SYSTEM DYNAMICS MODEL OF THE ORIGINAL PHILLIPS CURVE

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Abstract

An empirical inverse relation is argued between wage inflation and unemployment rate by Phillips(1958). This relation is later called Phillips Curve and interpreted as a trade-off between inflation and unemployment. In this study, we argue that the trade-off interpretation is incorrect and there is a disequilibrium explanation for the empirical inverse relation. We propose a system dynamics model which explains the phenomena and discuss the simulation results.

Key Words: System Dynamics, Disequilibrium Economics, Phillips Curve

ÖZGÜN PHİLLİPS EĞRİSİNİN SİSTEM DİNAMİĞİ MODELİ

Özet

Ücret enflasyonu ile işsizlik oranı arasında ampirik bir ters yönlü ilişki olduğu Phillips (1958) tarafından öne sürüldü. Bu ilişki daha sonra Phillips Eğrisi olarak adlandırıldı ve enflasyon ile işsizlik oranı arasındaki bir ödünleşim olarak yorumlandı. Bu çalışmada ödünleşim yorumunun yanlış olduğu ve ampirik ters yönlü ilişkinin denge dışı bir açıklamasının olduğunu iddia edilmektedir. Bu fenomeni açıklayan bir system dinamiği modeli önerilmektedir ve simülasyon sonuçları tartışılmaktadır.

Anahtar Sözcükler: Sistem Dinamiği, Dengesizlik Ekonomisi, Phillips Eğrisi

1. Introduction

In 1958,New Zealand economist A. W. BillPhillipsshowed the empirical inverse relation between unemployment rate and the changes in money wages(Phillips, 1958). Further studies of Phillips (2000) and Lipsey(1960)increased the confidence on the relation. The work of Samuelson and Solow (1960)shows a similar empirical relation, this time between unemployment rate and the changes in price level.Since then, this relation has been called ‘Phillips Curve’.

After the critics of Phelps (1967)and Friedman (1968), expectation factor is added to the relation, where expected inflation is formulated based on past values. Accordingly, lower unemployment does not only lead to a higher inflation but also an increasing inflation. The studies of Sargent (1971) and Lucas (1972; 1976) helped to introduce rational expectations assumption into macroeconomics and after the study of Calvo(1983)the New Keynesian version of the Phillips Curve (NKPC) gradually became the consensus model.

A comprehensive review of the Phillips Curve literature is out of scope in this study. Instead, we focus on the empirical relation in the study of Phillips (1958), which we call ‘the original Phillips Curve’.As mentioned before, the original Phillips Curve is about the inverse relation between unemployment rate and wage inflation. With the assumption that wage changes will be passed on into prices, the relation is interpreted as a trade-off between inflation and unemployment rate. This trade-off interpretation enabled the governments to buy lower unemployment with the cost of higher inflation and the main question became what the optimal trade-off would be.

According to Lipsey(2000), Phillips’ essay on wages and unemployment is “one of the seminal articles of the last half of the twentieth century”. However, the trade-off interpretation of the relationwas incorrect (Leeson, 1997). The study of Lipsey(2000)has similar misinterpretation arguments as well. One of the reasons for this misinterpretation is that, unlike the proceeding versions, the original Phillips Curve was completely a disequilibrium phenomenon.

In this study, we agree the misinterpretation arguments of Lipsey(2000)and Leeson (1997). We contribute the arguments by proposing a disequilibrium model of the original Phillips Curve. We use system dynamics methodology for modeling and simulation.

In section 2, a brief introduction of the system dynamics methodology will be given. In section 3, original Phillips Curve will be discussed. In section 4, a dynamic non-equilibrium model of the unemployment-wage relation will be introduced. Finally, the simulation results will be discussed and some conclusions will be derived.

2. System Dynamics

In this study we use system dynamics both as a modeling device and as an out-of-equilibrium modeling philosophy. Michael Radzicki defines system dynamics as follows:

"System dynamics is a computer simulation modeling technique originally created in 1956 to help corporate managers improve their understanding and control of industrial systems. Over the years, it has been used to address a wide variety of problems in social systems ranging from the transition from fossil fuels to alternative sources of energy in the United States economy, to the growth and decline of cities, to the causes of worker burnout and cost and scheduling overruns in R & D projects, to the diffusion of new medical technologies, to global warming, to the reasons for Hamlet's behavior in the well-known Shakespearean play" (M Radzicki, 2008).

It is also a simulation technique that is used to analyze complex nonlinear dynamic feedback systems for the purposes of generating insight and designing policies that will improve system performance. System dynamics models are created by identifying and linking the relevant pieces of a system's structure and simulating the behavior generated by that structure. Through an iterative process of structure identification, mapping, and simulation a model emerges that can explain (mimic) a system's problematic behavior and serve as a vehicle for policy design and testing.

From a system dynamics perspective a system's structure consists of stocks, flows, feedback loops, and limiting factors. Stocks can be thought of as bathtubs that accumulate/de-cumulate a system's flows over time. Flows can be thought of as pipe and faucet assemblies that fill or drain the stocks. Mathematically, the process of flows accumulating/de-cumulating in stocks is called integration. The integration process creates all dynamic behavior in the world be it in a physical system, a biological system, or a socioeconomic system. Examples of stocks and flows in economic systems include a stock of inventory and its inflow of production and its outflow of sales, a stock of the book value of a firm's capital and its inflow of investment spending and its outflow of depreciation, and a stock of employed labor and its inflow of hiring and its outflow of labor separations.

The simplest form of stock-flow representation is the form including one stock and two flows (one inflow and one outflow). Fig. 1 gives an example of a stock-flow structure.

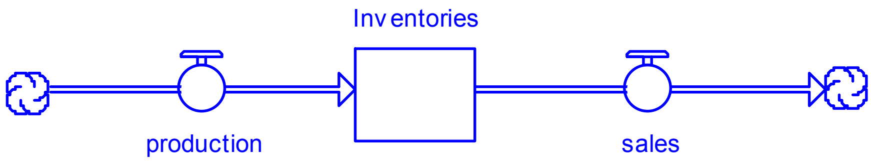

Figure 1. Inventory accumulating the difference between production and sales

Jay Wright Forrester defined the principles of system dynamics methodology and undertook the first studies(Forrester, 1961, 1969, 1971). Although it was first proposed for business management problems, system dynamics is later used in many different disciplines. Some of the examples are business strategy (Gold, 2005; Größler, 2010), supply chain management (Li & Maani, 2012; Schwaninger & Vrhovec, 2006), environmental problems (Vogstad, 2005; Winz et al., 2008), biomedical engineering(Hirsch et al., 2010; Incioğlu, 2007), project management (Mashayekhi, 2000)and energy (Ford, 1997).

One of the most suitable areas to use system dynamics for modeling and simulation is economics. The reason is that economic systems are very complex systems which can exhibit counterintuitive behavior (Anderson et al., 1988). Moreover, aggregate behavior, feedback mechanisms and time delays also make these systems suitable for system dynamics approach. Studies of Forrester (1980), Aktinson(2004), Yamaguchi (2010)and Radzicki(2011)are some examples of economic modeling with system dynamics.

A system dynamics economic model requires relevant information from the economics field. However, that information may not be suitable for using it in feedback analysis. In that case, it will be a necessity to interpret and restructure that information in a logical manner. Information about the underlying mechanisms may long have been skipped after the deduction of ready-to-use information by equilibrium oriented analysis. Digging deeper for such underlying mechanisms is important in the interpretation and restructuring process.

Why the ready-to-use information from the economics field may not be suitable for using in feedback analysis? The reason is that ready-to-use information is usually defined under the equilibrium conditions. On the other hand, system dynamics models are out-of-equilibrium models by nature. Thus the information about the causal structure underlying the equilibrium framework should be translated into disequilibrium information before using it in the modeling practice.

3. Original Phillips Curve

Since the first article about the empirical relation between wage inflation and unemployment (Phillips, 1958), Phillips Curve remained one of the most important and controversial topics in economics. It is important because a possible trade-off between inflation and unemployment has direct implications about the limits of governmental stabilization policies, whether it is fiscal or monetary oriented. It is also controversial because the true meaning of the empirical observation was at the center of discussions in economics.

In section 1, historical background of the Phillips Curve is given. Broadly speaking, the original Phillips Curve was interpreted as a trade-off between inflation and unemployment and this trade-off is used as a policy guide for a long time. Later, after years of boosting inflation for lower levels of unemployment, unemployment returned back to its normal levels although inflation did not. It was one of the motives for including the expectations factor intothe theory of inflation. Finally, econometric studies showed great shifts in the parameters of Phillips Curve and that lead to Lucas Critique and rational expectations, which is the backbone of the current mainstream theory of inflation. See Gordon (2011)for the history and different interpretations of Phillips Curve.

At the center of the critics for the Phillips Curve during this historical evolution is the menu of choice interpretation of the original empirical relation. In this study, it is argued that the menu of choice interpretation of Phillips Curve was a misinterpretation. "For the menu of choice interpretation to hold, each point along a Phillips curve must represent either an equilibrium position, or alternatively must incorporate some mechanism for perpetuating the disequilibrium in a predictable and non-pernicious manner" (Leeson, 1997).

The cyclical nature of the data rules out the perpetuating mechanism of the disequilibrium. Fig. 2, taken from Phillips (1958)clearly shows that the unemployment-wage inflation pairs in the data move around the fitted curve generating a cycle. A similar pattern is observed for different cyclical periods. Thus the economy does not rest at the same point as if it perpetuates the same trade-off mechanism.

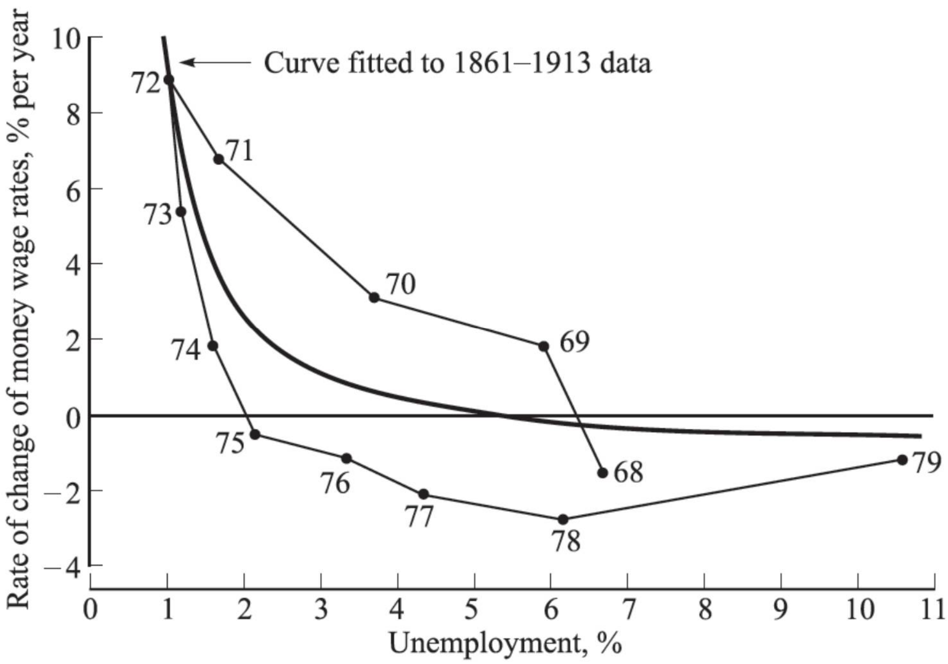

Figure 2. Wage Inflation – Unemployment relation during a cycle
Source:The Relation Between Unemployment and the Rate of Change of Money Wage Rates in the United Kingdom, 1861-1957(Phillips, 1958)

Other than that, the points along the curve do not represent equilibrium positions either. Although the versions of Phillips Curve after Friedman (1968), including the current version of NKPC, are based on equilibrium-oriented theories, the original Phillips Curve was completely a disequilibrium phenomenon. For this reason, the menu of choice interpretation of the original Phillips Curve was a misinterpretation.

The disequilibrium nature of the hypothesis behind the empirical Phillips Curve is often ignored. Richard Lipsey is one of the early contributors of the Phillips Curve (Lipsey, 1960). About the disequilibrium nature of the curve he says: “when I tried to work with a market-clearing interpretation in which each point on the curve was generated by the intersection of relevant demand and supply curves, Phillips told me forcibly that he thought I was on the wrong track because his curve was a disequilibrium phenomenon” (Lipsey, 2000).

Below is the first paragraph of Phillips in which he describes his hypothesis before presenting the famous relation between wage inflation and unemployment:

“When the demand for a commodity or service is high relatively to the supply of it we expect the price to rise, the rate of rise being greater the greater the excess demand. Conversely when the demand is low relatively to the supply we expect the price to fall, the rate of fall being greater the greater the deficiency of demand. It seems plausible that this principle should operate as one of the factors determining the rate of change of money wage rates, which are the price of labour services. When the demand for labour is high and there are very few unemployed we should expect employers to bid wage rates up quite rapidly, each firm and each industry being continually tempted to offer little above the prevailing rates to attract the most suitable labour from other firms and industries. On the other hand it appears that workers are reluctant to offer their services at less than the prevailing rates when the demand for labour is low and unemployment is high so that wage rates fall only very slowly. The relation between unemployment and the rate of change of wage rates is therefore likely to be highly non-linear" (Phillips, 1958).

The original Phillips Curve article is mainly an empirical study. However, the first paragraph mentioned above explains the theory behind.According to Phillips, it is the disequilibrium in the labor market which creates wage inflation. In other words, when firms increase their hiring, unemployment rate falls and wage rates increase.

The disequilibrium nature of the theory behind the empirical study can also be seen in other studies of Phillips. His first article titled M*echanical Models in Economic Dynamics*(Phillips, 1950)introduces a physical analog computer which is later called 'Phillips Machine'. The theoretical model behind this analog computer is an out-of-equilibrium stock-flow model which is consistent with the methodology explained in section 2.

He used the same continuous-time dynamic methodology in the two following papers and focused on the stabilization policy issue and the importance of time-lags (Phillips, 1954, 1957).These two articles are theoretical complements of the empirical paper and, according to Lipsey(2000), "those who interpret Phillips Curve on the basis of this article alone often fail to read the earlier two pieces on stabilization policy, although all three articles need to be seen as a unit".

At the same year with the empirical study, Phillips wrote another paper titled *Cybernetics and the Regulation of Economic Systems*(Phillips, 2000b)in which he clearly rejects the equilibrium view of the economic systems. If we look at these studies from 1950 to 1958, we see a line of continuity. These studies reflect the ideas of Phillips about how he thinks the economic system works. There is no reason that we do not expect the continuity of his beliefs also in his empirical studies about wage inflation and unemployment.

Phillips apparently does not have a static equilibrium model in his mind and he certainly does not believe that economic system will maintain stability on its own. He was thinking not in terms of equilibrium, supply and demand, but in terms of feedback loops. "He [Phillips] saw the economy as a dynamic system whose behaviour could not be understood using neoclassical static analysis" (Lipsey, 2000).

The disequilibrium nature of the original Phillips Curve is also apparent in the data. As seen in Fig. 2, data points are above the curve when unemployment is falling and below the curve when it is rising. There is a similar pattern in other cycle periods as well. Phillips explains this fact as follows:

"It seems possible that a second factor influencing the rate of change of money wage rates might be the rate of change of the demand for labour, and so of unemployment. Thus in a year of rising business activity, with the demand for labour increasing and the percentage unemployment decreasing, employers will be bidding more vigorously for the services of labour than they would be in a year during which the average percentage unemployment was the same but the demand for labour was not increasing. Conversely in a year of falling business activity, with the demand for labour decreasing and the percentage unemployment increasing, employers will be less inclined to grant wage increases, and workers will be in a weaker position to press for them, than they would be in a year during which the average percentage unemployment was the same but the demand for labour was not decreasing" (Phillips, 1958).

As a result, the observed inverse relation between wage inflation and unemployment rate is not the result of an equilibrium mechanism beneath. It is rather a causal relation when the economy is on an out-of-equilibrium transition. In the next section, a system dynamics model will be presented to explain this relation without restricting the reasoning to the equilibrium conditions.

4. Model Description

System dynamics models include stock, flow and auxiliary variables. Stock variables accumulate the flow variables which are connected to them. Flow variables have a time component in their units and the values of them are guided by stocks in continuous time. Auxiliary variables, on the other hand, are just converters of other stock and flow variables and used for the purpose of increasing the readability of the models.

System dynamics model proposed in this study is given in Fig. 3. Accordingly, there are two stock variables called employment and unemployment. Two flow variables, hiring and firing, represent the flows of workforce between stocks. These flows are guided by target employment which represents the amount of workforce demanded by the employers. Whenever target employment is higher (lower) than actual employment, the gap is eliminated with the help of hiring (firing).

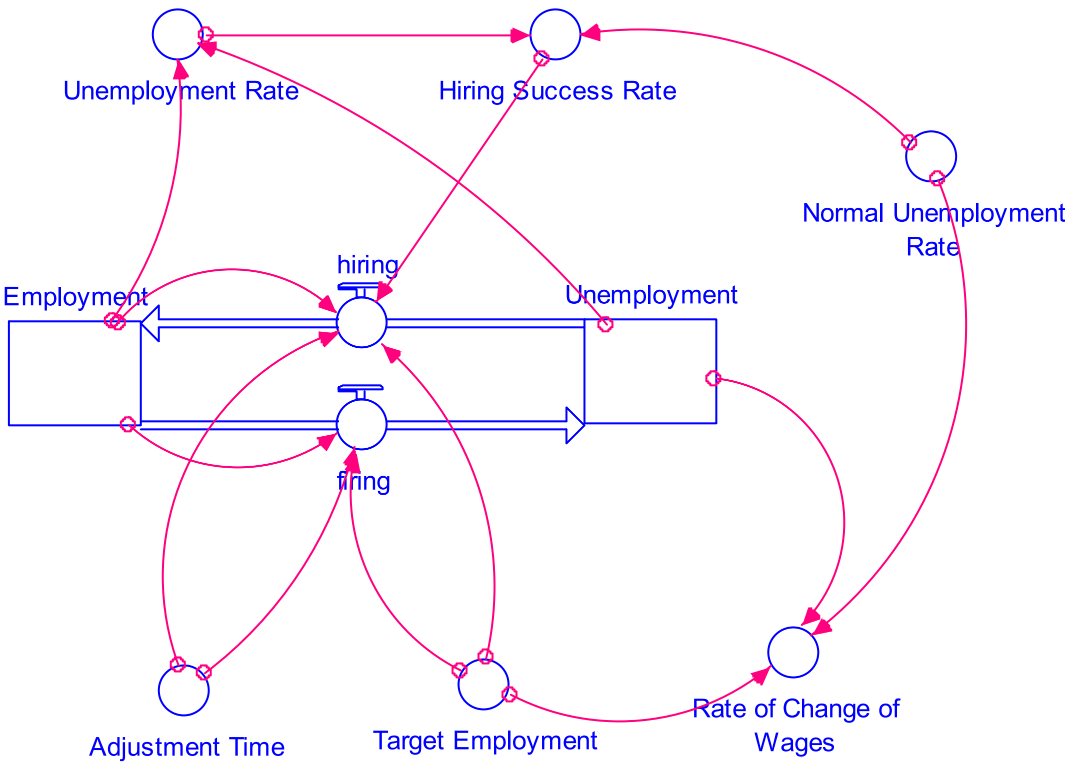

Figure 3. System dynamics model of the Original Phillips Curve

Using the language of differential equations, we can represent the model equations in terms of employment (E), unemployment (U), hiring (h), firing (f), hiring success rate (s), unemployment rate (u), adjustment time (a), target employment $(\bar{E})$, normal unemployment rate (n) and rate of change of wages (dw/dt) as follows:

$$E = E_0 + \int (h - f) * dt \quad (1)$$

$$U = U_0 + \int (f - h) * dt \quad (2)$$

$$h = Max(0, (\bar{E} - E) * s / a) \quad (3)$$

$$f = Max(0, (E - \bar{E}) / a) \quad (4)$$

$$s = 1 - e^{(-u/n)} \quad (5)$$

$$u = U/(U+E) \quad (6)$$

$$dw/dt = (\bar{E}/U - (1-n)/n) \quad (7)$$

Adjustment time and normal unemployment rate are constants with the values of 2 years and 0.1 respectively. Equation 6 is just the calculation of unemployment rate thus the meaning is obvious. Equation 1 and 2 are also ordinary integration thus their meanings are obvious as well. Other equations, however, require explanation.

Equation 3 simply tells us that the rate of hiring at any moment in time is proportional to the difference between target employment and actual employment. Adjustment time determines the speed of convergence. This factor provides a continuous-time delay for employment adjustment rather than a discrete-time lag. Moreover, hiring is also proportional to hiring success rate which is an increasing function of unemployment rate. Thus firms may or may not hire enough labor for a given time period even if they intend to.

Equation 4 is similar to the previous one except that hiring success rate does not play a role this time. Accordingly, firms can fire as many workers as they desire unless there is a legal constraint. For this reason, firing is not affected by the unemployment rate.

Equation 5 relates hiring success rate to unemployment rate. Whenever unemployment rate decreases, hiring success rate asymptotically converges to zero.The intuition behind this is that when unemployment rate is higher, the higher will be the chance to find the required amount of workers. When unemployment rate is lower, firms may not be able to find the required labor even if they intend to, or the workers they find would already be working for another firm; thus, this new hiring will not change the aggregate level of employment.

Equation 7 is about the key variable the model aims to explain; rate of change of wage rates. The idea behind this formula is that wage inflation is proportional to the bargaining power of workers and inversely proportional to the bargaining power of firms. Bargaining power of workers is assumed to be proportional to target employment, since it represents the amount of workers firms desire to have. Bargaining power of firms is assumed to be proportional to the level of unemployment. The greater the number of workers looking for a job, the more alternatives the firms would have. As a result, wage increase is proportional to the ratio of target employment to unemployment, being zero when the ratio is equal to some constant.

Formulation of target employment is not given as a differential equation because it is assumed to follow an exogenous cyclical pattern. In other words, the model takes target employment as given and determines the wage inflation accordingly. The exogenous cyclical pattern for target employment is generated in a rather unconventional way. Two different business cycles are assumed to exist in the economic system with different frequencies. The first is a shorter cycle of 7 years and the second is a longer cycle of 25 years. The numbers are chosen so as to sound reasonable and be relatively primes. Each cycle creates a 5% deviation at most from the baseline. With two different cycles having frequencies of relatively prime numbers, we can generate 7 x 25 years of non-repeating pseudo-data. Business cycles are virtually generated with sinus waves. Target employment generated according to the pseudo-cycles is given in Fig. 4.

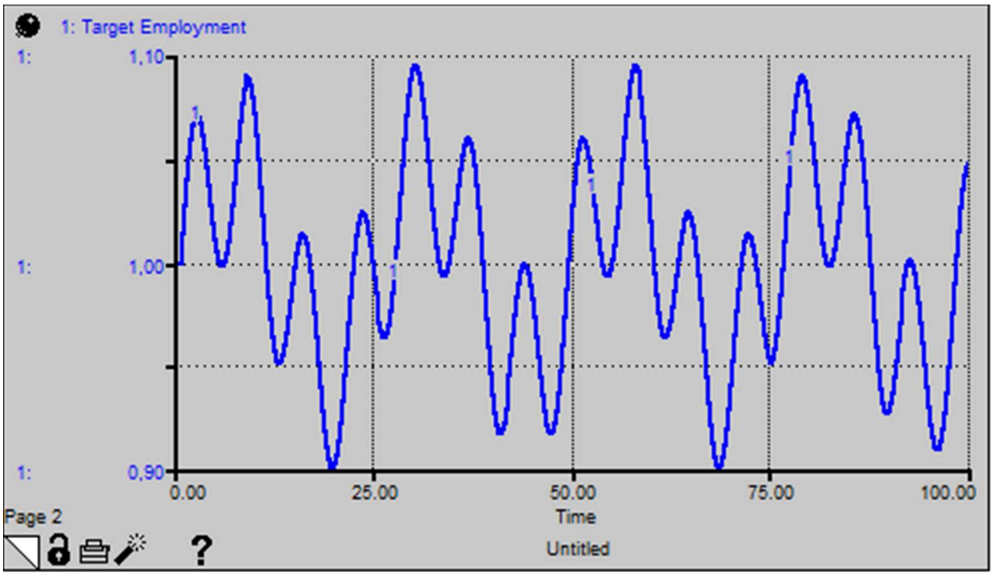

Figure 4. Target employment for 100 years

The initial values for employment and unemployment are 1 and 1/9 respectively. These initial values are consistent with 10% of unemployment rate. This unemployment rate is thenormal unemployment rate which makes wage inflation equal to zero when sustained.

5. Simulation Results

The model introduced in the previous section is simulated for 100 years. This is approximately the timespan considered in the original Phillips Curve article (Phillips, 1958). Relation between unemployment rate and rate of change of wages in the simulation result is given in Fig. 5.

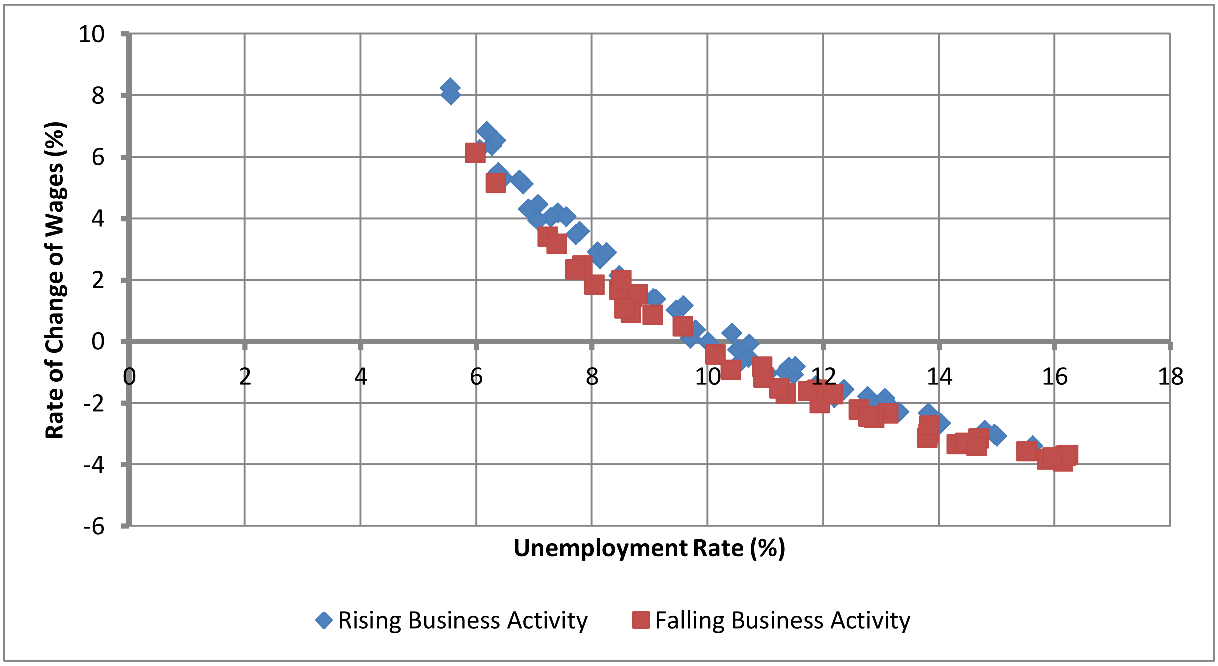

Figure 5. Relation between unemployment rate and rate of change of wages in the simulation results

Fig. 5 shows kind of a simulated Phillips Curve which resembles the empirical one. The similarity requires three important properties to note. First of all, the relation is an inverse relation parallel to the stylized fact. Accordingly, whenever unemployment rate decreases, rate of change of wages increases.

Secondly, there is a clear nonlinearity in the simulated relation similar to the original curve. This is apparent in the scatter diagram of Phillips (1958)and his interpretations. In other words, wages rise faster than they fall. Stock-flow structure given in Fig. 3 explicitly gives rise to this nonlinear behavior due to the causality beneath.

Finally, andmost importantly, the relation is asymmetric. As seen in Fig. 5, data points associated with years of rising business activity are above the ones associated with years of falling business activity. This shows that the rate of change of wages not only depends on unemployment rate, but also on the change of unemployment rate. As a result, the points along the curve do not represent equilibrium positions but are observations along an out-of-equilibrium transition.

Asymmetry in the relation is also obvious in Phillips (1958). Fig. 2 shows that yearly data moves around the curve during a cycle. Similar cyclical patterns exist for other periods as well. In each cycle, unemployment-wage increase pairs are above the average when unemployment rate is decreasing and they are below the average when unemployment rate is increasing. Simulation results of the model in Fig. 3 exhibit the same type of behavior along a cycle and Fig. 6 represents one of them.

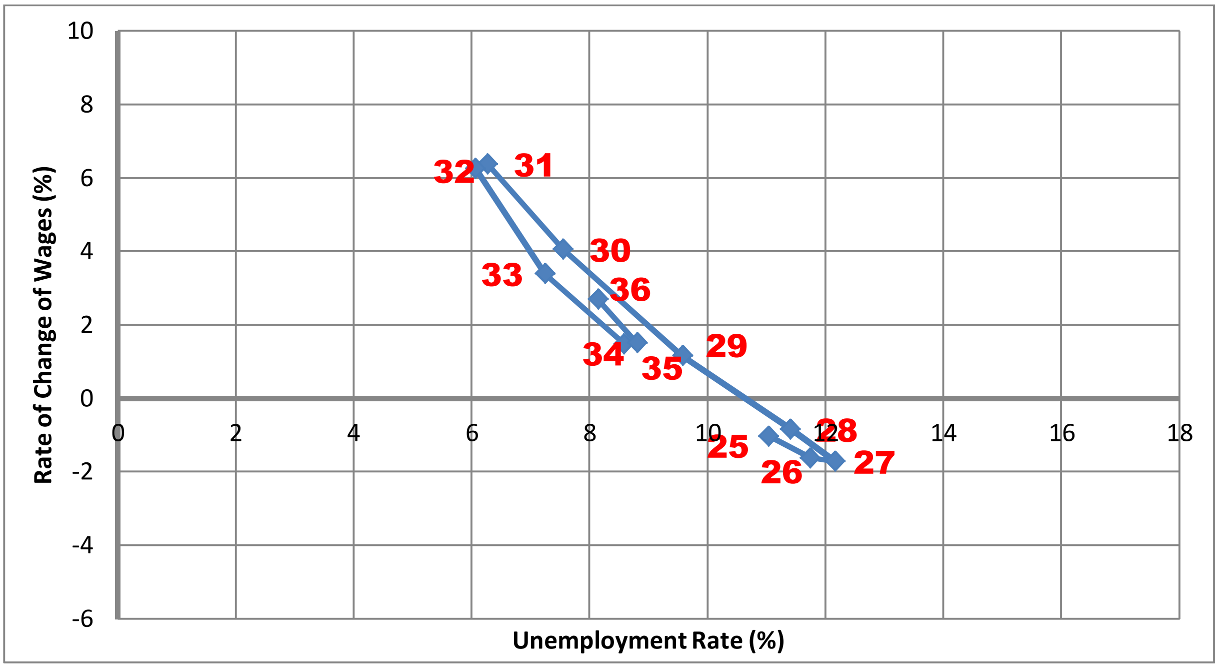

Figure 6. Simulated Phillips Curve during a cycle

Fig. 6 shows the data points for the years between 25 and 36. Economic activity rises in the years between 27 and 31, and then falls until year 35. The asymmetry in the data is similar to the one in Fig. 2. In other words, the unemployment – wage change relation is different than it would be if the unemployment rate remained unchanged.

6. Sensitivity Analyses

In this section, we analyze if the model behavior is sensitive to the parameters. Initial simulation results are given in the previous section where normal unemployment rate (n) is 10%, adjustment time (a) is 2 years and sinus wave coefficient (c) is 5%. For each of these three parameters, we consider slightly different values and check if there is a meaningful change in the model behavior.

Fig. 7 gives the simulation results for two different values of normal unemployment rate (n); 9% and 11%. Two simulations with different parameters of ‘n’ generate similar curves. Both curves show an inverse relation, nonlinearity and asymmetry.

Figure 7. Simulated Phillips Curve for different normal unemployment rates

The only difference between two cases is that the nonlinearity is more apparent when n = 9%. Phillips Curve in the left becomes almost vertical for lower values of unemployment rate. This result is consistent with our expectations since the empirical Phillips Curve given in Fig. 2 is also very nonlinear and the x-intercept of this empirical curve is much smaller, around 5%.

Other than normal unemployment rate, we also consider if the adjustment time of labor market (a) affect the model behavior. In the previous section, we assumed the adjustment time to be 2 years. For sensitivity analysis purposes, we simulate the model with adjustment time being 1.5 years and 2.5 years. Simulation results are given in Fig. 8.

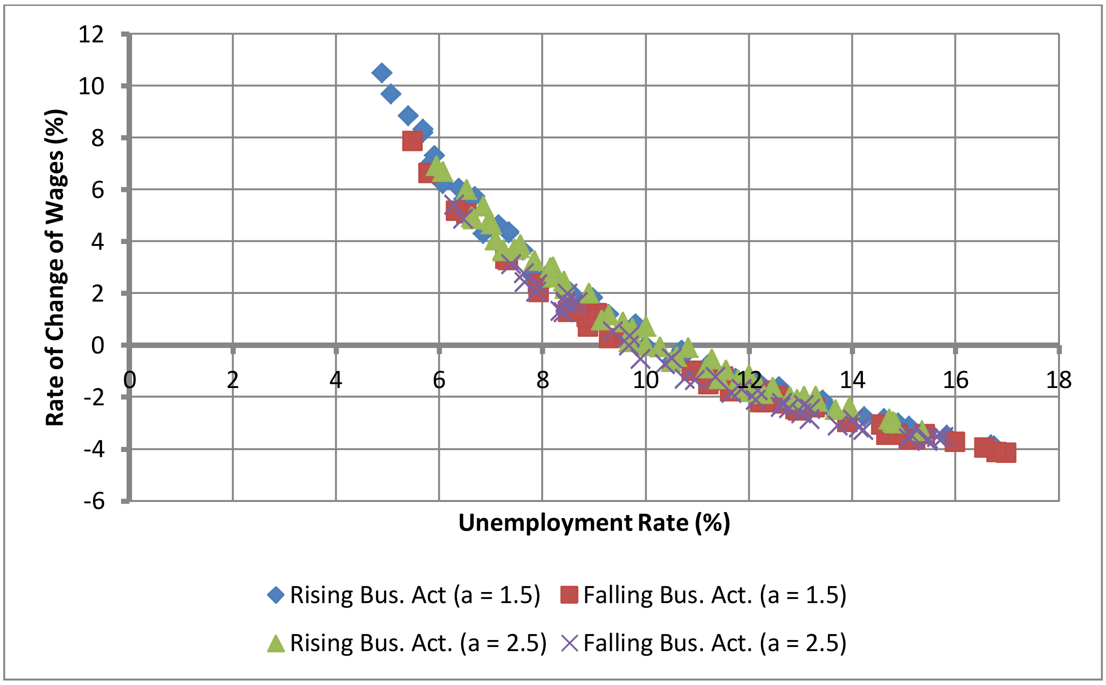

Figure 8. Simulated Phillips Curve for different adjustment times

As seen in Fig. 8, the value of adjustment time does not significantly affect the model behavior. The relation between wage inflation and unemployment rate is inverse, nonlinear and asymmetric in both cases. The only difference between two different parameter settings is that data points are more dispersed when adjustment time is smaller. This result makes sense because the adjustment process is faster when adjustment time is smaller and unemployment rate fluctuates between more distant points.

Finally, we want to see if the amplitude of the change in Target Employment affects the model behavior. In the previous section, we assumed that two sinus waves guide Target Employment exogenously, each of which affect the result at most 5%. In this section we use two different coefficients for sinus waves (c); 4% and 6%. The periods of the sinus waves remained unchanged. The simulation results are given in Fig. 9.

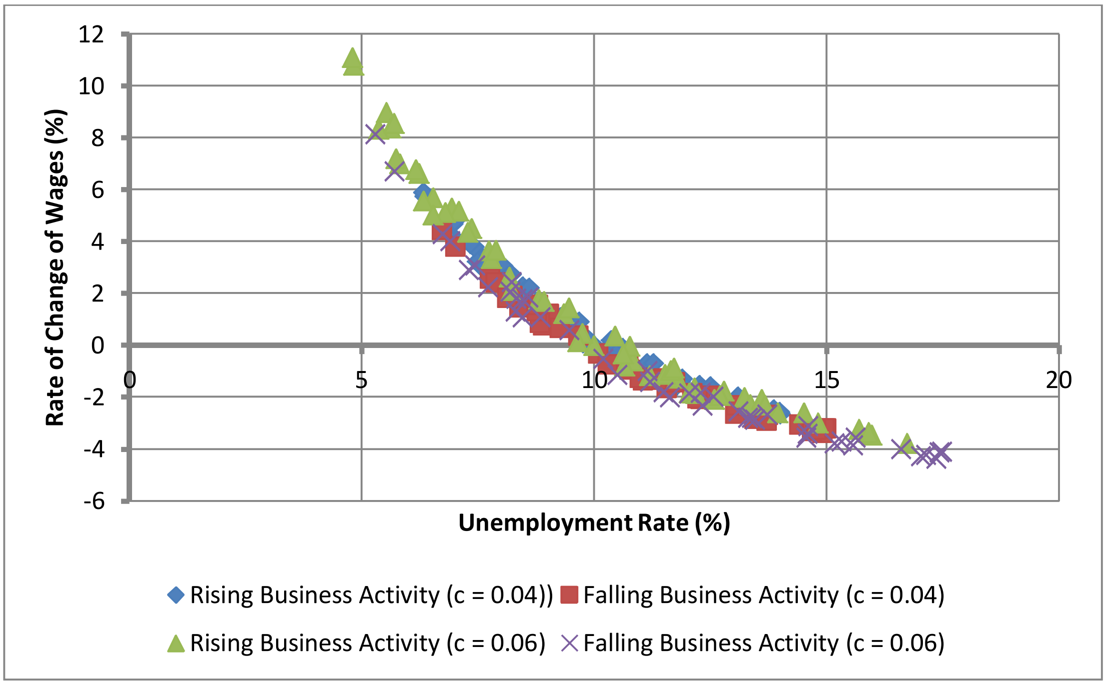

Figure 9. Simulated Phillips Curve for different sinus wave coefficients

According to the simulation results, the amplitude of sinus waves does not significantly affect model behavior. The only difference to note is that data points are more dispersed when the deviation of Target Employment from the baseline is greater. This result is similar to the case where adjustment time is smaller than the reference value.

To sum up, slight revisions of the parameters do not lead to great changes in model behavior. For different values of normal unemployment rate (n), adjustment time (a) and sinus wave coefficient (c), the model generates a similar Phillips Curve. In all cases, there is an inverse relation between unemployment rate and rate of change of wages and this relation is nonlinear. Nonlinearity is more apparent for the points with lower unemployment rates. Moreover, the data points for the periods of rising business activity are above the data points for the periods of falling business activity. This indicates an asymmetry in the relation and counter-clockwise cycles.

7. Conclusion and Discussion

In this study, we proposed a system dynamics model of the original Phillips Curve. Accordingly, wage level rises when the bargaining power of labor is greater than the bargaining power of employers and it falls when the bargaining power of labor is less than the bargaining power of employers. The bargaining power of labor is proportional to the labor demand and the bargaining power of employers is proportional to unemployment rate. For this reason, when the economic activity is rising, the demand for labor increases and the wage level becomes more than it would be otherwise. Likewise, when the economic activity is falling, the demand for labor decreases and the wage level becomes less than it would be otherwise. The change in the wage level depends not only on unemployment rate, but also on the direction of the economic activity.

According to the model, wage inflation is caused by the disequilibrium in the labor market, not the other way around. In other words, unemployment rate is the cause and wage inflation is the result. There is no reason to expect that wage inflation caused by any other factor (i.e. expectation factor) leads to a lower unemployment rate. Moreover, there is no reason to expect that a specific rate of unemployment corresponds to a specific rate of wage inflation. Thus, we cannot read the dynamic relation between unemployment rate and wage inflation as atrade-off between them.

The data given in the study of Phillips (1958)confirms this argument. In Fig. 2, the data pairs of wage inflation and unemployment generates a counter-clockwise cycle around the curve. The points are above the curve when the unemployment rate is falling and below the curve when the unemployment rate is rising. Simulation of our model generates similar results. These results are shown in Fig. 5 and Fig. 6.

The main contribution of this study is that it provides a theoretical model that supports the findings of the empirical Phillips Curve. This model truly captures the disequilibrium nature of the theory behind the study of Phillips (1958)and supports the misinterpretation arguments ofLipsey(2000)and Leeson (1997)about the Phillips Curve. Moreover, the model we provide is an example of how system dynamics methodology can be used to build disequilibrium economic models.

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