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Characterizing the Stability of Okun's Law during Economic Recessions by cross-Recurrence Plot and Rolling Regression

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Abstract: Using the quarterly U.S. unemployment and GNP data from 1948 to the present, we examine the stability of Okun's law. Using a powerful tool from nonlinear dynamics theory for detecting cross-correlations, the cross-recurrence plot, we find a surprisingly robust and persistent correlation between unemployment and production. Further rolling regression and regression analysis based on data during recessions and normal economic times separately show that this correlation is characterized by the Okun's law, with its coefficient rather stable during recessions. In contrast, Okun's law is continuously weakening during normal economic conditions, with the Okun's coefficient continuously decreasing, and approaching 0 in the recent few years, suggesting almost a total breakdown of Okun's law after the recent gigantic crisis.

Keywords: Okun's law, Economic recession, Cross-recurrence plot, Stability, Rolling regression

JEL Classifications: E24, C50, C52, B41

1. Introduction

Typically, rising unemployment coincides with growth slowdowns. This negative correlation between unemployment and gross domestic product (GDP) growth has been named “Okun's law”, after the economist Arthur Okun who first documented this finding in the early 1960s (Okun 1962). The enduring appeal of Okun's law lies in its simplicity, since it involves two important macroeconomic variables, and, together with the Phillips curve, is crucial for deriving the aggregate supply curve (Abel & Bernanke, 2005; Blanchard, 2006; Gordon, 2004). Moreover, Okun's coefficient is useful for forecasting and policy–making (Clark & McCracken, 2006; Harris & Silverstone, 2001; Villaverde & Maza 2009).

In the past two decades, many researchers have investigated the validity of Okun's law, fol-lowing the publication of Prachowny's important work (1993). While overall, those works tend to support Okun's law, a number of complicating factors have also been found: (1) Okun's coefficient, originally thought to be close to 3, has been found to be well below 3, and to vary substantially with time and with spatial samples under consideration (Perman & Tavera, 2004).

(2) Okun's co-efficient depends on the model specification and the method employed to estimate it (Villaverde & Maza, 2009). (3) Using regional data, Okun's coefficient has been found to vary from region to region (Freeman 2000; Adanu 2005; Christopoulos 2004; Villaverde & Maza 2009). (4) There appears to be an asymmetry in Okun's law, i.e., cyclical unemployment is more sensitive to negative than to positive cyclical output (Silvapulle et al. 2004), although this view is not largely shared by professional economists (Pierdzioch et al. 2011). (5) There is a time varying aspect of Okun's law, as can be revealed by rolling regressions (Moosa 1997; Knotek 2007), or by one-time breaks technique (Weber 1995; Lee 2000), or by explicitly allowing for time-varying coefficients (Sogner＆Stiassny 2002; Huang 2008).

A bigger puzzle regarding Okun's law recently has been observed in U.S. economy. As noted by Knotek (2007), unemployment from the beginning of 2003 through the first quarter of 2006 fell，consistent with the observation that real GDP in the U.S. during that period grew at an average annual rate of 3.4 percent. Over the course of the next year, average growth slowed to less than half its earlier rate, however, unemployment continued to drift downward. This thus presents a puzzling situation for policymakers and economists, who expected a rising unemployment alongside a slowing economy.

The numerous complicating factors concerning Okun's law and especially the puzzle observed in the U.S. economy between 2003 and 2007 motivate us to examine Okun's law from an evolutionary point of view. In particular, we ask: (1) Is Okun's law more stable during economic recessions or in normal, healthy economic conditions? (2) Would economic recessions disrupt Okun's law, and if yes, can the disruptions be quantified? To gain insights into these questions, we use quarterly U.S. unemployment and GNP data from January, 1948 to July, 2011. The data are downloaded at the website for Economics Research, Federal Reserve Bank of St. Louis, http://research.stlouisfed.org/fred2/categories/32263/downloaddata. The reason that GNP instead of GDP series are used is that Okun's original work and Prachowny's important work analyzed GNP rather than GDP series.

The remainder of this paper is organized as follows. Section 2 discusses how Okun's law should be specified to suit our purpose. Section 3 tries to detect invariant dynamics of unemployment and production, using a powerful technique from nonlinear dynamics theory, the cross-recurrence-plot (CRP) (Marwan & Kurths, 2002; Marwan, et al. 2007), which allows characterization of general, non-local correlations between two time series, irrespective of whether the time series are stationary or not. In Sec. 4, we first carry out rolling regression analysis, then define cumulative recession and cumulative normal periods, estimate Okun's coefficient in these periods, and show that Okun's law is quite stable during recessions, but is continuously weakening during normal economic conditions, with the Okun's coefficient for the recent few years approaching 0, suggesting almost a total breakdown of Okun's law after the recent gigantic recession. Section 5 summarizes our findings.

2. Model Specification of Okun's Law

To answer the questions formulated above, care has to be taken as how Okun's law should be specified. There are two basic forms of Okun's law. One is the first-difference form, described by

$$y_t - y_{t-1} = \alpha + \beta(u_t - u_{t-1}) + \varepsilon_t \tag{1}$$

where y_t is the natural log of observed real output, u_t is the observed unemployment rate, α is the intercept, β, which is negative, is Okun's coefficient measuring how much changes in the unemployment rate, $u_t - u_{t-1}$, can cause changes in output, $y_t - y_{t-1}$, and ε_t is the disturbance

term. A quick examination of the difference data of U.S. unemployment and production shown in Figure 1 would convince one that there indeed exists negative correlation between unemployment and production.

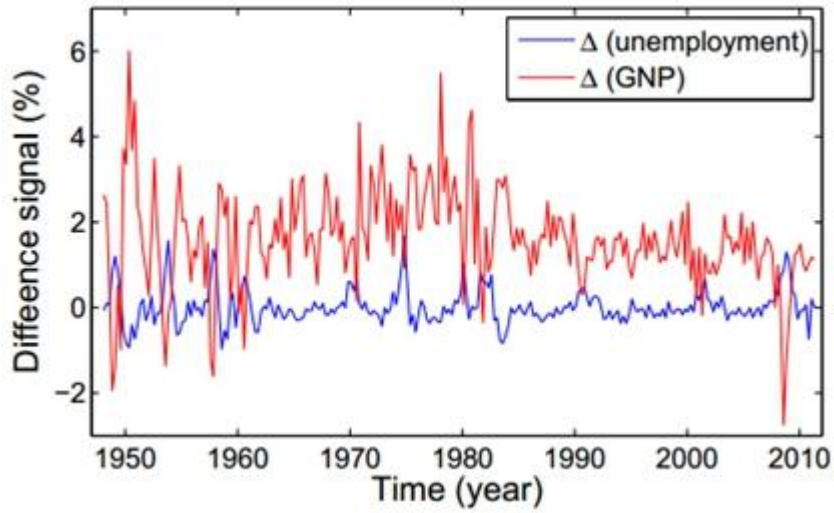

Figure 1. The differenced time series data

Note that the variation in production, $P_t - P_{t-1}$, is usually only a tiny fraction of the production P_t. Therefore, $y_t - y_{t-1}$ may also be written as

$$y_t - y_{t-1} = \ln P_t - \ln P_{t-1} = \ln P_{t-1}(1+\frac{P_t - P_{t-1}}{P_{t-1}}) - \ln P_{t-1} = \ln(1+\frac{P_t - P_{t-1}}{P_{t-1}}) \approx \frac{P_t - P_{t-1}}{P_{t-1}} \qquad (2)$$

where the last step involves Taylor series expansion of $\ln(1+x) \approx x$, when $|x|<1$. The negligible difference between $y_t - y_{t-1}$ and $\frac{P_t - P_{t-1}}{P_{t-1}}$ justifies that both may be denoted as $\Delta(\text{GNP})$。

The Okun's law may also be specified as the "gap" form,

$$y_t - y_t^* = \alpha + \beta(u_t - u_t^*) + \varepsilon_t \qquad (3)$$

where y_t^* represents the log of potential output, u_t^* is the natural rate of unemployment, and the other terms have the same meaning as in Eq. (1).

Note that y_t^* and u_t^* in the gap model are complicated functions of time. In particular, they may be determined as the trend signals y_t and u_t, using filters such as Hodrick-Prescott (HP) filter (Hodrick & Prescott 1997; Knotek 2007; Villaverde & Maza 2009). Such trend signals contain the very essential information about the effect of recessions on Okun's law that we aim to study here, and thus, the gap model is not a proper choice for our purpose. Therefore, we choose the first-difference model here. Note that the procedure of differencing in the first-difference model of Okun's law is beneficial, when y_t and u_t are random-walk type nonstationary processes — upon differencing, they become more stationary.

3. Identifying Intrinsic Dynamics of Unemployment and Production using cross-Recurrence-Plot

Cross-recurrence plot (CRP) (Marwan & Kurths 2002; Marwan et al. 2007) is an extension of recurrence plot (RP) (Eckmann et al. 1987; Gao 1999; Gao & Cai 2000). To better understand CRP, it is beneficial to first describe RP.

To understand the idea, let us consider a signal $x_1, x_2, \cdots, x_n$ which can be the unemployment or GNP data. We then construct vectors of the form:

$$X_i = (x_i, x_{i+L}, \cdots, x_{i+(m-1)L}) \tag{4}$$

This is a basic technique from chaos theory, where *m* is called the embedding dimension and *L* delay time (Packard, et al. 1980; Takens, 1981; Gao, et al. 2007). To obtain an RP, one puts a dot at (*i*, *j*) whenever

$$\varepsilon_2 \le \| X_i - X_j \| \le \varepsilon_1 \tag{5}$$

where ε_1 and ε_2 are pre-specified scale parameters. RPs have found numerous applications in diverse fields of science and engineering (e.g., Gao 1999; Gao & Cai 2000; Gao, et al. 2001; Gao, et al. 2003). When the idea is extended to 2 signals, $x_1, x_2, \cdots, x_n$ and $y_1, y_2, \cdots, y_n$, which, for concreteness, may be equated to unemployment and production data, one obtains CRPs (Marwan & Kurths 2002; Marwan, et al. 2007). Specifically, one puts a dot at (*i*, *j*) when

$$\varepsilon_2 \le \| X_i - Y_j \| \le \varepsilon_1 \tag{6}$$

where Y_j is the vector constructed from the $y_1, y_2, \cdots, y_n$ time series according to Eq. (4), and ε_1 and ε_2 are scale parameters.

Using the difference data of unemployment and production shown in Figure 1, we have computed CRPs with a number of different parameter combinations. A typical CRP is shown in Figure 2, with embedding parameters *m* = 3, *L* = 1, respectively and scale parameters $\varepsilon_1 = 2\sqrt{var(X) + var(Y)}$, $\varepsilon_2 = \sqrt{var(X) + var(Y)}/2$, where $var(X)$ and $var(Y)$ denote variance of the differenced data of unemployment and production, respectively. We observe chess-board-like features. What are those features? Do they correspond to the timing of economic recessions?

There are 11 documented economic recessions during the time period considered here, as shown in Table 1. When the start and end times of the recessions are superimposed on the CRP plot, as shown in the bottom of Figure 2, we observe that the vertical chess-board-like pattern precisely coincides with the recession times. This means the difference data of unemployment during recessions are correlated with all the difference data of production. In other words, the chess-board-like pattern is an indication of the invariant dynamics of unemployment and production.

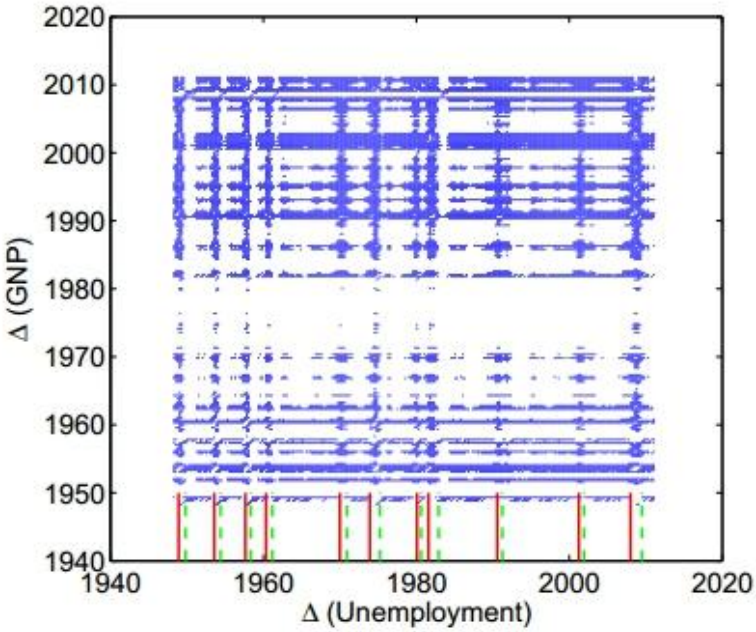

Figure 2. Cross recurrence plots (CRPs); notice the correspondence of vertical line-like structures and the timing of economic recessions, whose start and end times are indicated by solid red and dashed green vertical lines.

Table 1. List of recessions from 1948 - present
Data from National Bureau of Economic Research, http://www.nber.org/cycles/cyclesmain.html

Name	Dates	Duration	Notation
Recession of 1949	Nov 1948 - Oct 1949	11 months	r_1
Recession of 1953	July 1953 - May 1954	10 months	r_2
Recession of 1958	Aug 1957 - April 1958	8 months	r_3
Recession of 1960-61	Apr 1960 - Feb 1961	10 months	r_4
Recession of 1969-70	Dec 1969 - Nov 1970	11 months	r_5
1973 - 75 recession	Nov 1973 - Mar 1975	16 months	r_6
1980 recession	Jan 1980 - July 1980	6 months	r_7
Early 1980s recession	July 1981 - Nov 1982	16 months	r_8
Early 1990s recession	July 1990 - Mar 1991	8 months	r_9
Early 2000s recession	March 2001 - Nov 2001	8 months	r_{10}
Late-2000s recession	Dec 2007-June 2009	18 months	r_{11}

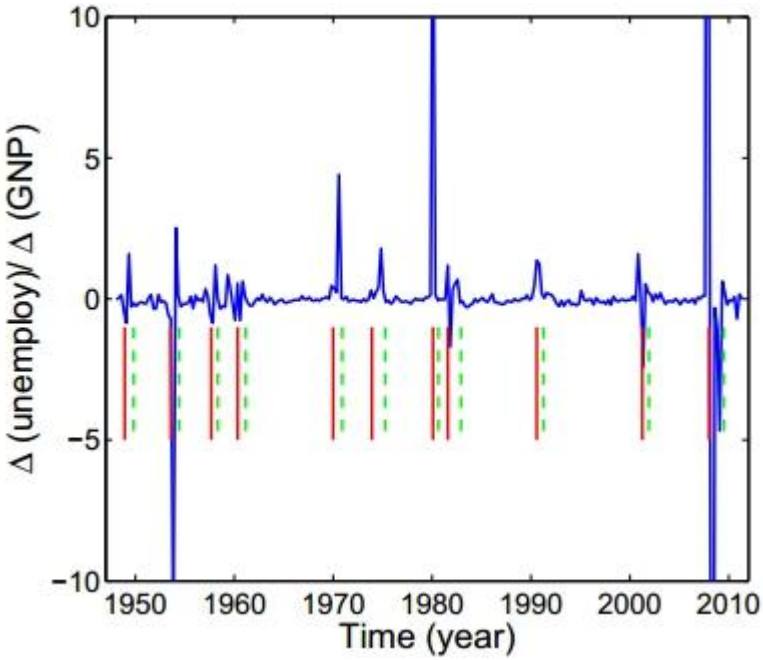

Figure 3.
The ratio time series

Notice: the correspondence of large amplitude local extrema and the timing of economic recessions, whose start and end times are indicated by solid red and dashed green vertical lines.

It needs to be pointed out the asymmetry of the vertical and the horizontal chess-board-like patterns. This may be related to the asymmetry of Okun's law suggested by Silvapulle et al. (2004). In particular, the information about recessions during 1970 – 1980 is less visible in the axis of production than the axis of unemployment. This may be associated with special features of the recessions in that period. For example, the 1973-75 period is remarkable for rising unemployment coinciding with rising inflation; the 1980 recession began as the Federal Reserve, under Paul Volcker, raised interest rates dramatically to fight the inflation of the 1970s. We shall see in the next section that this "abnormality" will be reflected when Okun's coefficient is estimated in cumulative recession and cumulative normal periods.

To better appreciate the CRP result and to further motivate the analysis to be presented in the next section, we have shown in Figure 3 the ratio between the difference data of unemployment and production. Again, the start and end times of the recessions are superimposed. We observe large positive or negative peaks in the ratio coinciding with the recessions. Therefore, economic recessions indeed play a special role when considering the correlation between unemployment and production. It should be emphasized that the ratio is not simply negative — the numerous positive peaks suggest that Okun's law, as comprehended in the literature, cannot fully capture the correlations between unemployment and production.

4. Temporal Variation of Okun's Coefficient in Recession and Normal Periods

To better reveal the temporal variation of Okun's coefficient, let us first apply the rolling regression technique to the quarterly unemployment and GNP data. The technique consists of choosing a window of length w points, estimating the regression coefficients for the initial window, which starts from the first point of the data, then advancing the window by one point, re-doing the regression, and finally plotting the regression coefficients with time. The regression results for each window may be associated with the time corresponding to the start, middle, or the end of the window. The last was adopted by Knotek (2007). Preferring symmetry, here, we choose the middle.

Because of this, the parameter w chosen here is an odd number. To better reveal the temporal variation of Okun's coefficient with time, we have chosen w = 9, which is considered fairly small in economics. To compare with the result of Knotek (2007), which was based on 52 quarters or 13 years, we have also tried w = 51. The results are shown in Figure 4.

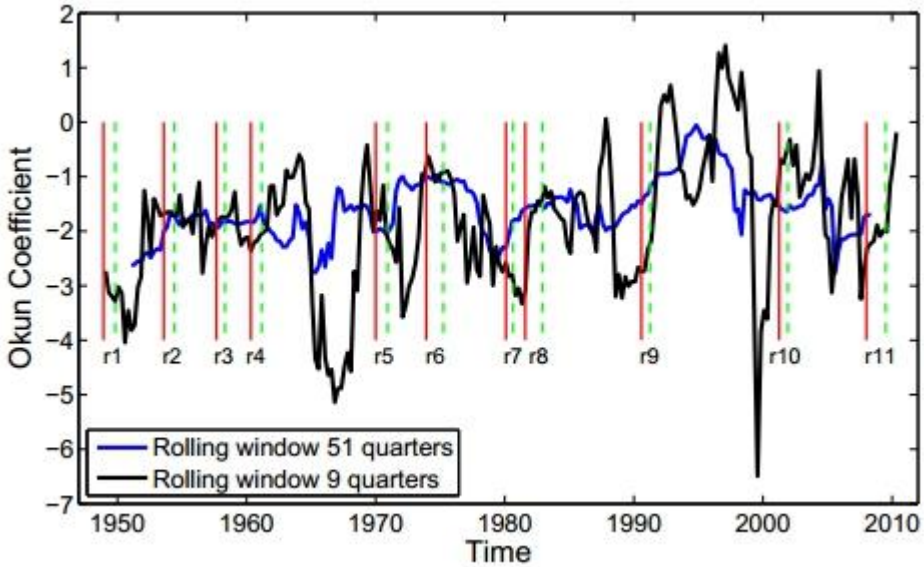

Figure 4. Rolling regression analysis with two rolling windows, 51 and 9 quarters. The time of each window is indicated by the middle point of the window. The start and end times of recessions are indicated by solid red and dashed green vertical lines.

To better see the stability of the Okun's coefficient during recessions and normal times, we have also indicated in Figure 4 the start and end times of the 11 recessions (see Table 1) by vertical solid red and dashed green lines. We observe that in general, Okun's coefficients for two very different w, 9 and 51, are very similar during the recessions (except sometimes when the recession was very brief), but can be very different during normal times. Furthermore, Okun's coefficients are similar in different recession periods. These features suggest that Okun's law is more stable during recessions than in normal economic times. However, rolling regression is not particularly suited to examining the stableness of Okun's law during economic recessions, since recession periods are very brief and often are much shorter than the rolling window chosen for regression. This motivates us to treat unemployment and GNP data in recession and normal periods separately. This is done as follows. Denote the 11 economic recessions listed in Table 1 by $r_i, i = 1, \cdots, 11$.

The normal periods before r_1, in-between r_i, and after r_{11} will be denoted as $n_i, i = 1 \cdots, 12$, accordingly. Now the question is, may we examine Okun's law for each recession and normal periods? The answer has to be no, since some periods contain too few sample points to reliably carry out regression analysis. Therefore, we consider the following *cumulative recession* and *cumulative normal* periods:

$$R_i = \sum_{j=i}^{11} r_j \tag{7}$$

$$N_i = \sum_{j=i}^{12} n_j \tag{8}$$

These equations mean that data from either recession or normal period *i* to the present are grouped together and called the *i*th cumulative recession or normal period. Therefore, when the

index i progresses, more recent data only are considered. For example, R_{11} is simply the 11th recession listed in Table 1, R_{10} is the summation of the 10th and 11th recessions listed in Table 1, R_9 is the summation of the 9th, 10th, and 11th recessions listed in Table 1, and R_1 is the summation of all the recessions listed in Table 1. Similarly, N_{12} is the normal period following the 11th recession listed in Table 1, N_{11} is the summation of the normal periods following the 11th recession and in between the 10th and 11th recessions, N_{10} is the summation of the normal periods following the 11th recession, in between the 10th and 11th recessions, and in between the 9th and 10th recessions, and N_1 is the summation of all the normal times.

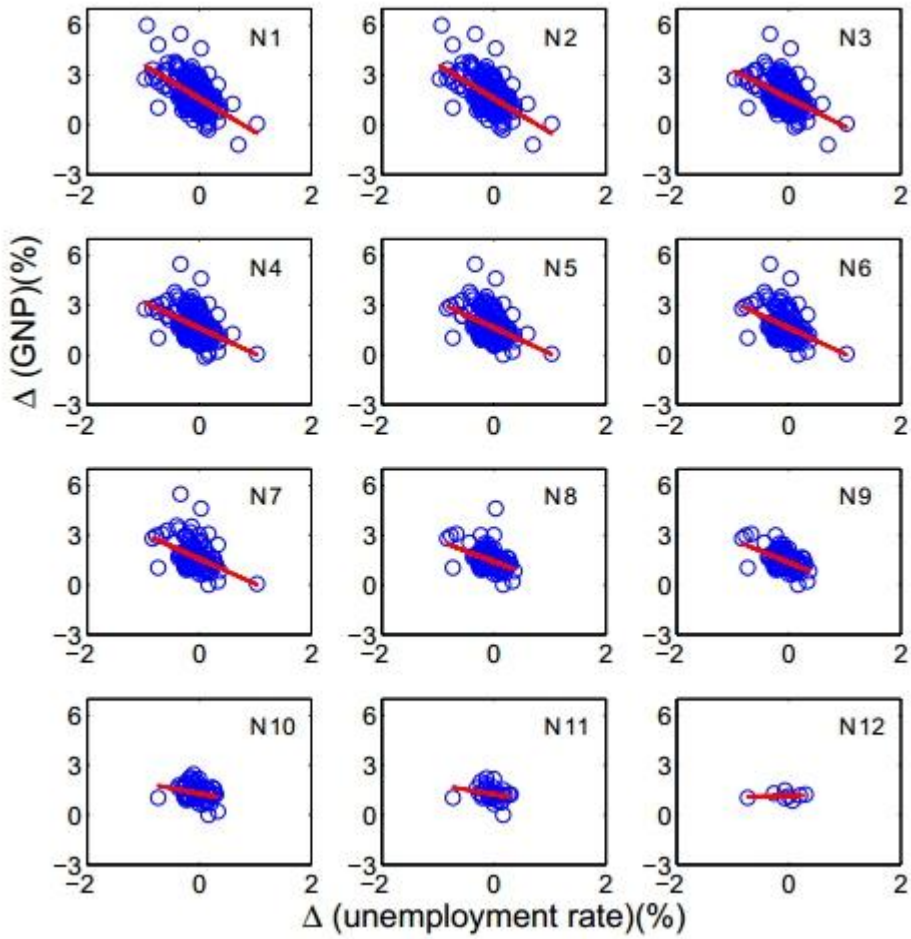

Figure 5. Scatter plots during 12 *cumulative normal* periods.

We have compiled the scatter plots for these *cumulative normal* and *cumulative recession* periods. They are shown in Figures 5 and 6. For Okun's relation to be truly significant, one would expect that it holds better during normal economic conditions than during economic recessions, since economic recessions are generally brief compared to normal economic conditions. However, what we observe from Figures 5 and 6 is the very opposite – the scatter plots are very similar in different *cumulative recession* periods, but differ a lot in *cumulative normal* periods. This unexpected observation can be quantified by the Okun's coefficient shown in Figure 7. We observe that Okun's coefficients remain almost a constant over different *cumulative recession* periods, except at the index i =7. On the other hand, Okun's coefficient continuously decreases during

cumulative normal periods, and approaches 0 in the current period. The last observation is consistent with the last scatter plot shown in Figure 5. This suggests an almost total breakdown of Okun's law.

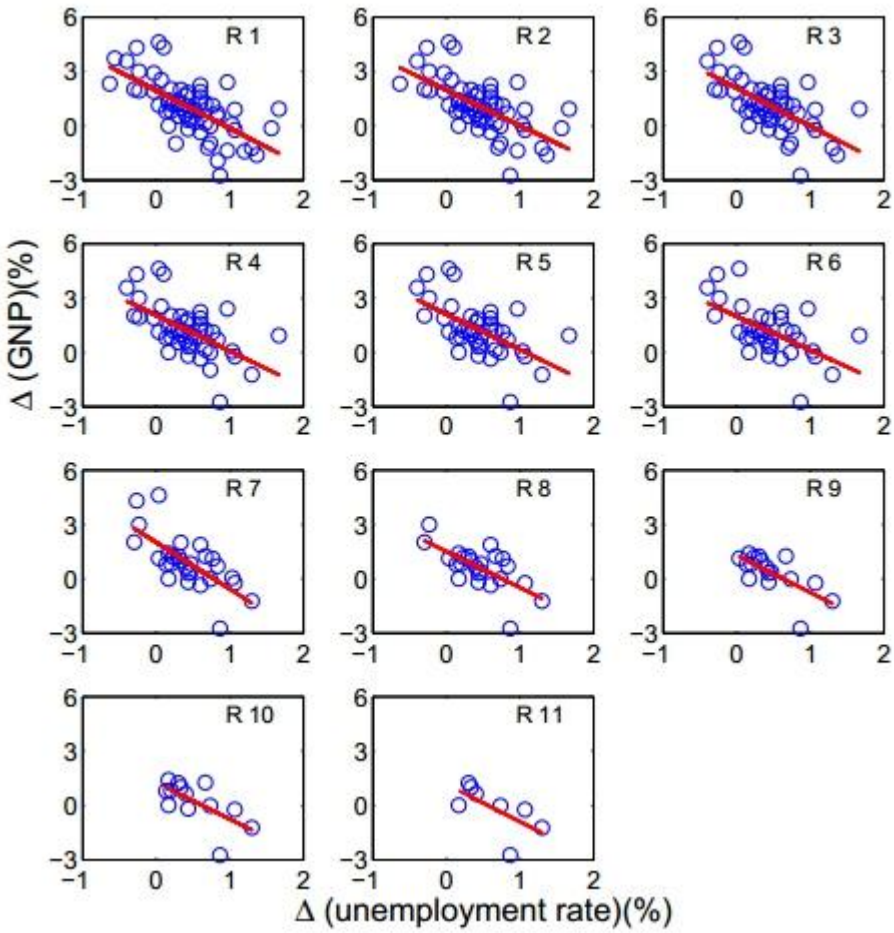

Figure 6. Scatter plots during 11 *cumulative recession* periods.

Since the number of sample points in both recent *cumulative recession* and *cumulative normal* periods is small, it is important to examine how much variation the simple linear regression has accounted for. This can be quantified by the coefficient of determination, R^2, which is essentially 1 minus the ratio between the variances of the residual data and the original data. R^2 for the 11 *cumulative recession* and 12 *cumulative normal* periods is shown in Figure 8. We observe that R^2 for the *cumulative recession* periods is on average around 0.4; R^2 for the *cumulative normal* periods is always smaller than 0.4, and fairly steadily decreases to almost 0 in the present normal period, which is fully consistent with the scatter plots and the Okun's coefficient shown earlier.

A few words about the value of $R^2 \approx 0.4$ for the cumulative recession periods are needed. This means the "disturbance" term in Eq. (1) is not a simple noise. Rather, it collectively represents noise and other factors such as changes in weekly hours, movements in capacity utilization, and adjustments in the unemployment gap (Prachowny, 1993).

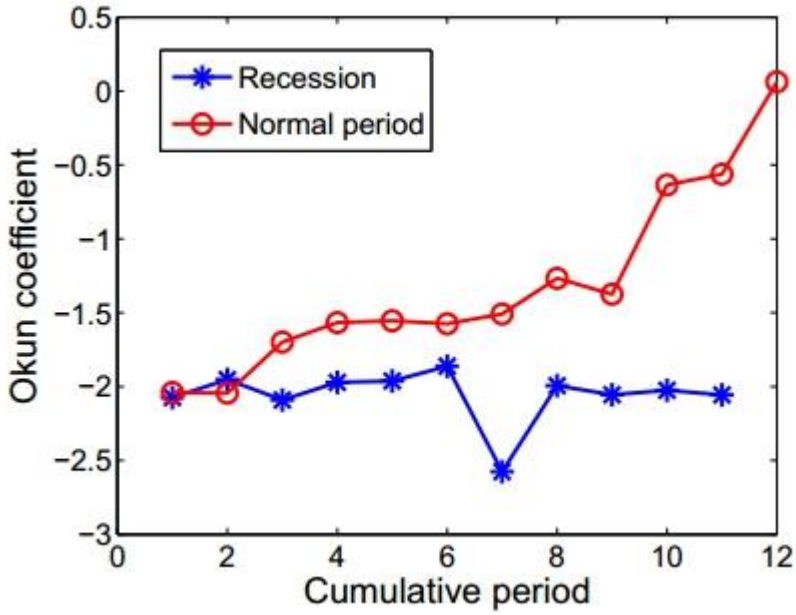

Figure 7. Variation of Okun's coefficient with the *cumulative normal* and *cumulative recession* periods

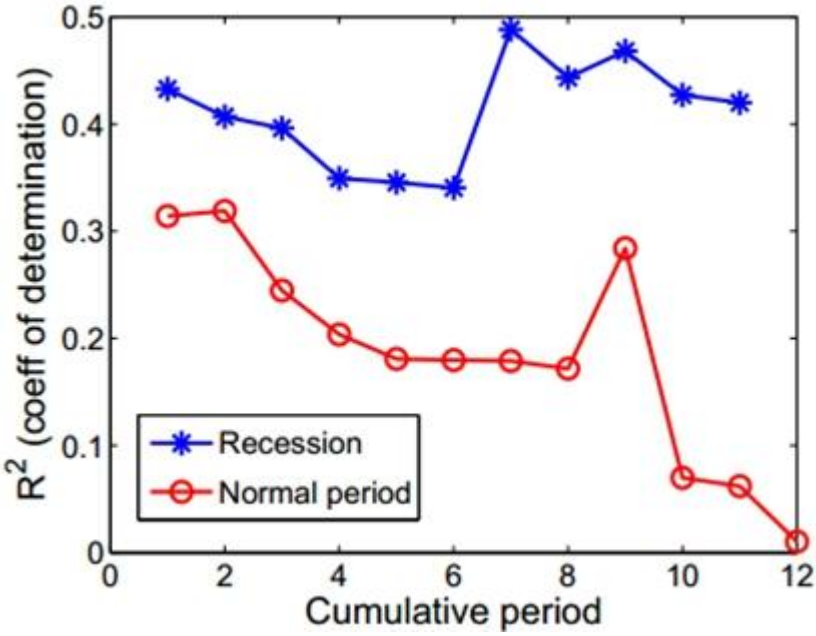

Figure 8. Variation of coefficient of determination with the cumulative recession periods (upper line) and cumulative normal periods (lower line)

Next, we comment on the big dip for the Okun's coefficient at the *cumulative recession* period $i = 7$. As we have mentioned earlier, the 1980 recession is a bit abnormal, in the sense that it causes some asymmetry between the arises of unemployment and production in the CRP plot shown in Figure 2. The NBER considers a short recession to have occurred in 1980, followed by a short period of growth and then a deep recession. The recession began as the Federal Reserve, under Paul Volcker, raised interest rates dramatically to fight the inflation of the 1970s. The very large (or more precisely, the very negative) Okun's coefficient may indicate some “imbalance” instigated by Federal Reserve's policy at the time, and subsequent greater restoration to “balance”.

5. Conclusion

The many complicating factors concerning Okun's law and especially the few puzzling situations that violate Okun's law have motivated us to examine Okun's law from an evolutionary point of view. To achieve our goal, we have employed the CRP, a powerful tool from nonlinear dynamics theory, to study the general, non-local correlations between unemployment and production. The patterns shown in the CRP plot suggest existence of an invariant aspect of the dynamics of un-employment and production during economic recessions. This is further corroborated by the ratio between the difference data of unemployment and production. These observations motivate us to define *cumulative recession* and *cumulative normal* periods, and examine Okun's law in these periods separately. We have observed that Okun's coefficient is remarkably stable during recessions. However, Okun's law is continuously weakening during normal economic conditions, with the Okun's coefficient continuously decreasing, and approaching 0 in the recent few years, suggesting almost a total breakdown of Okun's law after the recent gigantic recession.

The connection between the stability of Okun's law during economic recessions and the invariant dynamics of unemployment and production suggests that there may exist universal properties of macroeconomics during recessions. Some of the universal features of economic recessions have recently been studied by Gao, et al. (2011) and Gao and Hu (2014), such as dramatic increase of entropies from negative incomes, Pareto distributed loss, and propagation of instability among different sectors of economy. Such universalities, and especially the stability of Okun's law during recessions, suggest that the state of economy can be better assessed during recessions. Serious thinking will convince one that this has to be the case, since the evolution of economy in a recessed state often is as expected.

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