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On Fluctuations in the Cross-Sectional Distribution of Unemployment Rates

Fariba Hashemi[1]

[1] Swiss Federal Institute of Technology, Lausanne, Switzerland

Correspondence: Fariba Hashemi, Swiss Federal Institute of Technology, College of Management of Technology, CH 1015 Lausanne, Switzerland. Tel: 41-21-693-6367. E-mail: Fariba.Hashemi@epfl.ch

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Abstract

The cross-sectional distribution of unemployment rates has been relatively neglected compared to the study of unemployment rate differences across countries over time. This paper helps fill the gap. A drift-diffusion model is proposed to describe the dynamics of the cross-sectional distribution of unemployment rates. The model is fitted to the evolution of unemployment rate distribution across five regions, to estimate the *natural rates* and speeds of convergence to *natural rates* once an economy is hit by an exogenous shock. Given the importance of the *natural rate* for gauging the state of the business cycle, the outlook for future inflation, and the appropriate stance of monetary policy, techniques for its estimation would not be without merit.

Keywords: labor market dynamics, natural rate of unemployment, diffusion processes

1. Introduction

The study is motivated by the observation that the rate of unemployment across different states within a country, and countries within a region varies as a function of time. It would not be unreasonable to assume that a long-run distribution of the equilibrium or *natural rate of unemployment* exists with a certain mean and variance. It is hypothesized that over time a set of similar countries share the same natural rate of unemployment. Given an exogenous shock, the ensemble of states considered tends to converge to this long-run equilibrium. We build a theory of the distribution of the rate of unemployment as a drift-diffusion process, and propose a dynamic stochastic model to address the evolution of the cross-sectional distribution of unemployment rates. An empirical application fits the proposed model to the evolution of unemployment rate distribution across five different sets of countries: a) 52 states of the U.S. b) OECD member countries c) OECD Europe d) a handful of the major economies in South East Asia and e) a handful of major economies in South America. The results are novel. Given that estimates of the natural rate of unemployment and its time variation are typically imprecise and far from robust, the present paper suggests that diffusion may be a preferable technique for the estimation of the natural rate of unemployment and for monitoring labor market dynamics.

2. Literature Review

"Dynamic and stochastic elements have played an important role in shaping real-world outcomes. In *The Wealth of Nations,* Adam Smith described what he called the *natural price of a commodity. The Wealth of Nations* was a portrait of a dynamic stochastic model of a perfectly competitive industry, in which Smith's natural price was simply the deterministic steady state equilibrium price." (Rogerson 1997, p. 90). Likewise, Friedman's *natural rate* concept can be viewed as the deterministic steady state equilibrium rate of unemployment. Friedman argued that unemployment has an equilibrium or *natural rate*, determined not by the amount of demand in the economy but by the structure of the labor market. In his (1968) Presidential Address to the *American Economic Association*, Friedman echoed Adam Smith and described an economy in which at any moment in time, "actual unemployment may be either above or below its *natural rate*, but is continually gravitating toward it". In other words, as an economy adjusts to any average rate of inflation, unemployment returns to its *natural rate* (Rogerson 1997, p. 90). In support of Friedman's thesis, one may note that the rate of unemployment across different states within a country, and countries within a region, varies as a function of time. It would therefore not be unreasonable to assume the existence of an *equilibrium* or *natural distribution* of unemployment rates, towards which an out-of-equilibrium labor market tends to gravitate.

Standard economics literature on the determinants of unemployment is built on two main ideas: i) actual unemployment deviates from equilibrium unemployment as shocks hit the economy, and ii) equilibrium unemployment is determined by structural and institutional factors that differ across countries and even regions within the same country. The natural rate of unemployment is a concept frequently employed in fiscal and monetary policy deliberations. National governments use estimates of the natural rate to compute potential GDP, which in turn is used to make budget projections that affect decisions about federal spending and taxation. Central banks consider estimates of the natural rate to determine the likely course of inflation and what actions they should take to preserve price stability (Dickens 2009). It is therefore not surprising that the economics literature is rich with theories which can be employed to draw inferences about the equilibrium distribution of unemployment rates (Forder 2010, Gali 2010, Karanassou, Sala and Snower 2010, Buianovsky and Presley 2009, Petrongolo and Pissarides 2009, King and Morley 2007, Shimer 2005, Ball and Mankiw 2002, Yashiv 2000).

As it turns out however, estimates of the natural rate and its time variation tend to be rather imprecise and far from robust. The reason is that these estimates are typically obtained from estimates of the Phillips curve which in itself is problematic given the complicated relationship between the inflation rate, the lags in the inflation rate, the unemployment rate, its own lags, inflationary expectations, and supply shocks. In this paper, the characterization of the equilibrium unemployment in the standard literature is re-visited. It is considered that over time a set of countries share the same natural rate of unemployment. This assumption is more realistic across the states of the U.S., but also increasingly realistic across other regions which are going through integration and harmonization efforts. Our aim is to model the evolution of *density* of *cross-sectional distribution* of *unemployment rates*, and to build up a tractable structure for the analysis of the diffusion of shocks across its space.

3. The Model

Consider a region consisting of N states or countries, with differing rates of unemployment. Assume the existence of a long-run equilibrium or *natural distribution of unemployment* with a certain unknown mean and variance, towards which the distribution evolves over time. In general, one can study a Markov process generated by a matrix of transitions from one rate of unemployment to another, where the Markov process can be treated as unemployment rate diffusion. Then one can apply the general Fokker-Planck equation to describe evolution in time of unemployment. Hence, assuming that the rate of unemployment behaves like a stochastic process and that it is continuous and Markovian, consider the most natural candidate; a classical linear stochastic differential equation driven by Gaussian white noise:

$$dS_t + \lambda (u - S_t) dt = \sqrt{(2\varepsilon)} dB \tag{1}$$

where S_t denotes rate of unemployment. λ denotes velocity of adjustment to stationary equilibrium interpreted as unemployment rate adjustment (which for simplicity we assume constant), u denotes the mean of the stationary equilibrium distribution, $\varepsilon > 0$ is a constant diffusion parameter, and B_t is the Brownian motion. Equilibrium in this paper refers to a statistical equilibrium, characterized by a stationary probability distribution of unemployment rates. This equilibrium can be associated with level of unemployment which is in line with the *natural rate of unemployment.*

More precisely, consider the basic conservation law, with q a flux of probability, interpreted as the *spread,* or number of states exiting an unemployment rate interval. In this paper it is assumed that the spread is made of two different parts: a *drift* q_c and some *diffusion* q_d. *Drift* describes supply and demand forces at work, and *diffusion* describes random processes.

Thus,

$$q = q_c + q_d \tag{2}$$

The term q_c measures the portion of the function f transported by the drift velocity. For the drift spread, there exists some long-run equilibrium distribution of unemployment rates towards which the distribution drifts, based on a linear distance from equilibrium. I.e., a flux towards the equilibrium distribution. So,

$$q_c (s,t) = \lambda (u - s) f (s,t) \tag{3}$$

where s measures some relevant aspect of unemployment rate in logarithms. u represents where the mean of the distribution is headed, which we interpret as the natural rate of unemployment, and λ denotes the speed of convergence, or the velocity at which unemployment reaches its equilibrium level.

For the diffusion spread, random effects tend to cause a flux from regions of low concentration to regions of high

concentration. The simplest choice is Fick's law:

$$q_d\,(s,t) = -\,\varepsilon\ \partial f\ /\ \partial s\ \ (s,t) \tag{4}$$

where $\varepsilon > 0$ is a constant diffusion parameter. Thus we have

$$q = \lambda\ (u - s)\ f - \varepsilon\ \partial f\ /\ \partial s \tag{5}$$

This is our equation for the density of cross-sectional distribution of unemployment rates. The drift-diffusion mechanism applies to the transition between two long-term equilibriums from (u_0, σ_0) to (u, σ). The process derived from the diffusion model is the size distribution of the population at chosen sequences of times through the observation period. It evolves according to an Ornstein-Uhlenbeck, but with a transition, such that the mean tends to u, instead of 0. From the analytic solution to the model, the dynamics of the distribution can be followed through time, given our initial distribution function f_0. The dynamics of the proposed model rely on two opposing forces: (i) a mean reversion process, call it *drift*, meant to describe supply and demand for labor, concentrating the distribution, and (ii) a counteracting *diffusion* process which flattens the distribution out. Noise is generated by search and learning in the presence of incomplete information and bounded rationality (Levine 2009, Gigerenzer and Selten 2002, Hashemi 2011, Simon 1997, Arrow 1962 and Alchian 1950). Although an equilibrium or *natural* rate of unemployment exists for each region, this equilibrium is assumed uncertain from the point of view of wage and price setters. Agents take time to coordinate, because they collectively need to learn about price and wage rigidities in the economy. Agents follow no precise law to arrive at this optimum, they search and learn by means of trial and error and imitation. After all, labor markets are in a constant state of flux: some firms are expanding employment, others are reducing employment. In the United States alone, 90,000 jobs are destroyed every working day. However, 90,000 other jobs are also created and this intense turnover is a primary engine of fluctuations (Cahuc and Zylberberg (2006)). This search process generates randomness in the system. The drift-diffusion model proposed in this paper studies the fluctuations around the distribution of unemployment rates and measures the dynamics of convergence towards its long run state, or the natural rate of unemployment.

Remark: Fick's law is well known to govern the transport of mass through diffusive means. There are important analogies between Fick's law of diffusion, Fourier's law of heat conduction, Newton's law of viscosity, Darcy's law of permeability, and Ohm's law of electrical conductance. Fick's original experiments dealt with measuring the concentrations and fluxes of salt, diffusing between two reservoirs through tubes of water. Today, Fick's laws form the core of our understanding of diffusion in solids, liquids, and gases. Hashemi (2000) provides an elaboration of this model, albeit in a different context.

4. Empirical Application

4.1 Data and Descriptive Statistics

The empirical analysis applies the model to five different data sets of unemployment rates. The first data set pertains to the rate of unemployment for the 52 states of the United States. The data spans from 1976 up to 2010 and consists of a total of 1820 unemployment rates. The second data set pertains to the rate of unemployment for all countries in Europe that are members of OECD (OECD EU). The data spans from 1970 up to 2009, and consists of a total of 662 unemployment rates from 23 countries. The third data set pertains to all members of OECD. A total of 30 countries are reported and 889 unemployment rates are available from year 1970 up to 2009. The fourth data set pertains to the rate unemployment for Asia. The data spans from 1980 up to 2010 for 10 Asian countries, and consists of a total of 230 unemployment rates. The Asian countries included are: China, Hong Kong, Indonesia, Japan, South Korea, Malaysia, Philippines, Singapore, Taiwan and Thailand. The fifth data set pertains to the rate unemployment for South America (SA). The data spans from 1984 up to 2010 for 7 South American countries, and consists of a total of 91 unemployment rates. The South American countries included in the sample are: Argentina, Brazil, Chile, Mexico, Peru, Uruguay and Venezuela. In all cases, observations were available annually, and all data have been collected from the Bureau of Labor Statistics and the World Bank.

Figure 1 illustrates the evolution of unemployment rate from 1984 up to 2009 across the five data sets. It is on these years wherein all five data sets have values. Therefore, from this point onwards all analyses will include the data from 1984 to 2009 only. Moreover, it must be noted that data points graphed are based on the average rate per year for each country (or states in the case of the United States).

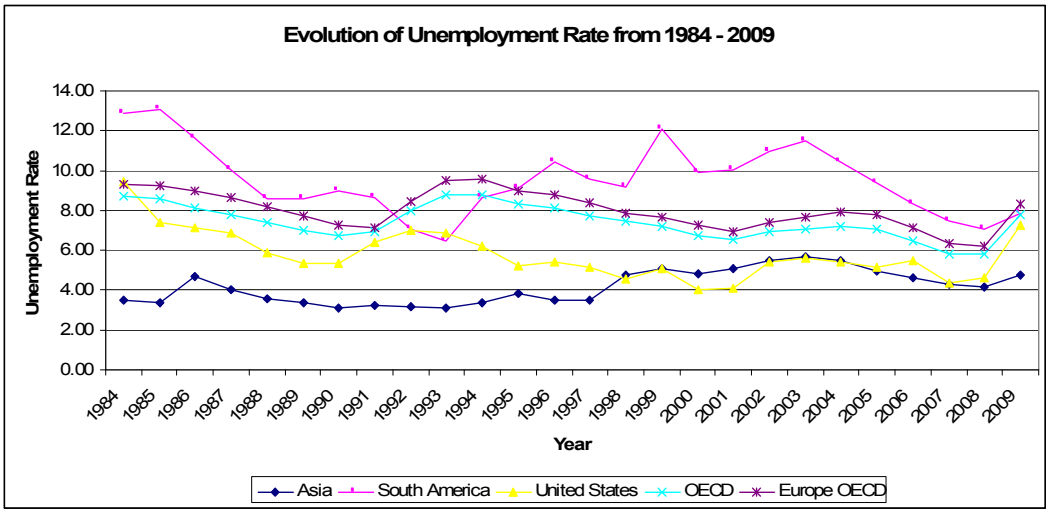


Figure 1. Evolution of Unemployment Rate from 1984 - 2009.

As can be seen, our Asian sample has the lowest but the most stable rate of unemployment and our South American sample on average, has the highest rate with the largest fluctuations. In order to compare countries in terms of the distribution around the mean rate of unemployment, the variance has been investigated. Figure 2 presents the evolution of distribution of unemployment rates for the five regions.

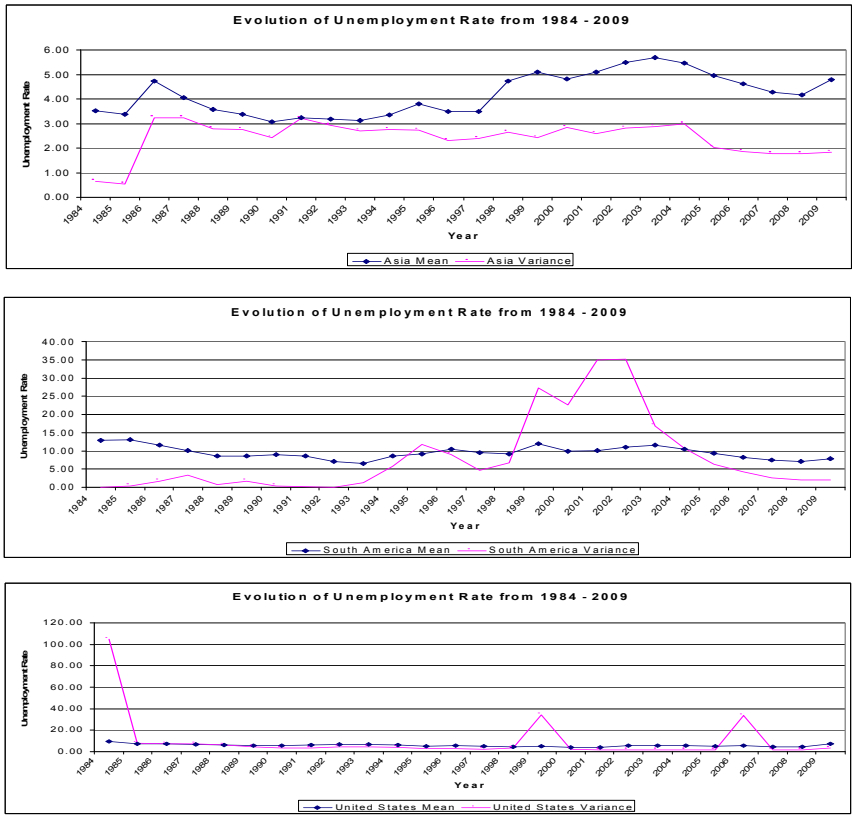


Figure 2. Evolution of Distribution of Unemployment Rates for Asia, South America, the States of the U.S., OECD, and OECD Europe; Mean versus Variance

The first panel in Figure 2 represents Asia. The panel illustrates that fluctuations around the mean unemployment rate significantly decrease from 1986 up to about 1997, however, the variability increases thereafter. This finding may suggest that from 1986 to 1997 the labor markets of our Asian sample were flexible enough to cope with the changing market demands, but may have lost their hold thereafter. This may be partly explained by the Asian financial crisis which began with the devaluation of the Thai Baht in July 1997 and spread like a wave across the region. The second panel illustrates the evolution of distribution of unemployment rates for our South American sample. Like in Asia, there are years where the variability decreases with respect to the mean unemployment rate but only for a while. In fact, during years 1999 to 2002, a sudden upward surge of variability was reported which may suggest that the labor markets of our South American sample may not handle the dynamic nature of their industry as well as those in the United States. One explanation for this variability may be the currency and financial crisis which began in S.E Asia in 1997 and spread like a wave, until it finally arrived in Argentina in 2002. The third panel illustrates the evolution of distribution of unemployment rates for the states of the United States. As can be observed, for most of the years except 1984, 1999, and 2006, the variability of unemployment rate around the mean is relatively small. We observe that only United States has somewhat flattened out the variation of unemployment rates as years pass by. The fourth panel illustrates the evolution of distribution of unemployment rates for OECD member countries. This figure suggests that the labor markets of these countries are having a *relatively* harder time adjusting, conforming to studies which highlight relatively less flexible labor markets in Europe (Nickell (1997), Nickell, Nunziater and Ochel (2005)). The fifth panel illustrates the evolution of distribution of unemployment rates for OECD Europe, and demonstrates the same trend as compared to our OECD sample.

Table 1 reports some descriptive statistics for the five data sets. It can be observed that Asia has the lowest average unemployment rate (M = 4.1746) among the five data sets and that South America has the highest (M = 9.5269). Moreover, the data reported in Table 1 suggests that large fluctuations in the average unemployment rate occurred in South America (SD = 1.7536), followed by the United States (SD = 1.2267), OECD Europe (SD = 0.9338), OECD (SD = 0.8497) and Asia (SD = 0.8380), as depicted by the standard deviations.

Table 1. Descriptive Statistics for the Five Regions

	N	Minimum	Maximum	Mean	Std Deviation
Asia	26	3.08	5.68	4.1746	.83796
South America	26	6.47	13.05	9.5269	1.75366
United States	26	4.02	9.42	5.7992	1.22672
OECD	26	5.78	8.81	7.4227	.84973
OECD Europe	26	6.20	9.55	8.0231	.93378

Furthermore, it is worth investigating if the means or the averages of the five data sets are different from each

other. Table 2 reports the independent samples t-test for all five data sets. The results illustrate that for all pair-wise combinations, there is a significant difference between the means of unemployment rates. Here, a significance value of less than 0.05 ($p < 0.05$) can be interpreted to mean that the average unemployment rate of the two compared countries are significantly different. Let us take for example the case of Asia and South America, a mean of 4.1746 for Asia and 9.5269 for South America, was deemed not to be significantly different with a significance value $p < 0.001$. This finding is the same throughout the pair wise comparison for all countries (Note: Alpha level is set to 0.05).

Table 2. Independent Samples T-test

					95% Confidence Interval of the Difference	
	t	df	Sig.(2-tailed)	Mean Difference	Lower	Upper
Asia South America	25.403 27.701	25 25	.000 .000	4.17462 9.52692	3.8362 8.8186	4.5131 10 .2352
Asia United States	25.403 24.105	25 25	.000 .000	4.17462 5.79923	3.8362 5.3037	4.5131 6.2947
Asia OECD	25.403 44.542	25 25	.000 .000	4.17462 7.42269	3.8362 7.0795	4.5131 7.7 659
Asia OECD Europe	25.403 43.811	25 25	.000 .000	4.17462 8.02308	3.8362 7.6459	4.5131 8.4002
South America United States	27.701 24.105	25 25	.000 .000	9.52692 5.79923	8.8186 5.3037	10 .2352 6.2947
South America OECD	27.701 44.542	25 25	.000 .000	9.52692 7.42269	8.8186 7.0795	10 .2352 7.7659
South America OECD Europe	27.701 43.801	25 25	.000 .000	9.52692 8.02308	8.8186 7.6459	10.2352 8.4002
United States OECD	24.105 44.542	25 25	.000 .000	5.79923 7.42269	5.3037 7.0795	6.2947 7.7659
United States OECD Europe	24.105 43.811	25 25	.000 .000	5.79923 8.02308	5.3037 7.6459	6.2947 8.4002
OECD OECD Europe	44.542 43.811	25 25	.000 .000	7.42269 8.02308	7.0795 7.6459	7.7659 8.4002

Table 2. Sample t-tests for the Five Regions

4.2 Method of Estimation

A second order partial differential equation has been proposed to express the dynamics of the distribution of unemployment rates across different regions. The model has five parameters: u_0, u, ε, σ_0^2 and λ. u_0 denotes the initial mean of the unemployment distribution (1980), and u denotes where the initial mean is heading, which we associate with the natural rate of unemployment. σ_0 is the standard deviation at time zero (1980), ε represents the diffusion parameter, and λ represents the rate of convergence to the long-run steady state equilibrium.

The model has been fitted to the log unemployment rate as a function of time, using non-linear least squares, and using a two-step procedure. First, the values for u_0, u and λ were estimated using the expectation of the distribution, expressed by the first moment:

$$u_t = u(1 - e^{-\lambda t}) + u_0 e^{-\lambda t} \tag{6}$$

In the second step, the values for ε and σ_0 were computed using the expression for the second moment of the distribution:

$$\sigma_t^2 = \sigma_0^2 e^{-2\lambda t} + \varepsilon/\lambda \ (1 - e^{-2\lambda t}) \tag{7}$$

The diffusive limit, as $t \to \infty$ of the variance is: ε/λ.

Remark: The Ornstein-Uhlenbeck process is the most general normal stationary Markovian process with zero expectations. For $t > T$, the transition density from (T, s) to (t, y) is normal with expectation $e^{-\lambda(r-t)}s$ and variance $\sigma^2(1 - e^{-2\lambda(r-t)})$. As $t \to \infty$, the expectation tends to 0 and the variance to σ^2. The analytic solution derived for our

diffusion equation is a normal distribution for all t. There is the $se^{\lambda t}$ factor; with a change of variables, it can be shown that the solution is normal with a constant multiplied by it.

4.3 Estimation Results and Model Checks

Tables 3-7 report estimates for the five model parameters λ , u, u_0, σ_0 and ε, along with the standard errors and t-values for our five samples: `

Table 3. United States Parameter estimates

Parameter	Value	Std Error.	t-value
λ	1.56	1.16	0.55
u	1.21	0.03	67. 68
u_0	1.26	0.04	21.04
σ_0	0.95	0.04	13.47
ε	0.65	0.04	14.62

Table 4. Asia Parameter estimates

Parameter	Value	Std Error.	t-value
λ	1.25	0.93	0.54
u	0.97	0.03	57.53
u_0	1.01	0.04	17.88
σ_0	0.76	0.04	11 .45
ε	0.52	0.04	12 .43

Table 5. South America Parameter estimates

Parameter	Value	Std Error.	t-value
λ	2.87	2.14	0.89
u	2.23	0.03	110.2
u_0	2.31	0.04	34.26
σ_0	1.74	0.04	21.93
ε	1.19	0.05	23. 81

Table 6. OECD Parameter estimates

Parameter	Value	Std Error.	t-value
λ	1.95	1.46	0.64
u	1.52	0.03	79.62
u_0	1.57	0.04	24.75
σ_0	1.18	0.04	15.84
ε	0.81	0.04	17.20

Table 7. OECD Europe Parameter estimates

Parameter	Value	Std Error.	t-value
λ	2.44	1.82	0.76
u	1.90	0.03	93.67
u_0	1.96	0.04	29.12
σ_0	1.48	0.04	18.64
ε	1.01	0.04	20.24

Tables 3-7: Parameter Estimates for the Five Data Sets

It can be observed from these tables that the parameter estimates conform to the real data presented in the descriptive analysis section above. The following observations can be made concerning the results:

1. The mean and variance of all distributions are clearly evolving, suggesting a clear trend for the natural rate of unemployment. This finding corresponds to our theoretical predictions.

2. The speed of convergence to long-run equilibrium or *natural rate* λ, varies from region to region, and is positive as expected. This velocity is fastest for our South American sample, followed by OECD Europe, OECD, the U.S., and our Asian sample. This finding is important as it illustrates that the velocity at which unemployment reaches it equilibrium level is not constant, but rather depends on the particular region considered.

3. The value for the diffusion parameter for all regions examined is small and positive, conforming to our theoretical predictions. The diffusive limit, i.e., the limit as $t \rightarrow \infty$ of the variance is ε/λ. The results predict that if we start with a normal distribution and let the model drive the distribution, the distribution variance will tend toward a constant ε/λ, and concentrated around a mean u, representing the natural rate of unemployment. This rate is largest for our South American sample, followed by OECD Europe, the OECD, the U.S., and our Asian sample.

Figures 3a - e illustrate the actual vs. predicted time plots that can be generated from the real and the estimated data, for the five regions:

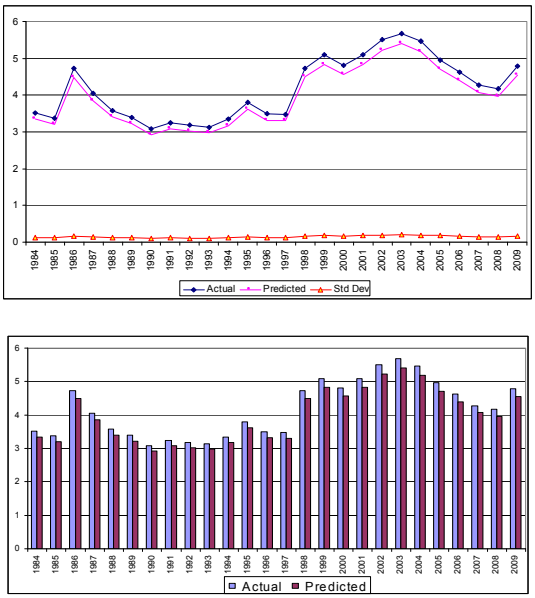
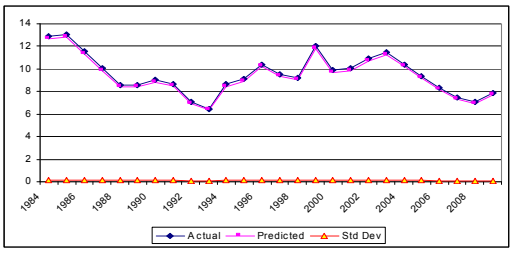


Figure 3a. Asia



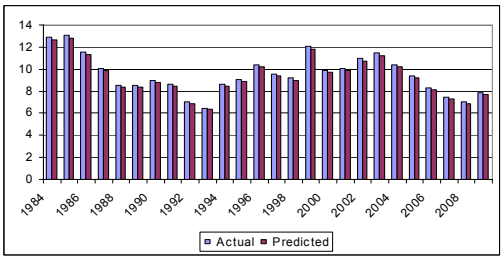
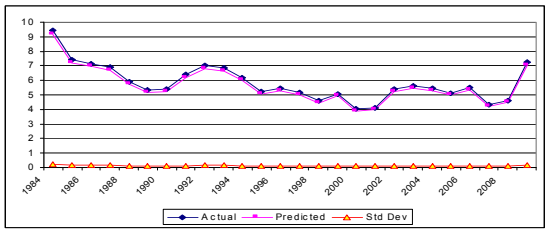


Figure 3b. South America



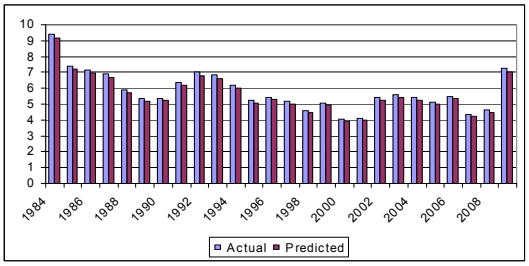
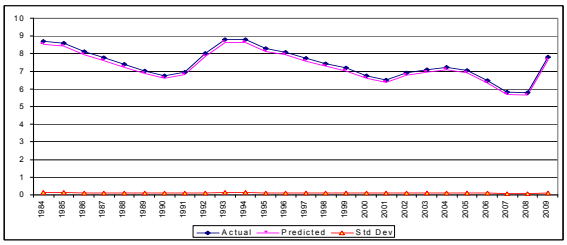


Figure 3c. United States



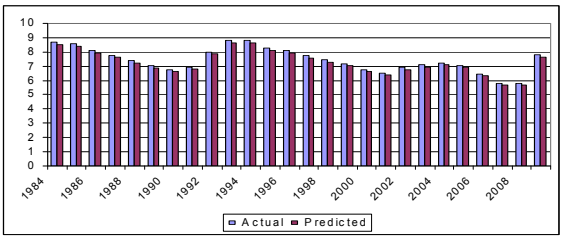


Figure 3d. OECD

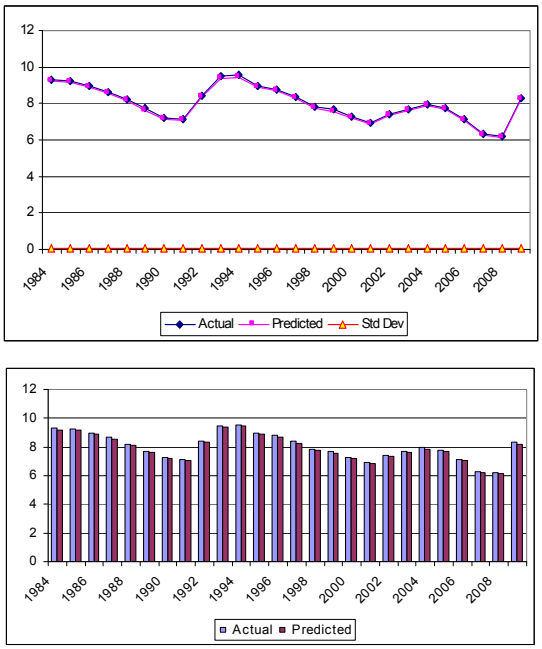
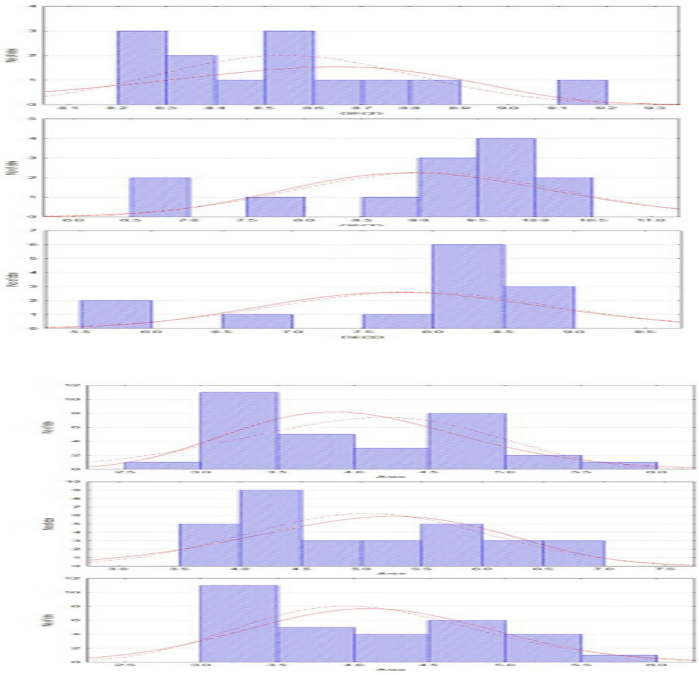


Figure 3e. OECD Europe

Figure 4 illustrates the evolution of the distribution of unemployment rates (log-normals) over time, superimposed on histograms which describe the time evolution of the distribution of the unemployment rates in the data (for selected years). The solid curves in these figures illustrate the distribution of the unemployment rates as predicted by the model, and the dotted curves illustrate the distribution of the unemployment rates in the data. The x-axes on these figures denote rate of unemployment and the y-axes denote number of observations. The five panels represent Asia, South America, United States, OECD and OECD Europe respectively:



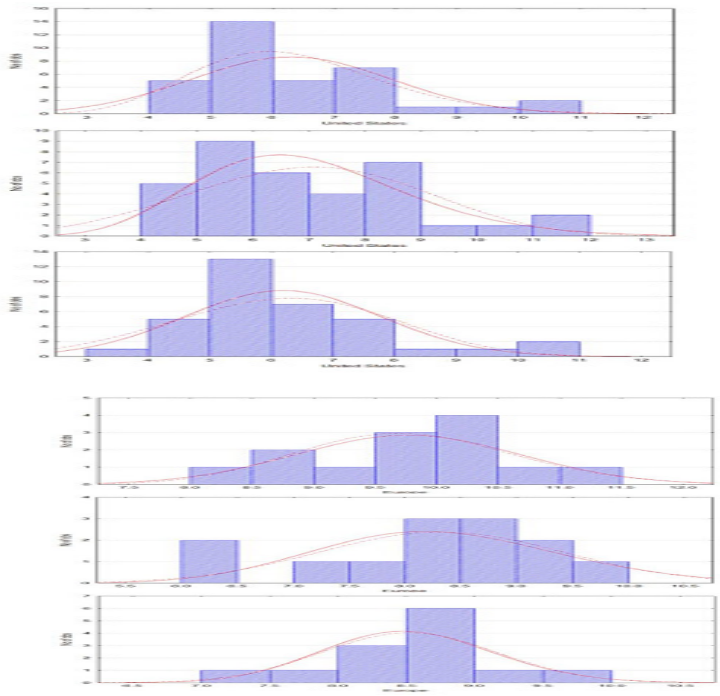


Figure 4. Actual vs. Predicted Distributions for the Five Regions (for years 2000, 2005, 2009)

As can be seen from Figure 4, the neat pattern which we see in the fitted log normals are being pulled out of a set of histograms whose shape are irregular. The actual and predicted values for all five data sets are almost in the same shape and within the tolerance limit for estimation. It can be concluded from the illustrations that the values generated by the predictive model are reliable in characterizing the five actual data sets.

5. Concluding Remarks

The present study provides a useful framework for thinking about macroeconomic policy questions, in particular with reference to the ability to explain changes in the inflation rate. When unemployment is below the *natural rate*, inflation can be expected to rise, and when it is above, inflation can be expected to fall. In general, a model that can successfully account for movements in unemployment will presumably be useful in analyzing how alternative policies would affect unemployment and what the welfare consequences of these policies would be. For example, the *natural rate of unemployment* is sometimes referred to as a proxy for broader macroeconomic equilibrium. A measure of the *natural rate* is therefore potentially useful for assessing the contribution of equilibrium fluctuations to overall macroeconomic volatility, the structural sources of equilibrium fluctuations, and the short run relationship between inflation and movements away from equilibrium (Stock and Watson (2002)).

By considerations of analytical tractability, the model developed in this paper constitutes a considerable simplification, for example with respect to homogeneity of parameters across countries. One may control for heterogeneity and introduce some determinant of the natural rate of unemployment and of the labor market dynamics. The present paper cites frictions in the labor market as a relevant determinant of the dynamics of unemployment when the stochastic equilibrium is reached. The first implication of such frictions may be to increase the *natural rate of unemployment*, and difference in frictions may generate difference in the *natural rate of unemployment*. The assumption that over time a set of countries share the same *natural rate of unemployment*, is more realistic across the states of the U.S., but also increasingly realistic in the European case moving forward. The dynamic process in the evolution of unemployment rates in Germany, France and Spain have been dramatically different over the last two decades. Once again, given the European integration efforts, the assumption that they would revert the same way and at the same pace becomes increasingly appropriate, were it not for the ongoing sovereign debt crisis which, at the time of writing, jeopardizes the whole European project. Finally, the assumption that the difference in unemployment volatility between these three countries is a matter of chance and due to different realizations of the shock process is also a strong assumption but becomes increasingly reasonable moving forward. The diffusion model developed in this paper is capable of extrapolation

to a variety of realistic assumptions pertaining to the functional form of the parameters. These extensions would no doubt enrich the model and should prove insightful but only at the expense of considerable complexity. Given the importance of the *natural rate of unemployment* as a benchmark for gauging the state of the business cycle, appropriate techniques for its estimation are not without merit. The present paper illustrates that diffusion is a potential method to estimate the *natural rate of unemployment* and to monitor labor market dynamics.

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