absolute value Okun coefficient. Since Freeman's work analyzes the United States at the regional rather than state level though, it is not unreasonable to suspect that the grouping of states hides information about individual state extremes.

Continuing to compare my results, for states that I found to be incompatible with fitting the original form of Okun's law, Blackley, Freeman, and Guisinger et al. do not appear to have run into the same challenges. Each was able to obtain Okun coefficients for all states that they observed. Nevertheless, Louisiana does stand out to me as possibly some common ground among our research because Blackley and Guisinger et al. report Louisiana to have the lowest absolute value Okun coefficient, Freeman reports the Southeast (the region that includes Louisiana) to have the third lowest absolute value Okun coefficient, and I report Louisiana to have the most positive Okun coefficient. In other words, Louisiana's behavior is a bit on the extreme when analyzed through the lens of the original form of Okun's law.

Although it is beyond the scope of my paper, future research will ideally be able to fully explain why the macroeconomic behavior of some states is better captured through Okun's law than others.

Overall, as I compare my results with Blackley, Freeman, and Guisinger et al., it is important to remember that no one should expect our results to match exactly. After all, we each used different data and fitting processes. The purpose of this comparison is to expose general patterns or lack thereof when researchers try to apply Okun's law to U.S. states, possibly inspiring future work on the subject. As my results stand next to those of Blackley, Freeman, and Guisinger et al., it is worth noting that while there is some general agreement in the ordering of states and regions with Okun coefficients, there is some unignorable disagreement too.

5.2 Okun's Law: Anelastic Form

My empirical examination of Okun's law in the United States continues with a fit of the discrete version of the anelastic form of Okun's law, Eq. (2), (Hawkins, 2014)

$$\tilde{u}_t - \tilde{u}_{t-1} = J_U\left(\tilde{y}_t - \tilde{y}_{t-1}\right) + \tau^{-1} J_R \tilde{y}_{t-1} - \tau^{-1}\tilde{u}_{t-1} \tag{3}$$

to the unemployment and output gaps of these economies.

Table 2: Parameter estimates and coefficient values in the United States for the anelastic form of Okun's law given by Eq. (3). The superscripts *, **, and *** indicate the p-value inequalities $p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.001$, respectively. Newey-West robust standard errors are shown in parentheses. The units of τ are quarters of a year.

State	J_U	$J_R\tau^{-1}$	$-\tau^{-1}$	J_R	τ	adj-R^2
AL	-0.404^{***} (0.099)	-0.398^{**} (0.147)	-0.404^{***} (0.115)	-0.985	2.47	0.537
AK	-0.013^{*} (0.011)	-0.009^{*} (0.007)	-0.147^{**} (0.055)	-0.059	6.82	0.088
AZ	-0.263^{***} (0.028)	-0.115^{***} (0.026)	-0.269^{***} (0.058)	-0.426	3.72	0.631
AR	-0.055^{*} (0.033)	-0.060^{*} (0.035)	-0.190^{*} (0.114)	-0.314	5.27	0.112
CA	-0.165^{*} (0.075)	-0.063^{*} (0.061)	-0.155^{*} (0.102)	-0.409	6.47	0.247
CO	-0.117^{*} (0.054)	-0.032^{*} (0.068)	-0.094^{*} (0.120)	-0.343	10.61	0.172
CT	-0.033^{**} (0.011)	0.014^{*} (0.021)	-0.030^{*} (0.068)	0.463	32.92	0.079
DE	-0.007^{*} (0.009)	-0.035^{*} (0.021)	-0.096^{*} (0.048)	-0.371	10.47	0.082
FL	-0.234^{**} (0.085)	-0.030^{*} (0.038)	-0.086^{*} (0.055)	-0.355	11.65	0.327

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Table 2 – Continued

State	J_U	$J_R\tau^{-1}$	$-\tau^{-1}$	J_R	τ	adj-R^2
GA	-0.209^{*} (0.093)	-0.227^{*} (0.108)	-0.313^{*} (0.129)	-0.725	3.19	0.332
HI	-0.170^{*} (0.098)	-0.039^{*} (0.023)	-0.135^{**} (0.047)	-0.291	7.39	0.181
ID	-0.030^{*} (0.063)	-0.002^{*} (0.075)	-0.103^{*} (0.088)	-0.020	9.67	-0.007
IL	-0.275^{***} (0.057)	-0.269^{**} (0.085)	-0.390^{***} (0.072)	-0.690	2.56	0.397
IN	-0.207^{**} (0.071)	-0.195^{***} (0.043)	-0.290^{***} (0.085)	-0.670	3.44	0.531
IA	-0.073^{**} (0.028)	-0.058^{*} (0.042)	-0.223^{**} (0.081)	-0.260	4.48	0.229
KS	-0.064^{*} (0.029)	-0.046^{*} (0.027)	-0.201^{*} (0.080)	-0.228	4.99	0.208
KY	-0.225^{***} (0.065)	-0.231^{***} (0.060)	-0.247^{**} (0.077)	-0.934	4.05	0.495
LA	0.105^{*} (0.122)	0.015^{*} (0.054)	-0.624^{*} (0.250)	0.025	1.60	0.277
ME	-0.087^{*} (0.054)	-0.034^{*} (0.037)	-0.087^{*} (0.054)	-0.393	11.45	0.032
MD	-0.114^{*} (0.087)	-0.101^{*} (0.062)	-0.079^{*} (0.060)	-1.290	12.72	0.117
MA	-0.159^{**} (0.049)	-0.179^{*} (0.077)	-0.248^{**} (0.079)	-0.721	4.03	0.398
MI	-0.154^{***} (0.020)	-0.294^{***} (0.066)	-0.408^{***} (0.086)	-0.721	2.45	0.687
MN	-0.151^{*} (0.070)	-0.169^{*} (0.067)	-0.351^{**} (0.119)	-0.482	2.85	0.331
MS	-0.055^{*} (0.103)	-0.155^{**} (0.050)	-0.419^{**} (0.142)	-0.371	2.39	0.145
MO	-0.021^{*} (0.035)	0.152^{*} (0.065)	-0.013^{*} (0.053)	11.376	74.99	0.246
MT	-0.096^{**} (0.035)	-0.008^{*} (0.033)	-0.090^{*} (0.093)	-0.084	11.07	0.234
NE	-0.046^{*} (0.020)	-0.056^{*} (0.034)	-0.207^{*} (0.084)	-0.268	4.82	0.231
NV	-0.181^{**} (0.061)	-0.075^{**} (0.027)	-0.107^{*} (0.057)	-0.705	9.39	0.402
NH	-0.054^{*} (0.035)	-0.123^{*} (0.067)	-0.185^{***} (0.044)	-0.664	5.41	0.242
NJ	-0.138^{*} (0.102)	-0.105^{*} (0.057)	-0.173^{*} (0.076)	-0.607	5.78	0.112
NM	-0.122^{*} (0.067)	-0.049^{*} (0.037)	-0.137^{*} (0.072)	-0.355	7.30	0.218
NY	-0.032^{*} (0.020)	-0.109^{**} (0.036)	-0.062^{*} (0.032)	-1.744	16.05	0.367
NC	-0.287^{*} (0.114)	-0.049^{*} (0.057)	-0.123^{*} (0.063)	-0.402	8.16	0.392
ND	-0.030^{*} (0.014)	-0.006^{*} (0.005)	-0.223^{*} (0.087)	-0.028	4.48	0.214

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Table 2 – Continued

State	J_U	$J_R\tau^{-1}$	$-\tau^{-1}$	J_R	τ	adj-R^2
OH	-0.195^{***} (0.047)	-0.335^{***} (0.061)	-0.499^{***} (0.077)	-0.672	2.00	0.636
OK	-0.076^{***} (0.021)	-0.054^{**} (0.020)	-0.293^{**} (0.093)	-0.185	3.41	0.505
OR	-0.206^{*} (0.094)	-0.007^{*} (0.043)	-0.115^{**} (0.044)	-0.064	8.72	0.187
PA	-0.159^{*} (0.086)	-0.089^{*} (0.089)	-0.193^{*} (0.136)	-0.463	5.19	0.189
RI	-0.101^{***} (0.030)	-0.163^{***} (0.046)	-0.150^{***} (0.025)	-1.092	6.68	0.418
SC	-0.279^{*} (0.142)	-0.089^{*} (0.068)	-0.152^{*} (0.069)	-0.590	6.59	0.223
SD	-0.051^{***} (0.013)	-0.038^{*} (0.024)	-0.170^{*} (0.094)	-0.221	5.87	0.230
TN	-0.102^{*} (0.131)	0.011^{*} (0.042)	-0.098^{*} (0.068)	0.112	10.23	0.031
TX	-0.077^{***} (0.016)	-0.082^{*} (0.035)	-0.288^{*} (0.122)	-0.284	3.47	0.416
UT	-0.158^{**} (0.049)	-0.099^{*} (0.057)	-0.228^{*} (0.118)	-0.435	4.39	0.267
VT	-0.081^{*} (0.069)	-0.039^{*} (0.035)	-0.130^{**} (0.050)	-0.296	7.68	0.105
VA	-0.176^{*} (0.078)	-0.187^{*} (0.084)	-0.124^{**} (0.045)	-1.513	8.08	0.201
WA	-0.137^{*} (0.061)	-0.091^{*} (0.057)	-0.184^{*} (0.080)	-0.493	5.43	0.157
WV	-0.149^{*} (0.074)	-0.057^{*} (0.064)	-0.129^{*} (0.093)	-0.442	7.78	0.170
WI	-0.173^{*} (0.074)	-0.236^{*} (0.094)	-0.246^{**} (0.077)	-0.961	4.06	0.384
WY	-0.078^{**} (0.024)	-0.031^{**} (0.011)	-0.214^{***} (0.048)	-0.146	4.68	0.430
DC	-0.067^{*} (0.073)	0.012^{*} (0.056)	-0.150^{*} (0.081)	0.081	6.66	0.092

As Table 2 displays, fitting the anelastic version of Okun's law does work for many states. Of those states, the three states with the highest absolute values of Okun coefficients (J_R) are Alabama, Kentucky, and Michigan tied with Massachussetts and the three states with the lowest absolute values of Okun coefficients are Montana, Wyoming, and Oklahoma. Unfortunately, there are quite a few states where the anelastic version of Okun's law does not work because their Okun coefficients either have the incorrect sign (are positive) or are inadequately significant (have a significance level of 0.05 or less); namely, these states are Alaska, Arkansas, California, Colorado, Connecticut, Delaware, Georgia, Hawaii, Idaho, Kansas, Louisiana, Maine, Maryland, Minnesota, Mississippi, Missouri, Nebraska, New Hampshire, New Jersey, New Mexico, New York, North Carolina, North Dakota, Oregon, Pennsylvania, South Carolina, Tennessee, Vermont, Virginia, Washington, West Virginia, and Wisconsin as well as the District of Columbia.

Comparing the results of fitting the anelastic version of Okun's law to those that come from its original version, as expected, the anelastic version's J_R values do somewhat correspond to the original version's J values. The reason I say "somewhat" is because I am hesitant about comparing compatible states from the original fitting with incompatible states in the anelastic fitting. Therefore, I only compare compatible states of each fitting. This definitely impacts the differences that are observed. In identifying the states with the highest Okun coefficient (J from fitting the original version of Okun's law or J_R from fitting the anelastic version of Okun's law), Alabama continues to be at the top with Kentucky and Michigan tied with Massachusetts having replaced South Carolina and Georgia respectively. In identifying the states with the lowest absolute value Okun coefficients (J from fitting the original version of Okun's law or J_R from fitting the anelastic version of Okun's law), Montana, Oklahoma, and South Dakota stand where South Dakota, Nebraska, and Montana used to respectively.

As briefly mentioned, one of the most notable differences from fitting the anelastic form is how many more states' Okun coefficients have inadequate significance. From fitting the original form of Okun's law, only nine states and the District of Columbia were incompatible whereas, from fitting the anelastic form of Okun's law, there are thirty-two states that are incompatible as well as the District of Columbia. The difference of twenty-three states are in addition to those that were already incompatible before. Since the anelastic version of Okun's law breaks up Okun's coefficient, J, into two parts, J_U and J_R, maybe this separation is responsible is for making compatibility (having the correct sign and adequate significance) more difficult.

Furthermore, to continue comparing how J from fitting the original version of Okun's law corresponds to J_R from fitting the anelastic version of Okun's law, it is helpful for us to take a closer look at some specific states as examples, like Arizona and New York. In the original version's fitting, Arizona is the state that has the highest adjusted R-squared value of 0.885; similarly, in the anelastic version's fitting, Arizona continues to be the state that has the highest adjusted R-squared value of 0.631, as depicted in Figure 1. Figure 1 breaks down the anelastic analysis of Arizona graphically. In the upper left and right panels, Arizona's gross state product and unemployment rate time series data from FRED-SD are graphed, respectively. In the bottom left panel, Arizona's output and unemployment gaps are graphed which have been calculated by using the HP filter. In the bottom right panel, the anelastic form of Okun's law has been fitted with Arizona's data. With this in mind, states like Arizona lead us to believe that J and J_R correspond to each other quite well.

When we look at states like New York, however, we might reconsider our confidence in the correspondence between J and J_R. In the original version's fitting, New York is the state that has the lowest adjusted R-squared value of -0.024; however, in the anelastic version's fitting, New York has an adjusted R-squared value of 0.367, as depicted in Figure 2. Figure 2 breaks down the anelastic analysis of New York graphically, just like Figure 1 does for Arizona. In the upper left and right panels, New York's gross state product and unemployment rate time series data from FRED-SD are graphed, respectively. In the bottom left panel, New York's output and unemployment gaps are graphed which have been calculated by using the HP filter. In the bottom right panel, the anelastic form of Okun's law has been fitted with New York's data. In the anelastic version's fitting, although New York does not have the lowest adjusted R-squared value (Idaho does at -0.007), it does not have the highest one either. In fact, in the anelastic version's fitting, New York's R-squared value stands somewhere in the middle. So, while, J and J_R might not correspond perfectly to each other, their correspondence is not awful either.

5.3 Clarification

For both versions of Okun's law, we expect to observe the J, J_U, and J_R coefficients as negative. This is because Okun's law expresses how an economy's unemployment gap and output gap are inversely related. Whenever this is not the case, it is peculiar because it means our data is suggesting the that there is a positive relationship between an economy's output gap and that economy's unemployment gap, the opposite of what Okun's law asserts. This may be the result of some type of issue in data collection for these particular states but having a confident understanding of why we see these unexpected results is a topic for future research.

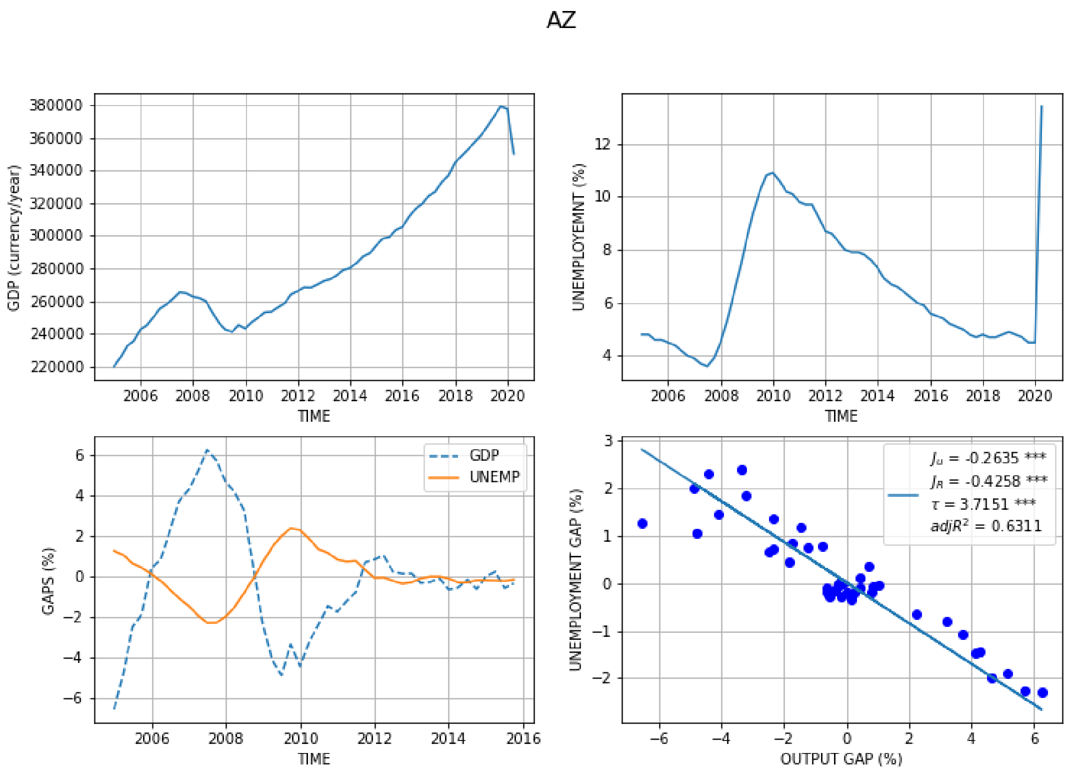

Figure 1: The anelastic analysis of Arizona. Gross state product in the upper left panel. Unemployment rate in the upper right panel. Unemployment and output gaps in the lower left panel. Anelastic Okun analysis in the lower right panel.

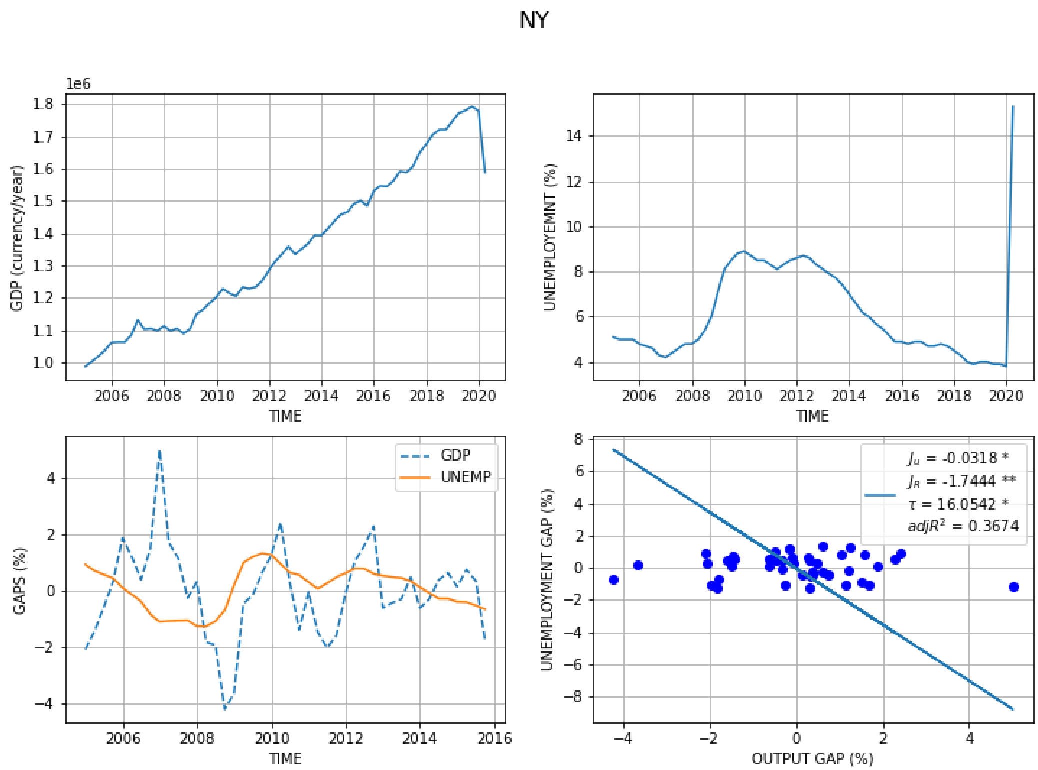

Figure 2: The anelastic analysis of New York. Gross state product in the upper left panel. Unemployment rate in the upper right panel. Unemployment and output gaps in the lower left panel. Anelastic Okun analysis in the lower right panel.

6 Conclusion

By applying an anelastic version of Okun's law (Hawkins, 2014) to U.S. states, for the most part, I obtained statistically significant results that support Okun's inverse relationship between an economy's unemployment gap and its output gap. Compared to the original version of Okun's law, this anelastic version has been constructed to intentionally account for the time lag which is often observed in the short run. Put otherwise, this anelastic version of Okun's law is useful for seeing the dynamics of Okun's law more frequently, in applications beyond the long run. In this paper's analysis, I observed some results for states that suggest the opposite of what Okun's law says; but, hopefully future research will be able to explain this. All in all, while the original form of Okun's law has resonated with economists worldwide, I believe that there is room for improvement and that my work is a steppingstone in achieving a better understanding how an economy's unemployment gap and output gap interact.

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