ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE
ENGINEERING AND TECHNOLOGY

SYSTEM DYNAMICS MODEL OF INFLATION

Ph.D. THESIS

Engin SANSARCI

Department of Management Engineering

Management Engineering Programme

FEBRUARY 2016

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

ENFLASYONUN SİSTEM DİNAMİĞİ MODELİ

DOKTORA TEZİ

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Engin SANSARCI, a Ph.D. student of ITU Graduate School of Science Engineering and Technology 507082003 successfully defended the thesis entitled "SYSTEM DYNAMICS MODEL OF INFLATION", which he/she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my family, and my beloved one,

FOREWORD

This study is set out to apply system dynamics principles to an economic phenomenon in order to contribute the theoretical understanding of how the economic system works.

I would like to thank Assoc. Dr. Ahmet Atıl Aşıcı, my thesis advisor, for his kind welcome at the beginning, academic support during the study, and generous patience when I was not around for a long time. I also would like to thank Prof. Dr. Ali Kerem Saysel, my co-advisor, for his advices about the model, and his supports during the set backs.

Finally, I would like to express my gratitude to my family for their love and encouragement.

February 2016 Engin SANSARCI

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ABBREVIATIONS

DSGE	: Dynamic Stochastic General Equilibrium
EU	: European Union
FED	: Federal Reserve System
GDP	: Gross Domestic Product
LSE	: London School of Economics
MONIAC	: Monetary National Income Analogue Computer
NAIRU	: Non-Accelerating Inflation Rate of Unemployment
NHS	: National Health Service
OECD	: The Organisation for Economic Co-operation and Development
QTM	: Quantity Theory of Money
SDNM	: System Dynamics National Model
UK	: United Kingdom
US	: United States

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SYSTEM DYNAMICS MODEL OF INFLATION

SUMMARY

Effect of money on output is an empirically observed phenomenon. Yet, the theoretical foundations and implications of this phenomenon is a debate in economics. In this study, System Dynamics Model of Inflation is developed in order to explain these foundations and implications based on a disequilibrium economic framework.

System dynamics is a modeling and simulation methodology which is suitable for analyzing the dynamic behavior of complex systems. In system dynamics models, systems are defined as the structural components and their interrelations. These interrelations are defined on time dimension, thus the whole system may show non-linear and unintuitive behavior.

Historically, system dynamics methodology is applied in various areas, from biological systems to social systems. Economics is also a suitable area to apply system dynamics principles for modeling, because of the complexity of the economic system structure, and the counter-intuitive behavioral observations in the system. Although there are many studies in the literature about the usage of this methodology for economic modeling, a complete system dynamics model could not be found which aims to explain the theoretical nature of the empirical relation between monetary and real economic variables.

There are several empirical observations related to the scope of this study. First, a monetary shock appears to affect economic activity and unemployment rate. This effect sustains and accumulates for more than a year. Secondly, there is a negative relation between unemployment rate and inflation rates. Finally, inflation is persistent to monetary shocks and there is a phase lag for inflation in the business cycle. These behavior patterns are all related and show that money has different effects on the real economic indicators.

Due to its ability to explain dynamic behavior of complex systems, system dynamics methodology is suitable to explore the structural reasons of these empirical regularities. However, the currently mainstream new-consensus model is not applicable in system dynamics models. Mainstream economic view is based on rational expectations and strict equilibrium assumptions, which conflicts the fundamentals of the system dynamics methodology.

Theoretical knowledge for a suitable framework can be found in the disequilibrium theories of Keynesian and Post-Keynesian schools of thought. A remarkable example is Phillips Machine, a hydraulic analog computer built by Bill Phillips in 1949, in London School of Economics. It simulates a set of differential equations of a Keynesian disequilibrium economic model. The beginning of this study is dedicated to Phillips Machine, because it is an impressive example of using system dynamics

methodology in economic modeling, and it is closely related with the purpose of this study. In this study, this machine is argued to be the first system dynamics model in the history of economics.

The study follows with a discussion chapter about different economic views and incompatibilities on the concept of equilibrium. For the first time, this historical debate is entitled as 'Time Controversy'. This discussion chapter is followed by introductory chapter, dedicated to introduce the system dynamics methodology. After that, literature review of inflation is given from a historical perspective. Finally, description of the proposed model is given, model behavior is analyzed, and validation tests are conducted.

System Dynamics Model of Inflation includes six sectors, or sub-models. Money sector explains the determination of demand-side by the circular flow of income. In the goods sector, supply-side is formulated and both sides are linked in real terms. In the price sector, pricing behavior of firms is explained. In the labor sector, employment dynamics are captured. In the wage sector, wage determination is explained by the feedback from labor sector. Finally, in the investment, investment decisions are described.

The proposed model is tested for two types of monetary shock, which are named as money shock and inflation shock. The simulation results show that, the model is able to generate the related behavior patterns similar to empirical observations. Accordingly, unemployment rate is inversely related with wage inflation, price inflation, unexpected inflation and real wage level. The simulated scatter diagrams share some properties with the empirical observations. Moreover, the model is able to generate the persistent behavior of inflation, and the phase lag between inflation and growth rate.

Depending on the parameter set, the model may generate limit cycles. These cycles share the behavioral properties of the conventional business cycles. The amplitude of this limit cycle is around 5% and the duration of cycles is approximately 4 years, for reasonable parameters.

For building confidence on the proposed model, some validation tests are applied. In the structure confirmation test, each equation in the model is evaluated for its relevance to empirical and theoretical knowledge. In the parameter confirmation test, model parameters are questioned for being empirically reasonable and theoretically consistent. In the direct extreme-condition test, model equations are hypothetically forced to extreme conditions, in order to compare the analytical results with the real life anticipations for these extreme conditions. In the dimensional consistency test, the units of the variables are questioned to be meaningful and consistent with each other. In the integration error test, the sensitivity of model behavior to the simulation step is considered and the accuracy of the integration process is questioned for validation. In the extreme condition test, model behavior is analyzed for extreme condition scenarios, which are not likely to observe in real life but theoretically possible. In the parameter sensitivity test, the sensitivity of model behavior to different parameter sets are analyzed. Finally, in the behavioral validation test, the simulation results are discussed to be consistent with empirical observations.

Model behavior shows that, labor market is the main source of economic instability. Likewise, sensitivity analysis show that, the behavior is significantly sensitive for some parameters, and the cyclic behavior is mainly the result of labor market conditions.

Specifically, when wage rates adjusts easily, the overall economic system become more unstable. As a result, governmental controls and regulations for wage determination are argued to be a reasonable policy for economic stability.

The proposed model in this study is the first system dynamics economic model which aims to explain the effect of money on output, and is the main contribution of this study. Other than that, the theoretical implications of the model behavior are also important for researchers and policy makers. Finally, the theoretical discussions about equilibrium and time controversy are scientifically valuable for the theoretical research in economics and system dynamics.

ENFLASYONUN SİSTEM DİNAMİĞİ MODELİ

ÖZET

Parasal genişlemenin ekonomik aktivite üzerindeki etkisi, ampirik olarak gözlemlenen bir olgudur. Bununla birlikte, bu olgunun teorik açıklaması ve sonuçları, iktisat literatüründe süregelen bir tartışma olmuştur. Bu çalışmada, Enflasyonun Sistem Dinamiği Modeli olarak isimlendirilen dinamik bir dengesizlik modeli sunulmuştur. Bu modelin amacı, parasal ekonomik verilerle reel ekonomik veriler arasındaki dinamik ilişkinin teorik temellerini ve sonuçlarını, denge dışı bir yapıyla açıklamaktır.

Sistem dinamiği, karmaşık sistemlerin dinamik davranışlarını açıklamaya ve analiz etmeye uygun bir modelleme ve simülasyon metodolojisidir. Sistem dinamiği modellerinde, modellenmek istenen sistemler, içerdikleri yapısal birimler ve bunlar arasındaki karşılıklı ilişkiler üzerinden tanımlanır. Bu karşılıklı ilişkiler zaman boyutunda tarif edilir, ve böylece sistemin bütününde doğrusal olmayan ve sezgilere aykırı davranışlar sergileyebilir.

Tarihsel olarak, sistem dinamiği metodolojisi biyolojik sistemlerden sosyal sistemlere kadar pek çok alana uygulanmıştır. Ekonomik sistemler de, yapısal karmaşıklık ve öngörülemeyen davranışların gözlenmesinden dolayı, sistem dinamiği prensiplerine dayanan modeller geliştirmek için uygundur. Literatürde sistem dinamiği metodolojisinin ekonomik modellerde kullanımı hakkında çok fazla çalışma olsa da, parasal ve reel ekonomik veriler arasındaki ampirik ilişkilerin teorik yapısını açıklamaya yönelik olarak kurgulanmış ve tamamlanmış bir sistem dinamiği modeline rastlanmamıştır. Bu açıdan önerilen model, bu amaç ve kapsamdaki ilk örnek olma özelliğini taşımaktadır.

Bu çalışmanın amacıyla ilişkili, ampirik olarak gözlenmiş bazı davranış kalıpları vardır. İlk olarak, parasal şokların ekonomik aktivite ve işsizlik oranı üzerinde belirgin bir etkisi olduğu görülmektedir. İkinci olarak, işsizlik oranı ile fiyat ve ücret enflasyonu arasında ters bir ilişki olduğu görülmektedir. Son olarak, enflasyon oranının parasal şoklara karşı direnç gösterdiği, ve ekonomik çevrimlerde büyüme oranlarına kıyasla bir faz gecikmesi oluştuğu gözlenmektedir. Bu davranış kalıpları birbirleriyle de ilişkilidir ve paranın reel ekonomik göstergelere farklı şekillerde etki ettiğini göstermektedir.

Sistem dinamiği, karmaşık sistemlerin dinamik davranış kalıplarını açıklayabilme yeteneğinden dolayı, ampirik verilerdeki bahsedilen davranış kalıplarının yapısal ve teorik nedenlerini açıklama konusunda uygun bir araçtır. Bununla birlikte, günümüz ana akım iktisat teorileri, sistem dinamiği modellerinde kullanılmak için uygun değildir. Çünkü ana akım iktisat, rasyonel beklentiler ve katı denge varsayımlarına dayanmakta, bu varsayımlar da sistem dinamiği metodolojisinin yapısal gereklilikleriyle belirgin biçimde çelişmektedir.

Sistem dinamiği modellerinde değişkenler, durum ve akış değişkenleri olarak tanımlanır. Akış değişkenleri, durum değişkenlerinin zamanla nasıl değiştiğini

gösterirler. Bu akış değişkenlerinin model içerisinde belirlenmesi, durum değişkenlerinin kendilerinin yerine, değişimlerinin modellenmesini gerektirir. Değişimlerin modellenmesi durumunda ise durum değişkenlerinin, değişim boyunca denge değerlerinden farklı değerler alması kaçınılmazdır. Diğer bir deyişle, sistem dinamiği modelleri doğası gereği denge-dışı modeller olmak zorundadır. Ana akım iktisatta çok temel bir varsayım olan denge varsayımı ise, ekonomik sistemin sürekli olarak bir dengede olduğunu, denge dışı durumların da yalnızca değişimin maliyetli olmasından kaynaklı bilinçli bir tercih olarak seçilmiş durumlar olduğu için yine bir çeşit denge durumu olduğunu savunmaktadır. Diğer bir deyişle, günümüz ana akım iktisat modellerinde, ekonomik ajanların faydalarını kendi kısıtları içerisinde eniyilemeyen, dolayısıyla da bu ajanlar tarafından bilinçli bir tercih olarak gerçekleşmeyen hiç bir durumun var olmasına izin verilmez. Bundan dolayı, ana akım iktisat içerisinde ileri sürülen teoriler, sistem dinamiği prensipleri içerisinde kurgulanmaya uygun teoriler değildirler.

Sistem dinamiği modellerinde kullanılmaya uygun teorik bilgilerin bulunabileceği alan, denge dışı teorilerin de yer aldığı Keynezyen ve Post-Keynezyen iktisat okullarıdır. Bu alandaki en etkileyici örnek, bir hidrolik analog bilgisayar olan Phillips Makinası'dır. Phillips Makinası, Bill Phillips tarafından 1949 yılında, London School of Economics'te tasarlanmıştır. Günümüzde bu makinanın benzerlerinden biri de, İstanbul Üniversitesi'nde bulunmaktadır.

Phillips Makinası, Keynesyen bir denge dışı ekonomi modeline tekabül eden bir diferansiyel denklemler sistemini simüle etmektedir. Bu çalışmanın ilk bölümü, hem sistem dinamiği metodolojisinin ekonomik modellerde kullanılmasıyla ilgili etkileyici bir örnek olduğu için, hem de çalışmanın teorik altyapısıyla ilişkili olduğu için, Phillips Makinası'nın tanıtılmasına ayrılmıştır. Bu çalışmada, Phillips Makinası'nın iktisat tarihindeki ilk sistem dinamiği modeli olduğu ileri sürülmüştür.

Phillips Makinası'nın tanıtıldığı giriş bölümünün ardından, denge kavramı üzerine birbirinden farklı ve uyumsuz iktisadi görüşler hakkında bir tartışma bölümü verilmiştir. İlk kez bu çalışmada, denge kavramı ve bununla ilişkili konular hakkında yapılan tartışmalar, 'Zaman İhtilafı' olarak olarak tanımlanmıştır. Bu tartışma bölümünün ardından, sistem dinamiği metodolojisinin tanıtıldığı ve ilgili literatür taramasının verildiği bölüm gelmektedir. Ardından enflasyon literatürü, tarihsel bir perspektif eşliğinde verilmiş, ve konu hakkındaki önemli noktalara değinilmiştir.

Enflasyon konusunun anlatıldığı bölümden sonra, model açıklamasının yapıldığı bölüm verilmiştir. Bu bölümde, sunulan sistem dinamiği modeli, alt modeller halinde gösterilmiş, ve açıklanmıştır. Buna göre modelde altı tane alt model vardır. Para alt modeli, Phillips Makinası'nın simüle ettiği ekonomik model baz alınarak tasarlanmıştır. Bu alt modelde, yaratılan gelirin para formunda devir daim etmesi açıklanmış, bu şekilde parasal talebin nasıl oluştuğu gösterilmiştir.

Ürün alt modelinde, reel talep ve arz arasındaki ilişki tanımlanmıştır. Arz ve talep değişkenleri birer akış şeklinde ayrı ayrı gösterilmiştir. Bu iki akış değişkeninin sürekli birbirine eşit olma zorunluluğunu ortadan kaldırmak üzere, bir envanter değişkeni tanımlanmıştır. Buna göre toplam arz envanteri artıran, toplam talep de envanteri azaltan bir akış değişkenidir.

Fiyat alt modelinde, ekonomideki genel fiyat düzeyi belirlenir. Arz edilen miktar tarafından belirlenen birim maliyet ve ortalama kar marjı üzerinden fiyat düzeyinin hedeflenen değeri belirlenir, ve fiyat düzeyi bu hedef değere belirli bir hızda yaklaşır. Fiyat düzenleme süresi, ekonomideki ürün fiyat etiketlerinin ortalama değişme süresini ifade eder, ve fiyat düzeyinin hedef değerine ne hızla yaklaştığını belirleyen parametredir.

İşgücü alt modelinde, toplam çalışan ve işsiz işgücü birer durum değişkeni olarak tanımlanmıştır. Bu durum değişkenleri arasındaki akışlar, arz-talep ilişkisi üzerinden tarif edilmekte, ve işsizlik oranını belirlemektedir. Ücret alt modelinde de, işgücü piyasasındaki değişiklikler ve işsizlik oranının, ücret düzeyini nasıl etkilediği modellenmiştir. Buna göre, işsizlik oranı düşük olduğunda ve düşmekte iken ücret düzeyi yükselmekte, yüksek olduğunda ve yükselmekte iken de ücret düzeyi düşmektedir.

Son olarak yatırım alt modeli tanımlanmıştır. Yatırım alt modelinde, yatırımların sermaye verimliliği ve talep tahmininden nasıl etkilendiği modellenmiştir. Bu alt modelde belirlenen hedeflenen parasal yatırım miktarı, ürün alt modelinde parasal talebin belirlenmesinde girdi olarak kullanılmaktadır.

Önerilen sistem dinamiği modeli, iki farklı şok uygulayarak test edilmiştir. İlk olarak sisteme tek bir defaya mahsus olmak üzere para enjekte edilmiş, ve modelin davranışı izlenmiştir. Ardından sisteme sabit bir oranda para enjekte edilmiştir. Simülasyon sonuçlarına göre, model ampirik gözlemlerdeki davranış kalıplarına benzer bir davranış sergilemektedir. Örneğin işsizlik oranı, ücret enflasyonu, fiyat enflasyonu, beklenmeyen enflasyon ve reel ücret düzeyi ile ters orantılı bir davranış sergilemektedir. Saçılım diyagramlarının özellikleri, ampirik verilerle düzenlenen grafikler ile benzerlik göstermektedir. Bununla birlikte önerilen model, enflasyondaki süreklilik davranışı ve enflasyon-büyüme oranları arasındaki faz farkını da yaratabilmektedir.

Model, kullanılan parametre kümesine göre değişkenlik gösteren limit çevrimi oluşturmaktadır. Bu çevrimler geleneksel iktisadi dalgalanmaların temel özelliklerini sergilemektedir. Makul parametre değerlerinde, çevrimlerin ortalama şiddeti %5, ve ortalama süresi 4 yıl olarak gerçekleşmektedir.

Modelin güvenirliğini belirlemek için bazı testler uygulanmıştır. Yapısal onay testinde, modeldeki her bir eşitlik ayrı ayrı ele alınmış, ve ampirik ve teorik bilgilerle ne ölçüde uyumlu olduğu irdelenmiştir. Parametre onay testinde, modelde kullanılan parametrelerin ampirik verilere kıyasla mantıklı, teorik olarak da uyumlu olup olmadıkları irdelenmiştir. Direkt aşırı durum testinde, modeldeki formülasyonlar varsayımsal olarak aşırı durumlara uyarlanmış, ve analitik sonuçlarla gerçek hayatta aşırı durumlarda gerçekleşmesini öngördüğümüz durumlar kıyaslanmıştır. Boyutsal tutarlılık testinde, değişkenlerin birimlerinin anlamlı olup olmadığı, gerçek hayatta neye tekabül ettiği, ve eşitliklerdeki birimlerin tutarlı sonuçlar verip vermediği irdelenmiştir. Parametre hassaslığı testinde, modelin davranışının farklı parametre değerlerine göre ne ölçüde hassas olduğu analiz edilmiştir. Aşırı durum testinde, modelin davranışı gerçek hayatta karşılaşılmayan fakat teorik olarak mümkün bazı aşırı durumlar için test edilmiştir. Son olarak, davranış güvenirliği testinde, simülasyon sonuçlarının ampirik gözlemlerle uyumlu olup olmadığı tartışılmıştır.

Modelin sergilediği davranışlara bakıldığında işgücü piyasasının, ekonomik değişkenliğin ana kaynağı olduğu söylenebilir. Benzer şekilde davranış hassaslık analizinin sonuçlarına bakıldığında, davranış kalıplarının bazı parametre değerlerine karşı belirgin biçimde hassaslık gösterdiği, ve çevrimsel davranışı etkileyen ana unsurun işgücü piyasası olduğu görülmektedir. Buna göre, eğer ücret düzeylerinin düzenleme süreleri kısalırsa, iktisadi sistemin bütününde istikrarsız davranış gözlenmektedir. Bu sebeple politika yapıcılara, ekonomik istikrar için, ücret düzeylerindeki ani değişimleri kontrol edecek regülasyonlar önerilmektedir.

Paranın ekonomik aktivite üzerindeki etkisini açıklamayı amaçlayan sistem dinamiği modeli, bu çalışmanın temel bilimsel katkısını oluşturmaktadır. Bununla birlikte, önerilen modelin davranışları ve bunların teorik çıkarımları, araştırmacılar ve politika yapıcılar için önemli bilgiler sunmaktadır. Son olarak, bu çalışmada denge ve zaman ihtilafı hakkında yapılan teorik tartışmalar, iktisat ve sistem dinamiği alanlarındaki teorik araşırmalara katkı sunacaktır.

1. INTRODUCTION

A remarkable paper of Phillips [1], who is also known with the famous ‘Phillips Curve’, introduces a machine, an analog computer, which simulates a set of differential equations of an economic model. It is 2 metres tall, 1.5 metres wide and a metre deep. It is an analog computer which uses colored water for calculations. The name of the computer is ‘Phillips Machine’, or The MONIAC (Monetary National Income Analogue Computer), or Phillips Hydraulic Computer, or Financephalograph. The first copy of the machine was also built by Phillips in 1949, in LSE [2].

Today there are several copies of MONIAC, some still working and some have modifications over the original one. University of Leeds, Harvard Business School, The Ford Motor Company, Science Museum of London, Reserve Bank of New Zealand and Istanbul University hold some of those copies [2]. MONIAC exhibited at the Reserve Bank of New Zealand is shown in Figure 1.1.

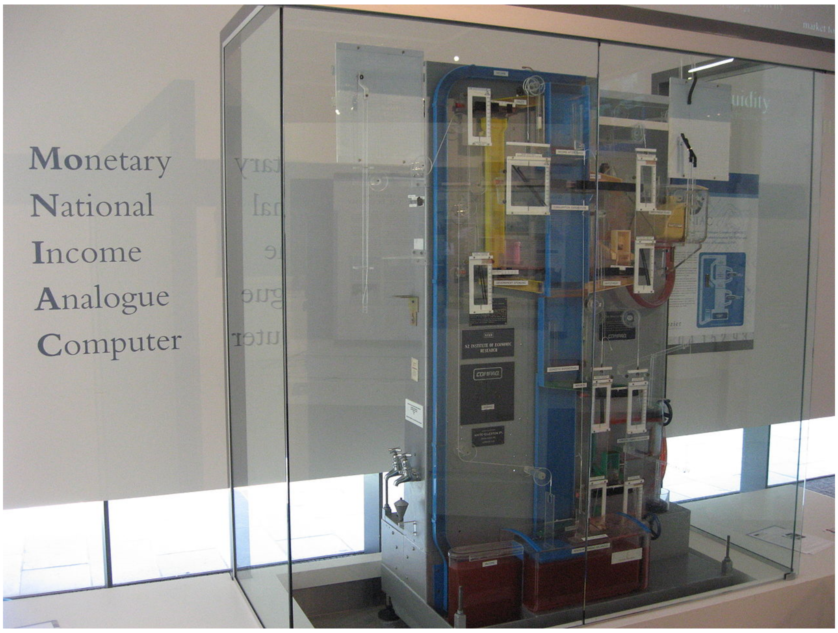

Figure 1.1 : MONIAC exhibited at the Reserve Bank of New Zealand, adopted from [2].

Phillips Machine is a revolutionary work in contemporary economics. According to Goodwin, “it took a visionary man to design and construct this unique machine” [3,

p. 118]. See Barr [4] and Dorrence [5] for a detailed history of the machine. See also Swade [6] for the importance of the machine in the history of computing.

The machine, or computer, is designed to perform some physical operations which are equivalent of a set of mathematical equations. This set of mathematical equations describes the parts of a system of equations, representing a hypothesis about an economic system as a whole. Those physical operations are the flow of colored water from one water tank to another through some pipes which are controlled by the amount of water in those tanks.

Water tanks are made of transparent plastic, which lets the observer to see the amount of water in each tank. Each water tank and pipe represents a variable in the system of interest. Seeing the change in the amount of water in tanks makes it possible to capture the dynamic interrelationship between the variables.

The flow of water between the tanks is determined by economic principles and the settings for various parameters. Different economic parameters, such as tax rates and investment rates, could be entered by setting the valves which controlled the flow of water. Users can experiment with different settings and note the effect on the outcome. The MONIAC's ability to model the subtle interaction of a number of variables made it a powerful tool for its time. When a set of parameters resulted in a viable economy the model would stabilize and the results could be read from scales. The output from the computer could also be sent to a rudimentary plotter.

The machine is unique in its kind. There are a few properties of the machine which makes it innovative. First of all, it is the first economic simulator in history. Secondly, it uses transparent tubes and colored water to dynamically visualize the amount of material or information in the model during simulation. Finally, it enables a continuous time dynamic economic analysis as opposed to discrete time static analysis.

The article of Phillips [1] describes three different models and imaginary machines based on these models. The first model is about the price mechanism of a single commodity. It demonstrates how the price evolves over time based on the production and sales of the commodity and the inventory which decouples them. The second model, on the other hand, is a macroeconomic model. It is a demand driven Keynesian model which represents the evolution of aggregate demand and output with respect to changes in money supply. The third model is an extension of the second model which incorporates fiscal policy and open economy assumptions. Although Phillips built prototypes for all models, the machine known as 'Phillips Machine' today is based on the third model. The prototype for the first two models can be called 'the early versions of Phillips Machine'.

The first model in the article shows how the production flow, consumption flow, stocks and the price of a commodity may react on one another. There is a water tank made up of transparent plastic in the model. This tank represents the goods inventory. The vertical axis of the tank represents the price. When the amount of water in the tank increases, price decreases. Model assumes that price is directly determined by the amount of inventory. Drawing of the model is given in Figure 1.2.

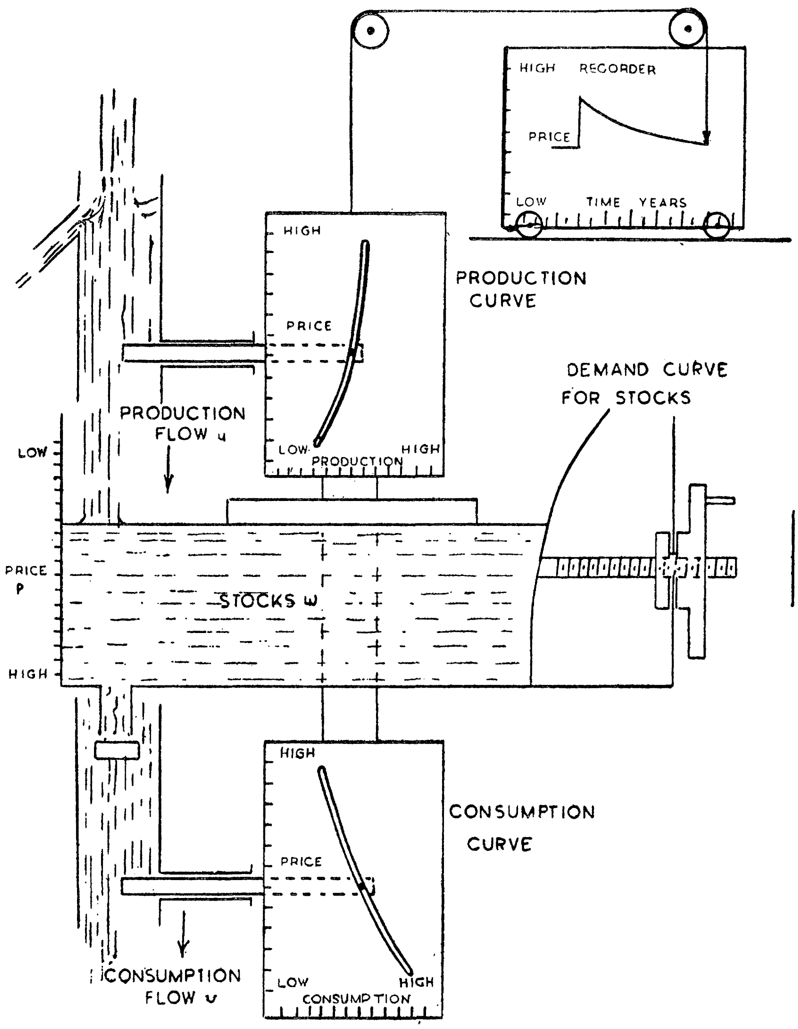

Figure 1.2 : Drawing of Model 1, adopted from [1, p. 285].

There are two flows in and out of the tank. The flow of water into the tank represents production and the flow of water out of the tank represents consumption. Both production and consumption are the functions of price. As stated before, price is determined by the level of inventory. There is an apparatus floating over the water, which moves along the level of water in the tank. This apparatus moves two flat plates, which represents production and consumption schedules in relation to price.

Assume that production and consumption are initially equal. If, for any reason, production increases, the difference between production and consumption begins to accumulate in the inventory. The level of water in the tank begins to increase gradually. Higher level of water means lower price. The increase in the level of water moves up the apparatus floating over the water and moves up the flat plates showing production and consumption schedules. Lower price means lower production and higher consumption.

The flat plates act as valves for the slots which controls inflow and outflow of water. With the help of the valves, production flow becomes lower and consumption becomes higher. These changes in the level of water in the tank, the rate of production and consumption continue until the price level reaches a value such that production and consumption for that price level are equal.

This imaginary example can be illustrated graphically. Suppose that price-inventory, consumption-price and production-price relationships are as shown graphically in Figure 1.3. Initially there are 100 units of goods in the inventory, production and consumption are equal to 100 units / time. Assume that at $t = 1$, for some reason, production curve shifts and doubles its value for any given price.

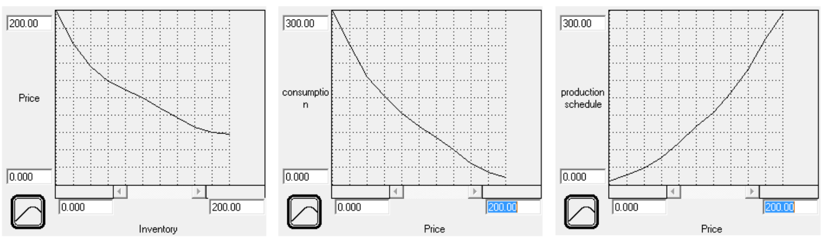

Figure 1.3 : Graphical representation of relationships between variables in the imaginary example.

The system is on equilibrium and there is no reason for that to change until $t = 1$. However, at $t = 1$, the production flow doubles and the inventory begins to increase gradually. We expect the price to gradually decrease as the excess amount of production accumulates in the inventory. After that, production and consumption are expected to change in response of the change in price. If we move along the changes in very small time steps we will get the graph shown in Figure 1.4.

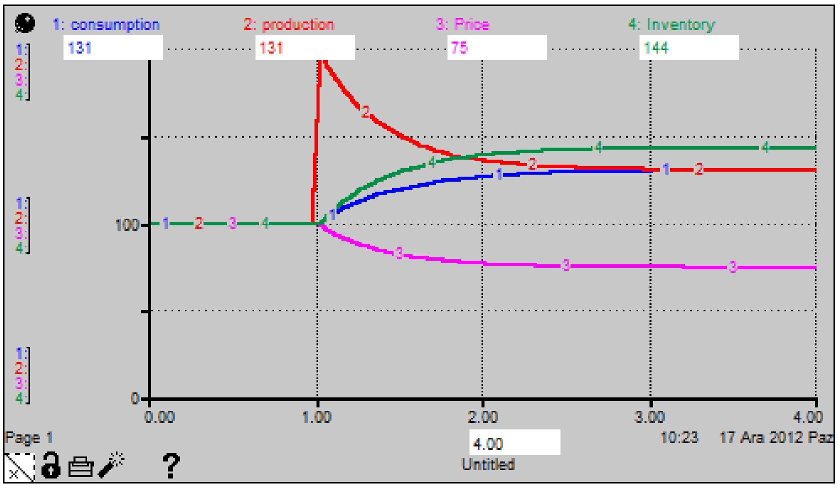

Figure 1.4 : Graphical representation of the simulation of imaginary experiment.

As seen in Figure 1.4, the system is in equilibrium until $t = 1$. At this time, production increases to 200 units / time instantly. This increase leads to a gradual increase in inventory, which is shown with a green line. Price responses to the change in inventory and begins to decrease gradually. Price continues to decrease until a level such that consumption and production become equal.

This illustrative simulation gives answer to two different questions. The first question is what the equilibrium price, consumption and production values would be after the shock at $t = 1$. The answer is that equilibrium price is 75, and equilibrium production and consumption are 131 units / time. This answer could easily be given without running the simulation (or running the machine described by Phillips). The answer is obvious in the graphs shown in Figure 1.4. We need to shift the production curve first, then embed the graph for consumption on it, and find the crossing point.

The second question is about "how" the system reaches the equilibrium state explained above. This "how" question is about "the path to the equilibrium". As seen in Figure 1.4, production and consumption move to the equilibrium level gradually, with a decreasing speed. At $t = 3.1$, they become equal. The path of the price is also similar; it reaches to the equilibrium value of 75 gradually with a decreasing speed. It takes approximately 2.1 units of time to reach the equilibrium. The path, and the time required for reaching the equilibrium were not included in the answer of the first question. We would not be able to answer this question without running the simulation (or running the machine described by Phillips). In other words, we were able to have more insights about the model by doing the simulation instead of just working with the graphs. The simulation let us see how the system evolved over time with the help of feedback mechanisms included in the model.

The properties of the model can be summarized as follows:

- Price is assumed to be a function of inventory. Price responses to the changes in inventory in the opposite way.
- Any discrepancy between production and consumption accumulates in the inventory.
- This accumulated difference leads to a change in price in a way to decrease this discrepancy.
- Price mechanism constitutes a feedback mechanism to fix the discrepancy in production and consumption
- This feedback mechanism takes time to do its job. The time required is not obvious in the production-price and consumption-price graphs.
- The feedback mechanism moves the system to a new equilibrium through a path. This path is non-linear and is not obvious in the production-price and consumption-price graphs.

The second model is given in Figure 1.5. This model is a simplified form of the famous 'Phillips Machine' and it represents an aggregate economic model for the British economy. It is a demand-driven Keynesian model where consumption and investment adds up to form expenditure. That expenditure later becomes output or income with a delay. That income is later divided into consumption and savings according to a constant saving rate.

There are two transparent water tubes in this model. The first one, $M1$, represents minimum working money balances. It is assumed to be a linear function of income;

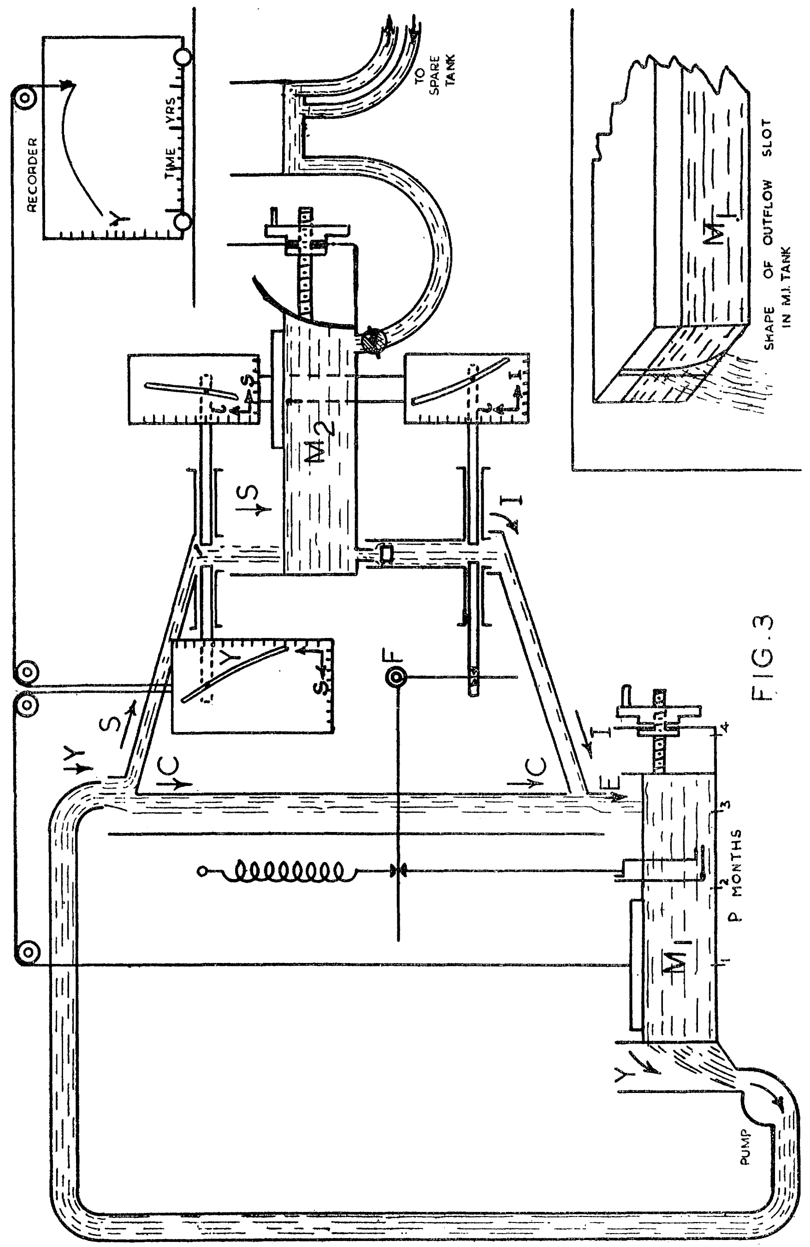

Figure 1.5 : Drawing of Model 2, adopted from [1, p. 290].

Y. $M1/Y$ thus represents the time required for the active balances to circulate once round the system, the circulation period. This period is constant because Y is directly defined to be proportional to $M1$. Y is measured as the amount of water flows out of $M1$ through a slot.

The second transparent water tube is $M2$ and it represents all money in excess of minimum working balances. Inflow to $M2$ is savings and outflow from $M2$ is investment. When income flows out of $M1$, it divides into two and the saving part feeds $M2$. The other part of income, which is consumption, merges with investment to form expenditure and fills in $M1$ again.

There is an apparatus floating over $M2$ which is connected with two flat plates. These flat plates act as valves for savings and investment and show the effect of interest rate on them. Savings is assumed to be effected positively and investment is assumed to be effected negatively with increasing interest rate. Interest rate moves to the opposite way as the amount of water in $M2$. This way savings and investment are affected by the level of water in $M2$ indirectly.

There is another flow into and out of $M2$ which represents extension and contraction of money supply and this flow is connected to a separate tank which is not shown in the drawing. If this flow is used to add water to $M2$ representing money supply extension, $M2$ starts to increase gradually. This increase decreases interest rate, decreases savings and increases investment gradually. Both the decrease in savings and increase in investment increases total expenditure which is an inflow to the other tank, $M1$.

This increase in total expenditure increases $M1$ and output gradually. According to Phillips, "[t]his lag between expenditure and income (and their real counterparts sales and output) occurs because an increase in expenditure and sales at first leads chiefly to a reduction in stocks, and must be transmitted through complex chains of intermediate transactions, some short, others very long, before it produces an equivalent increase in output and income" [1, p. 292]. The system becomes stable when savings is equal to investment and expenditure is equal to output. However, it takes time to reach that equilibrium and the time required may not be known trivially without running the simulation (running the machine). On the other hand, the path to the equilibrium may not be known trivially without running the simulation as well.

For an illustrative example, suppose $M1$ and $M2$ are 100. Output is also 100 units / time, interest rate is 5 (%5), saving rate and investment rate corresponding to this interest rate is 0.3, thus both savings and investment are 30 units / time. System is on equilibrium until $t = 3$. At $t = 3$, 50 units of new money is added to $M2$ from a separate tank in one time unit. Phillips noted that the model can either be read as real units or nominal units with the assumption of constant prices. In this illustrative example, the variables are assumed to have real values. The relationship between M2 and interest rate, interest rate and investment rate, interest rate and saving rate are given in Figure 1.6.

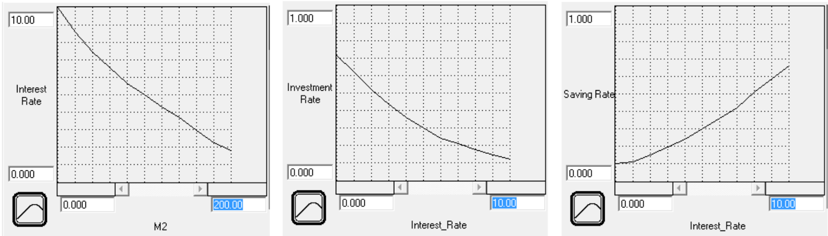

Figure 1.6 : Relationships between M2, interest rate, investment rate and saving rate in Model 2.

In this illustrative example, real money injection to $M2$ will decrease interest rate. Investment will increase due to both the increase in $M2$ and the decrease in interest rate. Saving rate is expected to decrease because of the decrease in interest rate. Total expenditure will increase due to two different factors; an increase in investment and an increase in consumption. This increase in total expenditure will result an increase in output with a delay. This increase in output will balance the decline in savings (due to the decrease in interest rate) but there is not a trivial answer to which effect on savings would be greater. In the end, we expect the system to reach equilibrium where savings is equal to investment and expenditure is equal to output. However, the time required for this equilibrium and the path to the equilibrium is unknown until we run the simulation.

Graphical representations of the simulation result are given in Figure 1.7 and Figure 1.8. When we look at Figure 1.8, we see that there is a sharp decrease in interest rate from 5 to 4.25. Then at $t = 4.45$ it starts to increase gradually to its initial level, 5. The change in interest rate continues until $t = 12.35$. In other words, it takes approximately 9.35 time units for the interest rate to reach its equilibrium.

When we look at Figure 1.7, investment starts to increase at $t = 3$ right after the injection of new money. It increases up to its equilibrium value, 45, until $t = 12.35$. Consumption gives an immediate response to this money injection as well. The output, however, response later and continues to grow until it is equal to 150. The growth of output looks like an S-shaped growth.

The behavior of savings is much more interesting. At $t = 3$, it starts to fall until $t =$ 3.85. After that, it starts to increase again, and this increase continues up to $t = 12.35$

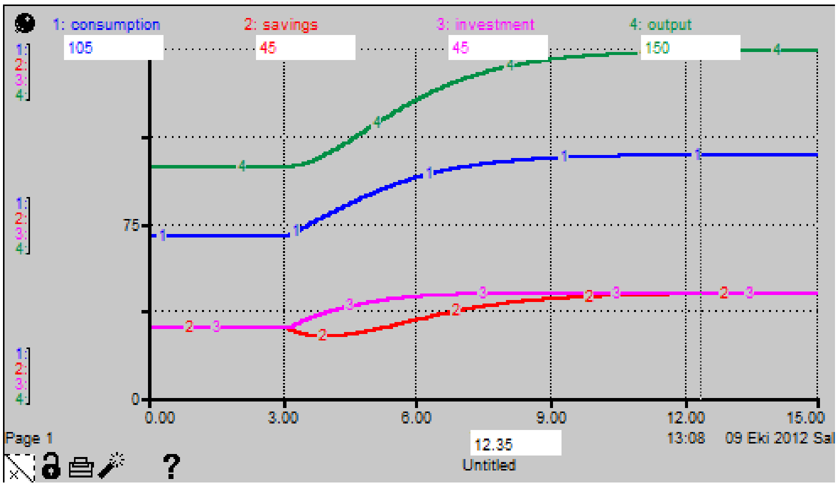

Figure 1.7 : Simulation result of consumption, savings, investment and output for Model 2.

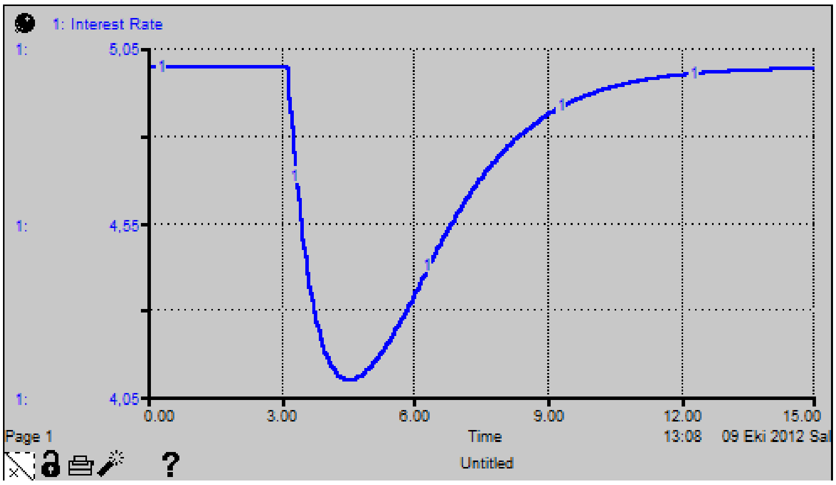

Figure 1.8 : Simulation result of interest rate for Model 2.

where it equals to 45 units / time. The initial decrease in savings happens due to the decrease in interest rate. With a lower interest rate, the benefit of savings is lower, so the households would prefer to consume more of their income. However, after the increase in output generates more income, savings starts to increase due to the income effect. We see the income effect on savings clearly in the graph where savings starts to increase at $t = 3.85$ while interest rate continues to decrease until $t = 4.45$. In other words, the effect of interest rate and effect of income works simultaneously but with different time lags.

After 9.35 time units, interest rate returns back to its initial level and the economic aggregates, output, consumption, investment and savings increase %50. The amount of real money injection creates an equal amount of economic growth. This result may seem trivial. However, the time required for this new equilibrium to be reached and the dynamic path of the variables towards equilibrium are not trivial. The dynamic paths of output, investment and savings cannot be determined intuitively or by equilibrium analysis. Interest rate effect and income effect on savings would not be separately seen by equilibrium analysis. In other words, we would not be able to get these results without running the simulation.

If we look at Figure 1.7 and Figure 1.8, we see that the sum of consumption and investment is not equal to output until $t = 12.35$. Likewise, there is a great amount of difference between savings and investment and this difference does not vanish until $t = 12.35$. At $t = 12.35$, expenditure becomes equal to output and investment becomes equal to savings. The time required for equilibrium to be reached is 9.35 time units. The lag between expenditure and income is assumed to be 1 unit of time. In order to have an analogy with real life, if the lag between expenditure and income is approximately 3 months, the time required for equilibrium would be approximately 28 months. It is obvious that this much amount of time is more than negligible.

If we accept that the amount of time required for equilibrium is not negligible, we have another important conclusion. By looking at the model with a continuous-time thinking, we can see that the money shock at $t = 3$ could have happened again at anywhere between $t = 3$ and $t = 12.35$. In that case the unintuitive and non-linear path of the variables towards the equilibrium would be interrupted and these paths would change. As a result, we can no longer accept that the model will be on equilibrium at any time. If it is reasonable to assume that the amount of time between shocks is less than the time required for reaching equilibrium, the system never experiences an equilibrium condition. It is always on a disequilibrium path evolving continuously towards an equilibrium which it will never reach at all.

This conclusion becomes stronger when there are many interconnected equilibrating dynamics working simultaneously. In that case, shocks which seem to be exogenous according to the focused sub-model can be an endogenous response through another sub-model which is interconnected to the former, and disequilibrium will be a built-in structure of the system. According to Denis:

> [T]he processes underpinning the continuity of the system as a whole may be conceived as equilibrating processes; however, the equilibrium towards which they are moving is never

> attained as other processes intervene and prevent them from running to their conclusion. The persistence of the system as a whole depends on the maintenance of these equilibrating processes, and disequilibria giving rise to them. The equilibrium which constitutes the logical terminus of each of these processes, were it ever attained, would also spell the dissolution of the system itself. In this case the equilibrium of the equilibrating processes is not how they are, but how they would be, were they to continue in isolation. Equilibrium is an abstraction, a helpful one perhaps, but not one which describes anything that exists. [7, p. 20]

The second model is important because of the time delays it includes about the economic aggregates. Expenditure creates output or income with a time delay. Phillips notes that the model incorporates only the delay between expenditure and output because that seems to be the most significant one. However, he adds, that there is a delay in reality between expenditure and output, output and income, and income and expenditure. He explains how these three delays can be included in the model if necessary. See also Machlup [8], Goodwin [9] and Metzler [10] for a detailed explanation of the delays in economic aggregates.

The third and final model represents the so-called ‘Phillips Machine’. A graphical representation is given in Figure 1.9. It is an extension of the second model described before. The extensions are about open-economy modifications and government expenditures. There are also a few more delays included in the model.

In this model, $M1$ and $M2$ tanks have the same meaning as they did in the previous model. Income is divided into taxation and income after taxation. The flow of taxation is controlled by a valve which operates through $M1$ tank. The flow of taxation accumulates in another tank smaller than $M1$ and $M2$ and this tank is drained by the flow of G, representing government expenditure. Government expenditure adds up with investment and consumption to form total expenditure flow filling into $M1$.

Income after taxation, on the other hand, accumulates in another small tank and is then divided into two as consumption and savings. As opposed to model 2, consumption is controlled by propensity-to-consume curve and interest rate – consumption curve. Savings is left as a residual.

In model 2, there is a delay between expenditure and output. Output is assumed to generate disposable income instantly. This disposable income is then divided

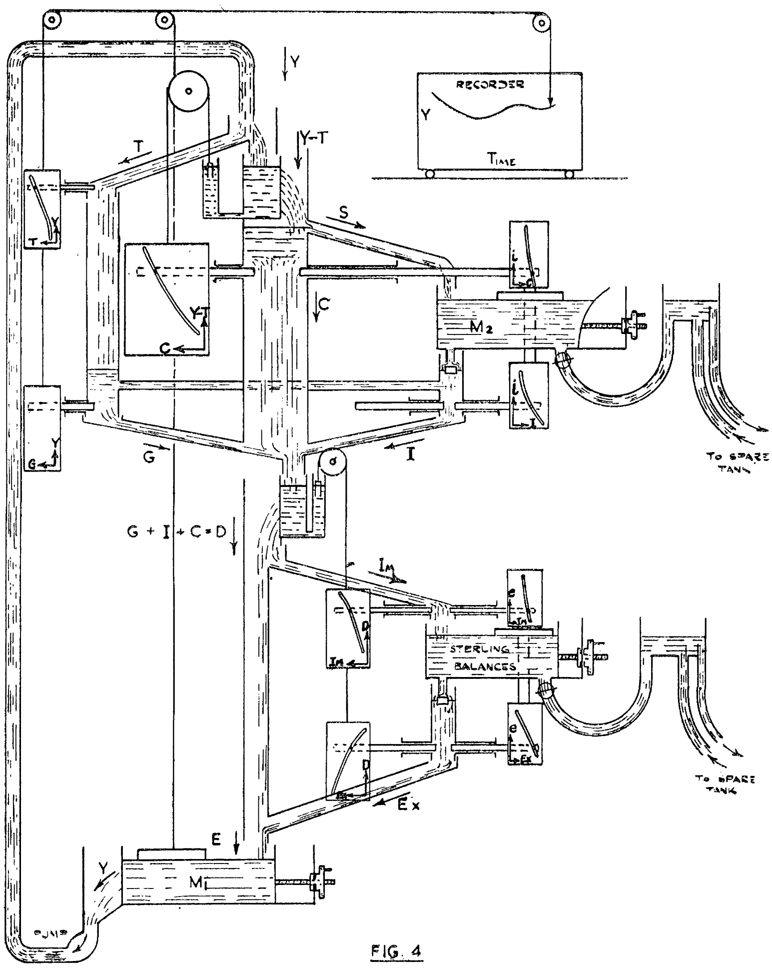

Figure 1.9 : Drawing of Model 3 , adopted from [1, p. 302].

into two as consumption and savings. There is not a delay between income and consumption. However, in model 3, there is another delay between income and consumption. The flow of income after taxation accumulates in a small tank before flowing again as consumption and savings. Thus, an increase in income leads to an increase in consumption with a delay. Phillips explains this delay as a psychological lag, representing the inertia in the changing of habits.

Another extension of the third model is the tank called 'Sterling Balances'. The level of water in this tank represents foreign holdings of the money of the home country (in this case sterling). The level of water in this tank determines exchange rate similar to $M2$ determining interest rate. Imports and exports are functions of this exchange rate determined by the level of sterling balances. Inflow from a separate tank is also possible representing the fund flow for exchange rate control.

Model 3 is the extension of Model 2 which includes fiscal policy and foreign exchange functions of the economy. There is this delay mechanism between expenditure and output similar to Model 2. In addition, there is a delay mechanism between income after taxation and consumption. Government expenditure has a stabilizing effect on income with a delay. A similar stabilizing effect is introduced into the model by foreign exchange flows. Model 3 becomes more realistic and also more complex with these extensions.

An illustrative simulation example of this broader model would be much more complex and is out of the scope of this study. However, we would draw similar conclusions from such an illustrative example as we did before. We can summarize what we learnt from the three models of Phillips as follows:

- We can represent the key concepts in an economic system with an analogy of stocks and flows of water circulating throughout the system.
- Stock-flow representation enables us to monitor the evolution of a system of differential equations over time.
- There are significant time delays in the economic system which cannot be ignored.
- Stock-flow representation enables us to include continuous-time delays directly into the model.
- The inclusion of delays directly affects the dynamic behavior of key variables in the model.
- A hydraulic simulation machine can be built to simulate the dynamic behavior of the key variables in the model.
- The simulation may give counter-intuitive results. The key variables may reach to an equilibrium value after some non-linear up's and down's, may reach an equilibrium after some damped oscillations or may not even stabilize for specific parameter combinations.
- This kind of simulation makes it possible to see not only equilibrium conditions (if it stabilizes) but also the non-linear and counter-intuitive dynamic paths of the

variables towards that equilibrium. It provides more insights about the system of interest compared to equilibrium-oriented analysis.

Perhaps the most striking point of Phillips in these models is that flow variables are decoupled through stock variables and inflows and outflows are allowed to be determined separately. The separation of expenditure and income is one example. The pre-assumed identity between expenditure and income comes from the assumption of instantaneous equilibrium in conventional economic thought. This can be called 'instantaneous market clearance'. According to this assumption, the disequilibrium in an economic system is due to random shocks and the equilibrium will be reached in a very short amount of time. For this reason, there is no need to worry about the departures from equilibrium since they are only temporary, and thinking about the equilibrium conditions is enough to understand what is going on in the system.

From the viewpoint of Phillips, this assumption is wrong. The time necessary for a disequilibrium state to vanish can be significantly large and this time can be more than enough to move the system towards a completely different equilibrium condition. Moreover, according to this way of thinking, one disequilibrium creates another, thus, the disequilibrium is itself the part of the system and not a temporary phenomenon to ignore.

Instantaneous equilibrium assumption, in a sense, is an analytical necessity to solve the game-theoretic problem of mutual interdependence. This game-theoretic approach assumes that decisions turn out to be actions in no time and they are instantaneously restrained by the consequences of them. The aim of this approach is to find the consistent plans of different economic agents which are optimal at micro level and feasible at macro level. When different types of decisions require different amounts of time to turn out to be actions, the game-theoretic framework does not work. In that case, decisions or plans of different economic agents may not be consistent with each other and this inconsistency is tolerated within the system by stocks. For example, whenever production is less than sales, the difference is tolerated by inventories, or, when someone is unemployed she can spend the previous savings. Equilibrium defines an approximated end result (or limit) which can be realized after the mechanisms are allowed to work undisturbed for a long enough time. As the models of Phillips [1] shows, this time can be too large to be ignored. In that sense, it is equilibrium, not disequilibrium, which can be defined to be an exception.

What Phillips tells in his study using three different models is by a very high degree consistent with a relatively recent scientific methodology called 'system dynamics'. This is the main reason why this dissertation begins with exploring his work. Illustrative simulations given before to show how the Phillips Machine works are prepared using a system dynamics software (STELLA 7.0.3), because the principles of a computer model and the machine built by Phillips are similar. Moreover, the arguments of Phillips are suitable for the principles of system dynamics methodology. The stock-flow representation for the digital re-make of Model 2 is given in Figure 1.10.

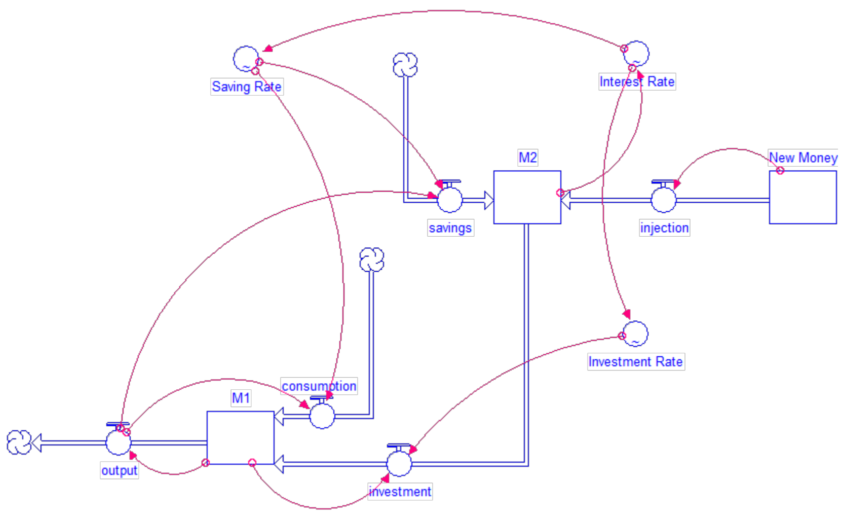

Figure 1.10 : Stock-flow representation for the digital re-make of Model 2 [1].

System dynamics is a computer-aided approach to modeling and simulation of complex systems. Socio-economic systems are also considered to be a complex system according to this methodology. Managerial, environmental, biological and medical systems are some other examples of the areas the methodology is applied to. System dynamics methodology is explained in detail in Chapter 3.

System dynamics models include stock and flow variables and link them in a logical manner such that the model creates dynamic behavior similar to the observed behavior. It is important to note that stock-flow representation is not solely about differentiating between stock and flow variables, it is also about defining how the stocks control the flows. Thus, flow variables change gradually and show inertial behavior. The links between variables create circular relationships. These circular relationships are either negative or positive feedback loops working simultaneously with different time delays. Delays play an important role in the dynamic behavior and are not ignored.

System dynamics is a suitable method for modeling problems which are complex and dynamic. Economic systems are complex because there are inter-related actions of bounded rational agents and these actions create counter-intuitive behavior. According to Joffe [11], system dynamics can help to understand how the complexity arises in economic systems. These systems are also dynamic, which means that there is an endogenous, evolving and ongoing change in the system. There are many interacting circular causation in economic systems the result of which are not trivial most of the time. For this reason, system dynamics is a suitable tool for modeling systematic problems in an economic system.

Mainstream economics has two important assumptions contradicting the principles mentioned about system dynamics. The first assumption is the equilibrium assumption. According to this assumption, economic system is always on equilibrium and the only departures from the equilibrium are because of random shocks in the system. As a result, all markets clear instantly and aggregate supply is equal to aggregate demand, labor supply is equal to labor demand and money supply is equal to money demand at all times. In other words, the famous 'invisible hand' needs no time to do its job.

However, system dynamics models are non-equilibrium models. By non-equilibrium we mean that there is no presupposition of equilibrium. Equilibrium is a special case in system dynamics models. The outcome of an equilibrium analysis should not be treated as given rules or identities in system dynamics modeling.

The second important assumption of mainstream economics is the perfect rationality assumption. According to this assumption, the individual micro agents in an economic system are perfect optimizers. They decide about consumption, labor participation and investment in order to maximize their utilities and they have this perfect knowledge about the working principles of the aggregate system. They have perfect projections into the future and the reality does not disappoint them unless there is an unpredictable random shock or the governmental decision makers lie to them.

However, according to system dynamics discipline, humans are not perfect optimizers. Instead they follow simple rule of thumbs in decision making processes. They form their decisions based on their habits which cannot be changed instantly. They adjust their habits gradually with the help of feedback mechanisms from their perceptions of the environment. Perceptions of the environment are delayed or imperfect information about the reality. As a result, humans intend to act rational by adjusting their decisions based on the feedback they receive while the delays included in the perception and habits slow down this adjustment process. This is called the bounded-rationality principle of system dynamics modeling.

It will be convenient to claim that three models proposed by Phillips are indeed system dynamics models even the name does not appear anywhere in the study. There are several reasons for these models being consistent with the principles of the methodology. First of all, the machine described in the study is the physical equivalent of a stock-flow model which can be built by any system dynamics software nowadays. The transparent water tubes and the pipes carrying water in and out of those tubes is pretty much the same with the ones visualized by the computer using a system dynamics modeling software.

Secondly, Phillips used circular relationship in his models. Circular relationships are one of the major properties of system dynamics models. They enable us to model positive and negative feedback loops. Positive feedback loops amplifies the initial effect while the negative feedback loops balance it. The final change in the system state depends on the dynamic interaction of all positive and negative feedback loops.

Finally, Phillips did not ignore the delays in the system which can have significant effects to the behavior of system variables. Delays are the key to circular relationships in system dynamics. They link the concepts of desired state and desired action on the time domain. They also help to differentiate cause and effect on the timeline and give a direction to a causal relationship.

Other than the models of Phillips being system dynamics models, we can also claim that Phillips was a system dynamicist. Arthur Brown, Chair of the Faculty of Social and Political Sciences at Cambridge University, describes Phillips with the following words: “Primarily, he was a problem-solver. In keeping with his engineering background and talents, he wanted to know how systems worked, and how they could be made to work better" [12, p. xiv]. How the systems work and how they can be made to work better are by all means a system dynamics approach.

The study of Phillips is the first in the economics literature which is consistent with system dynamics modeling. It is also worth to note that the term 'system dynamics' was not even born yet at that time. After the methodology is introduced in the scientific community by Jay Forrester in 1950's, many studies were published which uses system dynamics methodology to address economic issues.

Inflation is an important economic issue and an active research area in economics. It is defined as the increase in the overall level of prices. In the long run, this rise is believed to be a monetary phenomenon. However, in the short run, it appears to have interactions with other economic aggregates, such as GDP and unemployment rate.

In this study, System Dynamics Model of Inflation is presented. The purpose of the model is to explain how money affects output. The proposed model focuses on the dynamic interaction between inflation, unemployment rate and real economic activity. The structure of the model is expected to explain and the simulation is expected to mimic the observed behavioral patterns of inflation and other related economic variables.

An important observation about inflation is that it is negatively correlated with unemployment rate. This relation is initially shown by Phillips [13] and the relation is called Phillips Curve. Although the interpretation of this curve is changed as the profession progress, the main implications remain open for theoretical explorations.

It is also worth to note that inflation is persistent. It behaviorally shows a desire to remain constant for a while and responds to supply and demand side changes in the economic activity with a delay. For this reason monetary and fiscal actions need time to have the desired effect on inflation. The reason for this persistence is still a debate in economics which will be mentioned in detail in Chapter 4.

One of the problems to be explained about inflation is the short-run trade-off between inflation and unemployment. Mankiw [14] argues that this trade-off is still inexorable and mysterious. This trade-off is an open area for theoretical explanations.

Inflation is a suitable topic for a system dynamics modeling practice because of several reasons. First of all, there are circular causations in the system. Wage – price spiral and the effect of expectation on inflation are some examples of these circular causations. Secondly, there are significant delays in the system. Persistence in inflation is a sign of delays in the processes affecting inflation. Thirdly, inflation is multi-causal and multi-behavioral as explained before. Finally, there is no study in the literature proposing a generic system dynamics model to explain inflation.

This study focuses on the inter-connected causal structure of the economic system which creates the dynamic behavior of inflation. The main concern about the dynamic behavior of inflation is its persistence, response delay to monetary and fiscal policy changes, and its dynamic relationship with other economic variables such as GDP and unemployment. The proposed model, which aims to explain inflation, focuses on different inter-connected mechanisms regarding inflation.

This chapter started with introducing the Phillips Machine. It is a physical analog computer built by A. W. Phillips in 1949. Starting with introducing this machine is important because it directly presents the modeling concept used in this study and the motivation behind it.

Perhaps the most important topic to discuss before introducing a dynamic disequilibrium model is the time issue. Conventional definition of equilibrium is static and ignores time as an element of economic analysis. In Chapter 2, background of the issue is discussed, namely why 'time' creates such a problem and how it can be resolved.

In Chapter 3, the modeling and simulation methodology of system dynamics is introduced. First, the definition and basic concepts are given. Then, some generic structures which are used in the proposed model are explained. Finally, some examples from the literature is summarized.

In Chapter 4, current literature about inflation will be discussed. A literature review will be given by trying to maintain a chronological order in order to explain the evolution of theories. Later, the motivation to approach the problem with system dynamics methodology will be given.

In Chapter 5, the proposed model is described in sectors. The formulations and the reasoning behind is explained in detail. In this chapter, some simulation results are also presented in order to explain a part of the model partially.

In Chapter 6, model behavior is analyzed. Two experiments are designed to test the model behavior after monetary shocks. The behavior of key variables is given with the explanation of the behavior, the structural reason behind it and the consistency with empirical regularities.

In Chapter 7, some validation tests are applied. For each test, the meaning and purpose of the test is explained. Later, the results of the tests are given. Finally, the overall evaluation will be discussed.

In Chapter 8, the proposed model is analyzed for its theoretical and real life impacts. The behavior of the model for different parameter sets, and different amounts of monetary shocks is discussed. After that, conclusions and recommendations are given in Chapter 9.

2. TIME CONTROVERSY IN ECONOMICS

About 'time', Robinson says:

> 'Today' is at the front edge of time. It moves continuously forward with an ever lengthening past behind it. Any event that occurred at any date in history occurred when that date was 'today'. We attempt to understand its causes, which lay in its own past and to trace its consequences which followed in its own future. The future up to today of any event in the past has already happened. [15, p. 219]

Time, as we know it, unfolds continuously. The change in the state of a system occurs continuously as well. The future will realize itself through the accumulated motion of change which we can define for every 'now'. This motion of change regarding 'now' is related to what happened in the 'past', what is allowed to happen 'now' and what we expect to happen in 'the future'. The effect of 'past' on the change in 'now' is carried out through history in the forms of resources and inertia. What is allowed to happen 'now' both depends on the accumulated state given by history and our way of processing that accumulated state in the present (as one of the change creating actors in real life). What we expect to happen in 'the future' depends on our expectations, formed through the continuum of the history, whether biased or unbiased.

Time is the essential element in system dynamics. Without the concept of 'continuously flowing' time, system dynamics methodology means absolutely nothing. Time, on the other hand, is one of the controversial elements in economics. In that sense, the concept of time is not about a problem between economics and system dynamics; it's a problem within economics.

Why the concept of time creates so much trouble in economics? There is no single satisfying answer to this question. One of the reasons may be that economic systems are composed of many economic actors each of which has its own agenda in its unique setting which is hard to figure out precisely. Aggregating the actions of economic actors is not an easy task as well because their actions are interdependent. One agent's action of buying a product for consumption is another agent's action of selling it in order to make profit. However, that profit is also an income for another, maybe the same agent who actually bought the product in the first place. Not only the human agents in the system, but also institutions, firms, different parts of government, all have their own goals. It is like a ball of yarn which one cannot easily figure out where to start unreeling it.

2.1 Game Theoretic Approach to Equilibrium

When the actions of the agents are interdependent, it would be a reasonable way to explain 'why it is what it is'. Dual nature of the economic transactions makes this way of thinking even more reasonable. Each economic transaction has two sides (when someone buys the other sells, when someone works the other hires etc.). For this kind of activities, or transactions, to occur, each side should agree on the terms. Since each agent in the economic system has its own agenda, transactions occur only when the agendas of the agents on the different side meet. More or less, this has been the apparent evolutionary path in economic thinking.

This approach is surely game-theoretic. Equilibrium is the natural outcome of this way of thinking. The concept of equilibrium is a useful way of abstraction when there is little or no change in the state of the system and a natural 'balance' is perceived. After satisfactorily answering the first question about explaining 'why it is what it is', the economic thinking would be able to focus on another important question, a question about 'how it can be what we want it to be'. At least that should be the aim of the mankind and the scientific society. According to Hayek, "[w]e must not lose sight of the reason we are interested in the analysis of a particular economic system at a given moment of time: our purpose is to be able to proceed from a diagnosis of the existing state of affairs to a prognosis of what is likely to happen in the future" [16, p. 22].

However the economic thinking historically evolved in a different way. A progress from an abstraction about 'why it is what it is' into a set of more useful guidelines about 'how it can be what we want it to be' has not been occurred. Kaldor emphasizes this lack of progress in a very elegant way as follows:

> In terms of gradually converting an 'intellectual experiment' … into a scientific theory – in other words, into a set of theorems directly related to observable phenomena – the development of theoretical economics was one of the continual degress, not progress: the ship appears to be much further away from the shore now than it appeared to its originators in the nineteenth century. The latest theoretical models, which attempt to construct an equilibrium path through time with all prices for all periods fully determined at the start under the assumption that everyone foresees future prices correctly to eternity, require far more fundamental 'relaxations' for their applicability than was thought to be involved in the original Walrasian scheme. The process of removing the 'scaffolding,' as the saying goes, -in other words of relaxing the unreal basic assumptions – has not yet started. Indeed, the scaffolding gets thicker and more impenetrable with every successive reformulation of the theory, with growing uncertainty as to whether there is a solid building underneath. [17, pp. 1238-1239]

Why such a progress has never happened? There is no single satisfying answer to this question either. One of the reasons may be about the answer of the 'why it is what it is' question. After Adam Smith and the interpreters of his conclusions, the common belief in economics became that 'it is already at its best and there is not much thing we can do to make it even better'. The appeared answer to the 'why' question turned out to be a justification for free-market economy. Accordingly, i) everyone is already considering his/her own interest or at least we must assume that they are, ii) equilibrium is only possible when those interests meet in the market, iii) with some assumptions (about perfect rationality, perfect foreseeing ability, perfect mobility etc.) it is analytically possible that an equilibrium occurs, iv) it is also analytically possible to make this equilibrium stable with a few more assumptions (since we already observe more or less stability in real life), v) everyone maximizes their interests under this equilibrium (since that was our assumption in the first place), vi) everyone gets what they deserve (contribution to production) on equilibrium and vii) thus we should let these ground-laws to do their jobs for everyone's sake.

Kaldor asks the question about where economic theory went wrong. Then he gives his answer as follows: "In my own view, it happened when the theory of value took over the centre of the stage – which meant focusing attention on the allocative functions of markets to the exclusion of their creative functions – as an instrument for transmitting impulses to economic change" [17, p. 1240].

After the answer to the ‘why’ question left not much room for the ‘how’ question, the concept of equilibrium became the center of the theory of economics and ruled out the time dimension from the analysis. Time dimension is an essential part of an analysis in order to understand how the system works and how we can solve economic problems when they arise. According to Hayek:

> [The concept of dynamic] has indeed two altogether different meanings according as it is used in contrast to the concept of a stationary state or in contrast to the wider concept of equilibrium. When it is used in contrast to equilibrium analysis in general, it refers to an explanation of the economic process as it proceeds in time, an explanation in terms of causation which must necessarily be treated as a chain of historical sequences. What we find here is not mutual interdependence between all phenomena but a unilateral dependence of the succeeding event on the preceding one. [16, p. 17]

The ruling out of time dimension from the analysis has some consequences about the use of economic models for real life problems. First of all, when one assumes that it is all about equilibrium and not about time, then every change in the system becomes exogenous and/or temporary. When the economy runs into a recession, it is because of a negative supply shock. When there is a high unemployment, it is because the wages did not adjusted yet and we have to wait. When there is inflation, it is because the government prints too much money and private central banks should do it for them.

Secondly, we cannot trace the causal structure in the system without a time component. Equilibrium is a static condition by definition. When everything happens at the same time, we cannot know which caused which. For this reason, there is always a debate about the way of causalities in interpreting the same equalities about the ‘imaginary’ equilibrium model. For example, one may argue that inflation triggers economic growth while another may argue that inflation is the consequence of the increase in growth rates. As another example, if one believes that supply creates demand, he may propose a tax cut for the richer in order to promote supply, while another may propose a tax cut for the poorer in order to promote demand if he believes that demand creates supply. It is not possible to justify one way of thinking over the other since they lead to the same equation in the equilibrium model.

Finally, when the change in the economic system is explained by exogenous factors and we do not have a causal structure defined in terms of time, we would not be able to solve economic problems when they arise. The theory depicts that those problems are temporary and equilibrium will be maintained soon. However, the experience tells us the opposite. When there appears a recession, world-wide crises, high unemployment or inflation, economic system does not normalize itself for years as it had not in the great depression.

2.2 Allocation versus Change

Thinking the economic system as a set of mutually interdependent optimized decisions requires a static equilibrium analysis. Moreover, this type of thinking defines the aim of economic theory to explain the allocation of scarce resources. One of the objections of Kaldor to orthodox economic theory is as follows:

> [It] regards the essence of economic activities as an allocation problem – "the allocation of scarce resources among alternative uses" – to use Lord Robbins' famous definition of the subject matter of economics. This means that attention is focused on what subsidiary aspects, rather than the major aspects, of the forces in operation. The principle of substitution (as Marshall called it) or the "law of variable proportions" or of "limited substitutability" is elevated to the central principle on the basis of which both the price system and the production system are explained; and it is implied that the world is one where elasticities of substitution are all important. This approach ignores the essential complementarity between different factors of production (such as capital and labor) or different types of activities (such as that between primary, secondary, and tertiary sectors of the economy), which is far more important for an understanding of the laws of change and development of the economy than the substitution aspect. Indeed, it is, I think, the concentration on the substitution aspect, which makes "pure" equilibrium theory so lifeless and motionless: it purports to "explain" a system of market-clearing prices that are the resultant of various interactions: it cannot therefore deal with the problem of prices as signals or incentives to change. Attempts have been made to graft growth and development to equilibrium theory, but they have not succeeded in transforming it into a sequence analysis in which the course of development is dependent on the path of evolution. [18, p. 348]

As Kaldor [18] explains, orthodox economic theory focuses on "the allocation of scarce resources among alternative uses" and implicitly assumes that this allocation is handled by the system itself. There is not much we can do about it except making the markets more efficient by leaving it alone. Of course this conclusion leads to policy suggestions about privatizing governmental sectors and limiting government interventions.

This way of thinking over-emphasizes the role of static equilibrating forces which is thought to 'allocate resources'. If this way of thinking were all about the reality, we should not have any problem as we call 'economic problems'. But we do have economic problems. Moreover, not all of the economic problems are exogenously created. Business cycles, recessions, persistent high inflation, persistent high unemployment, financial crises, asset bubbles, underdevelopment, high rates of government debts, income inequality and many other socio-economic problems are examples.

Dealing with this kind of problems requires a causal structure which is defined over the time dimension. The existing economic system enables us to intervene with the economic system in the direction we desire. In order to do that, we need to know what will be the consequences of our actions and when those consequences will occur. This kind of information is only possible when we have a casual structure defined in terms of time. Phillips points out the importance of knowing the consequences and timing of those consequences after we intervene with the system as follows:

> If at a certain time unemployment is felt to be too high and short-term interest rates are lowered in order to raise the demand for goods and so for labour, how large will the effects be and when will they occur; will the higher demand also lead to an increase in fixed investment and if so how large an increase and after what interval of time; will wage rates and prices rise more rapidly as a result of the higher demand; if internal demand and prices rise will imports rise and exports fall, and if so when and by how much? If we are to assess the effects of our attempts to influence the course of economic affairs we need answers, numerical answers, to questions like these. If we do not have this knowledge the policy adjustments will almost certainly be inappropriate in magnitude or timing or both and may well cause, as I believe they have often caused in the past, unnecessary and harmful fluctuations in economic activity. [19, p. 2]

According to Goodwin [20, p 181], "it is necessary to introduce into economics both dynamical relations and general interdependence". Deriving causal structures on time dimension requires relaxing the strict definition of the term 'equilibrium'. The theories about equilibrium surely realize the internal forces of the system and not many economists completely deny their existence. What we need to realize is that the theory of general equilibrium has many unrealistic assumptions some of which should be relaxed in order to get closer to defining reality. That was what Keynes did (at least partially). Hayek explains the necessity of progressing from a static analysis of general interdependence to a dynamic analysis on real time as follows:

> The explanation of why things ever should, and under what conditions and to what extent they ever can, be expected to approximate to it, requires a different technique, that of the causal explanation of events proceeding in time. But the fact that it is probably impossible to formulate any conditions under which such a state would ever be fully realized does not destroy its value as an intellectual tool. On the contrary it seems to be a weakness of the traditional use of the concept of equilibrium that it has been confined to cases where some specious 'reality' could be claimed for it. In order to derive full advantage from this technique we must abandon every pretence that it possesses reality, in the sense that we can state the conditions under which a particular state of equilibrium would come about. Its function is simply to serve as guide to the analysis of concrete situations, showing what their relations would be under 'ideal' conditions, and so helping us to discover causes of impending changes not yet contemplated by any of the individuals concerned. [16, p. 28]

So far it is apparent that the debate about time is strictly related with the debate about equilibrium. Although the orthodox theory is strongly tied to the general equilibrium theory, many criticisms arise to the theory within economics discipline. In order to deeply understand the main components of the debate and to define the standpoint of system dynamics in this debate, we should explain different aspects of the debate.

2.3 Logical Time versus Historical Time

About logical time, Robinson says:

> In a properly specified stationary state, there is no distinction between any one day and any other. On a properly specified growth path, such as a von Neumann ray, exhibiting a particular

> pace of expansion of employment and of a specified stock of means of production, there is no movement forward or backward and downward, except the movement of the reader's eye along the curve. [15, p. 220]

The time passes as the movement of the reader's eye along such a curve is defined as 'logical time' by Robinson [15]. Logical time is an abstraction in equilibrium analysis. Using this type of time in equilibrium analysis is essential because equilibrium is defined to hold 'any time'. In other words, whenever there is a distortion in equilibrium, a new equilibrium is generated instantaneously by the internal forces of economic system. The logical time, in that sense, is only a time for us, model readers or analysts, as a way of our understanding of the equilibrating mechanisms. It does not represent a time for the model we refer to.

If a model does not include time, we cannot define a sequential order of events. As Robinson says:

> Now we are told, if price at any moment is not at the equilibrium level, it will tend towards it. This means that historical events are introduced into a timeless picture. As Professor SAMUELSON kindly explained to me, 'When a mathematician says "y rises as x falls", he is implying nothing about temporal sequences or anything different from "When x is low, y is high". [15, p 220]

What Robinson [15] implies is a contradiction about explaining a static phenomenon by defining it through historical events which are dynamic by nature. The term 'historical time' is the time we perceive as those historical events occur. Robinson [15] argues that the mechanisms of the economic system should be defined in terms of this historical time concept.

A graphical representation of logical time and historical time is given in Figure 2.1. This representation tells us that historical time has the true physical meaning of time. Logical time, on the other hand, is only an abstraction of time, an imaginary time window, which is encapsulated in a single point along the dimension of historical time.

Robinson [15] criticizes the usage of logical time concept and focuses on the consequences of this in long-run growth models. However, using logical time in short-run models has some consequences as well. Yamaguchi [21] points out the

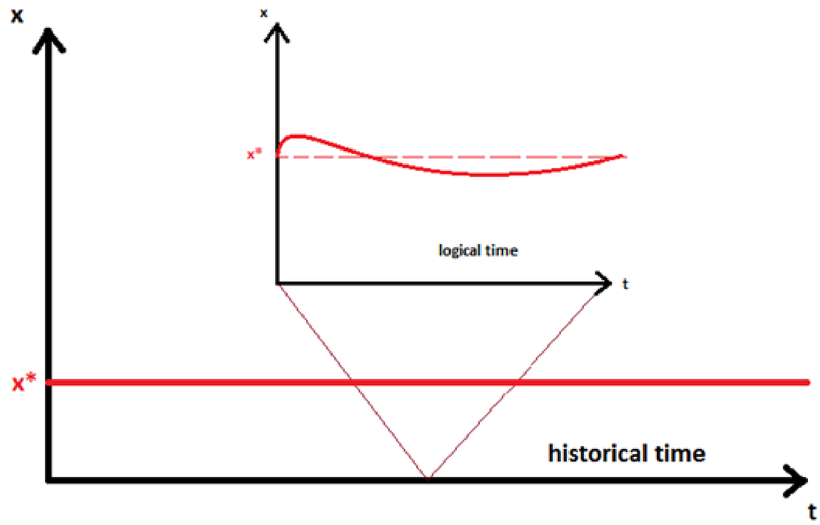

Figure 2.1 : Logical Time versus Historical Time.

differences between logical time and historical time which are apparent even in the short-run.

The difference between logical time and historical time can be illustrated with an example. There is a market game called ‘Tâtonnement Adjustment by Auctioneer’ which works in logical time. Yamaguchi explains this game as follows:

> The important rule of this market game is that no deal is made until market equilibrium is attained and buyers and sellers can make contracts of transactions. In this sense, time for adjustment is not a real time in which economic activities such as production and transactions take place, but the one needed for calculation. The time of having this nature is called *logical time* in [3]. In reality, there are very few markets that could be represented by this market except such as stock and auction markets. Even so, neoclassical school seems to cling to this framework as if it represents many real market transactions. [21, p. 6]

‘Tâtonnement Adjustment by Auctioneer’ can be represented as in Figure 2.2. In this market game, supply and demand are determined as a function of price, and the level of price is adjusted in order to make supply and demand equal to each other. The game starts with an initial value of price, and supply and demand are calculated based on this price. If, for example, demand is greater than supply, price is adjusted to a slightly higher value than before, and supply and demand are calculated based on this new value of price. The transaction does not take place until supply and demand are equal to each other. For this reason, the time required for the adjustment of price to its equilibrium value is logical time, which is only an abstraction. In other words, this time is required for only the auctioneer's calculation, not for the transactions to occur.

A similar market game can be defined in historical time. In this game, the transactions occur 'during' the adjustment, or auction. In other words, even if supply and demand are not equal for a given price, supply and demand realize at that time point as production and sales. The gradual adjustment of price occurs during these production and sales activities. This type of transactions is called 'short-side transactions'. In order to enable these transactions, there must be an inventory which decouples the actions of different sides in the game. The mechanisms of short-sided transactions can be represented as in Figure 2.3.

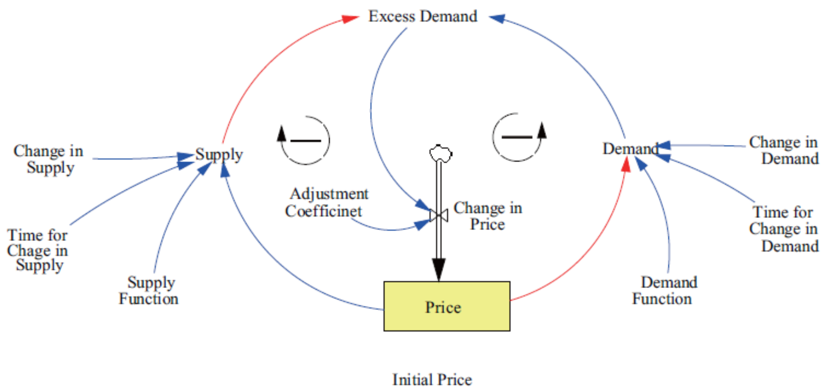

Figure 2.2 : Auctioneer's Tâtonnement Model, adopted from [21, p. 8].

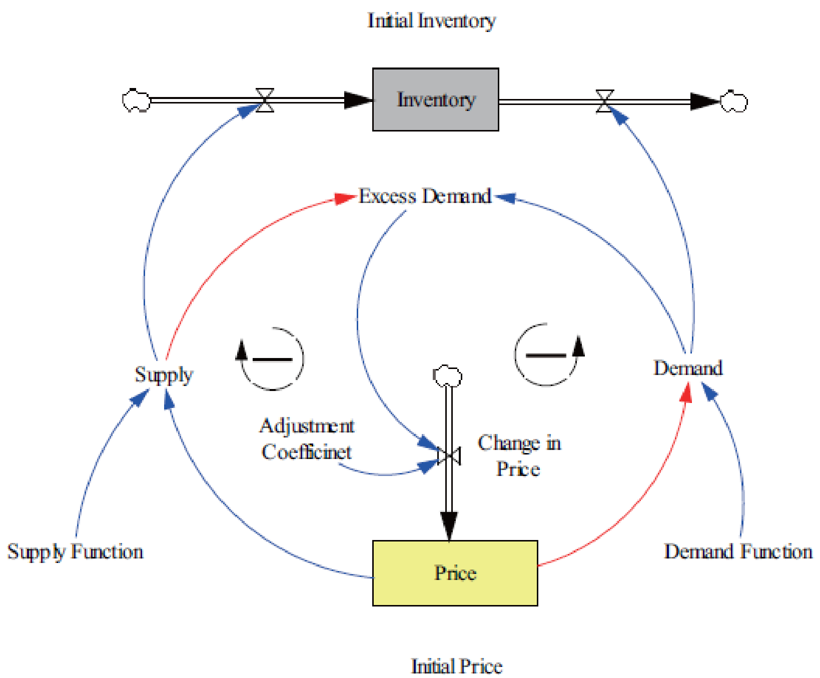

Figure 2.3 : Short-side transaction model and inventory, adopted from [21, p. 10].

Logical time represents the time window for us, as analysts and model readers, as we walk through the working mechanisms implied in an equilibrium model. The system which we refer to does not have a time component according to the theory. The challenge is to introduce the mechanisms which initially defined in this static equilibrium theory with a time component in a dynamic framework.

2.4 Equilibrium and Time Horizons

Logical time is an abstraction for modelers and model readers. Modelers need to solve the optimization problem of 'idealized' economic agents and solve the game-theoretic problem between different types of agents on the different sides of transactions. This process, searching for a pareto-optimal solution of the aggregate, requires an abstraction of time for which the modeler would able to solve the problem step-by-step or to justify its stability or validity. In that sense, logical time may be considered as a heuristic tool for the optimization procedure regarding the economic agents which are assumed to be 'perfectly rational'. The same abstraction of logical time is also necessary for the model readers so that they can understand the logic of the modeler in developing the solutions and follow its stability by their eyes through a what-if way of thinking.

The logical time necessary to use as a tool for modelers and model readers does not represent a time period in 'real time' (clock time, historical time). It is assumed to point to a specific moment in time. Thus the mechanisms we assume to work continuously in logical time are supposed to finish their works instantaneously. It is critical that representing a moment in time with the results derived in logical time is only a supposition.

One may misunderstand the aim of 'thinking in historical time' as if it only means integrating short-run and long-run. It is beyond that. Time horizons are just 'definitions' of us, which we use in determining the 'pareto-optimal' solutions in game-theoretic problems based on our concerns about the optimal behavior of economic agents. This distinction between short-run and long-run is a requirement of the tool we use.

In equilibrium analysis, we try to find the equilibrium solutions based on the 'optimal decisions' of the agents. We assume that those decisions are 'instantaneous actions' of them. Decisions (actions) of the agents generate a constraint for the other side of the transaction. We then derive the feasible decisions of the agents by defining their decisions as constraints to the others. The solution set is then called 'equilibrium'.

For example, when we use equilibrium analysis, we assume that firms decide how much to produce a certain product given a price and they hire enough labor (and raw material) for this production. Workers hired by firms bargain for a wage which is consistent both to the labor/leisure decision of the workers and the costs affordable by firms considering the price of the products. These workers receive their wages and decide to spend a portion of it for consumption. Each worker maximizes his utility function by choosing from different products based on their prices. Workers then go and buy from the products exactly the same amount the firms decided to produce in the first place. These all happen, as we assume, at the same time.

There is a logical inconsistency in this story if we look at it in historical time. Even if everything happened instantaneously, there is a circular reasoning. The consumption decision 'resulted' from an income 'cannot be a part of' the transaction which will 'lead to' that income (unless they are all determined at the same time in accordance but that is impossible in an environment with too many decision makers). The consumption decision 'resulted' from a certain income only can be a part of 'another transaction' which may result 'an equal amount of' income so that the consumption will be the same 'next time'. If such a recursive process occurs, we can say that 'the system is in a dynamic equilibrium'.

When we observe such a dynamic equilibrium, if the actions take almost no time, we may think that there is no one way causality in the system but interdependence. That would be an illusion of us, as observers who are not able to focus on the tiny moment in time. There is always, as Hayek [16, p. 3] states, "a unilateral dependence of the succeeding event on the preceding one".

To sum up, static equilibrium method uses game-theoretic approach to find the pareto-optimal solutions for optimizing agents. Circular reasoning in this method is a purposeful abstraction which is useful in this kind of framework. However, this method assumes that decisions and actions are instantaneous. Only with this assumption the method may have reliability.

When the actions take time, we get a different picture. As Keynes [22, p. 33] states, “During the lengthy process of production the business world is incurring outgoings in terms of money - paying out in money for wages and other expenses of production - in the expectation of recouping this outlay by disposing of the product for money at a later date”. This lengthy process of production is an example to an economic activity requiring time. In that sense, firms do not compare the costs and revenues of a certain production ‘event’, rather they compare the costs incurred during the production process and the revenues expected to be generated upon them at a later date. The key point is that, decisions and their consequences do not happen at the same momentary time.

Every economic action, like producing a product, hiring a worker, ordering raw materials, paying wages, acquiring relevant information, making a decision and purchasing a product, requires time for completion. Only when we focus on a time period, with a crude assumption that it represents a unique time frame, we may assume that all the economic activities happen at the same time. Then we can apply a static and game-theoretic method to find a solution for that time-frame, which may represent the reality with an acceptable error (if our assumptions about the decision rules of economic agents are valid). The time-frame should be long enough that unidirectional causalities can be approximated with instantaneous interdependence of all actions. Moreover, this time-frame should also be short enough that other forces have insignificant effects.

We have different time horizons because the method we use in equilibrium analysis, game-theoretic static analysis, requires such a simplification. Short-run and long-run distinction makes it possible to focus on the equilibrium results of economic forces which require similar amount of times to work out. This method gives us useful information about the optimal decisions of economic agents when they are in complete accordance. The cost of this method is that we ignore the effects of other forces which do not give up working.

As a result, different time horizons are our purposeful abstractions, when we cannot solve everything at once with a concern of optimization. They are not facts of the nature. We should use the information we can get from static equilibrium analysis in our interpretations of reality without ignoring the required restrictions of the method. According to Hayek [16, p. 21], “to make full use of the equilibrium concept we must abandon the pretence that it refers to something real”.

2.5 Standpoint of System Dynamics in the Debate

Whether macroeconomics should be concerned with absolute levels of variables or with the change of them is an important question. Keen asks this question and argues as follows:

> We … live in a changing – and normally growing – economy. Surely we should be concerned, not with absolute levels of variables, but with their rates of change? Should not demand and supply analysis, for instance, be in terms of the rate of change of demand, and the rate of change of supply? Should not the outcome of supply and demand analysis be the rate of change of price and quantity over time, rather than static levels? Should not macroeconomics concern itself with the rate of change of output and employment, rather than their absolute levels? [23, p. 177]

According to the mainstream economic theory, economic system is composed of rational agents each of which has a vector of decisions. These decisions are tightly coupled through market transactions. In other words, they are mutually interdependent. State of the economic system, at any time, is determined both by the objectives of the agents and the mutual interdependence of the decisions. The objectives of the agents ensure that the state is optimal at micro level and the mutual interdependence ensures that it is feasible at macro level. This outcome is called ‘market clearance’. This mechanism is assumed to work at all times. The resultant equilibrium is a static equilibrium. We represent this approach as in Figure 2.4.

However, things will be different when decisions are not just ‘decisions’. There are three such situations. First of all, the actions associated with decisions may require a significant amount of time to be completed. Production is an example. The ‘economics’ about producing a car, for example, cannot be just a binary decision (i.e.

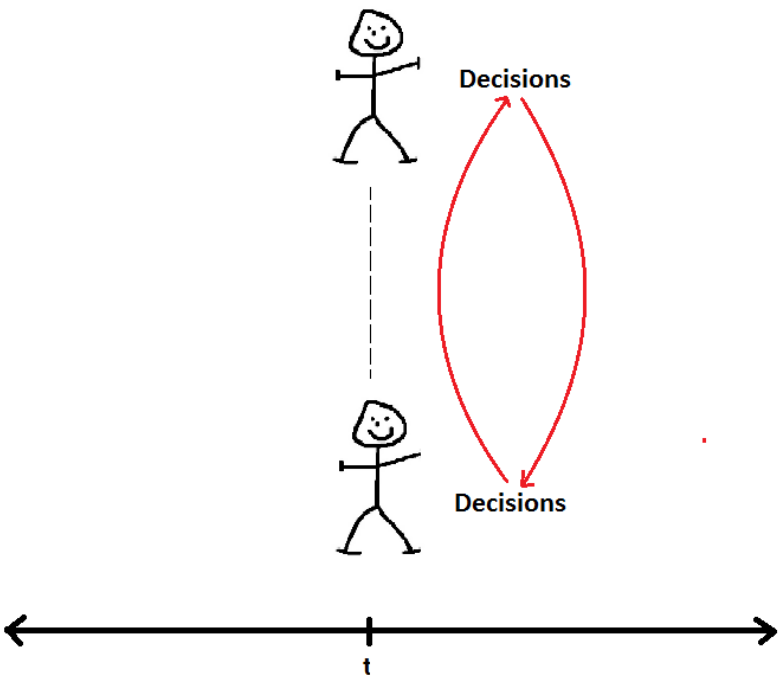

Figure 2.4 : Mutual interdependence of decisions.

to produce a car, or not to produce a car). It requires a scale and continuity through a long chain of operations and supply. Besides, it requires planning involving many different firms in the supply line. Although production is a sound example, other economic 'actions' take time as well, be it signing a wage contract, searching for a worker to employ, investing in new capital and even forming expectations.

Secondly, even if some decisions do not require a significant amount of time, it is not independent of the previous decision of the same agent. For example, consumption is mainly driven by habits. One does not usually make independent consumption decisions every time s/he goes to shopping. Decisions show a degree of continuity and smoothness in time. Expectations also show continuity and smoothness, they do not instantly jump from one level to another, at least in aggregate level.

Finally, some decisions have a precedence relation with others. As an example, hiring decision of a firm should come before production decision. Without a necessary amount of labor, firms cannot instantly decide about production. As another example, someone needs income before spending it. Expectations do not solve the problem of precedence since most of the time they are the results of past results. The nature of economic decisions is not precisely how it is represented in Figure 2.4. Figure 2.5 gives a more accurate representation.

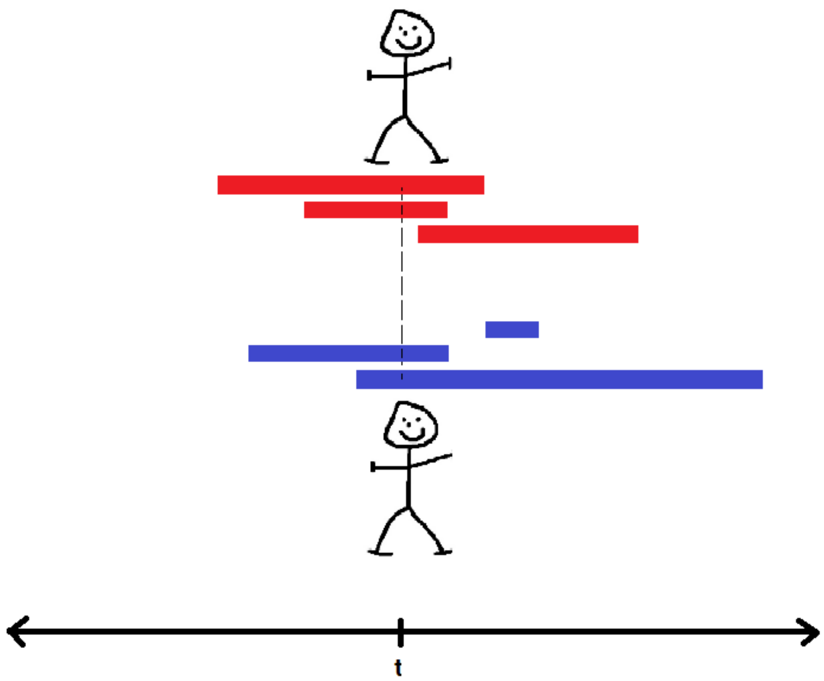

Figure 2.5 : Lengthy process of actions.

As seen in Figure 2.5, decisions are not ‘instantaneous’ by nature. The have different time lengths and they do not occur at the same time (because of the precedence relationships between them). As a result, we cannot talk about mutual interdependence on a single moment in time. Since the lengthy nature of decisions is undeniable, the static analysis accepts another assumption, which is treating a time period as a single time point. It is assumed, afterwards, that the decisions can be solved interdependently and the results can be assumed to hold on the average, during the time period. Figure 2.6 represents this assumption.

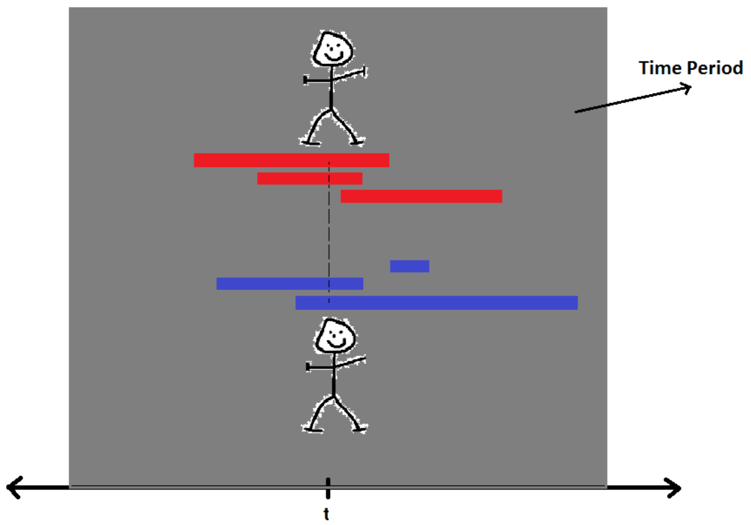

Figure 2.6 : Time period treated as a time point.

Applying static analysis to a period of time creates another problem. We get one single result and we assume that it possess reality for the given time period. We than use the data belonging to the end of the period, either the end results of the stock variables or the cumulative results of the flow variables. It is clear that the change within time period is pretty much ignored in the analysis. However, change within the time period is inevitable. This change can be an increase, a decrease or a cycle. Either way, this change is ignored by static analysis because the static analysis by nature gives a unique solution.

As an example, suppose that the average propensity to consume is %80, there is a %5 growth in the economy per year ($100 per year at the beginning and $105 per year at the end), the change in income leads to a change in consumption in one month and the initial rate of consumption is $80 / year. At the end of the year, the consumption rate will not be $84 per year because it needs one more month to adjust to the income level of $105 per year. As a result, when we measure the rate of consumption and the rate of production, we will find a rate below %80 as the average propensity to consume. In other words, we would have wrong estimates of the parameters because we ignored the change within the time period. Figure 2.7 gives a graphical representation of the phenomenon.

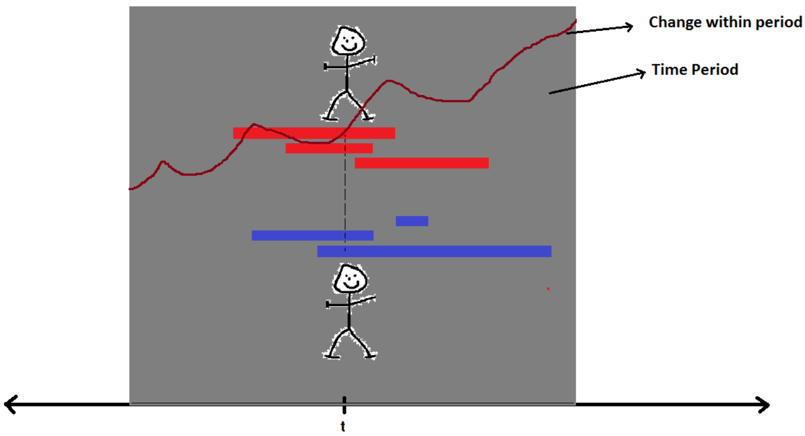

Figure 2.7 : Change within time period.

If we accept the unilateral dependence of the succeeding event on the preceding one, the relationship between economic decisions will be dynamic. In that sense, each economic decision will affect the aggregate decisions of the future while possessing a degree of continuity and smoothness in time. The new picture for decisions is seen in Figure 2.8.

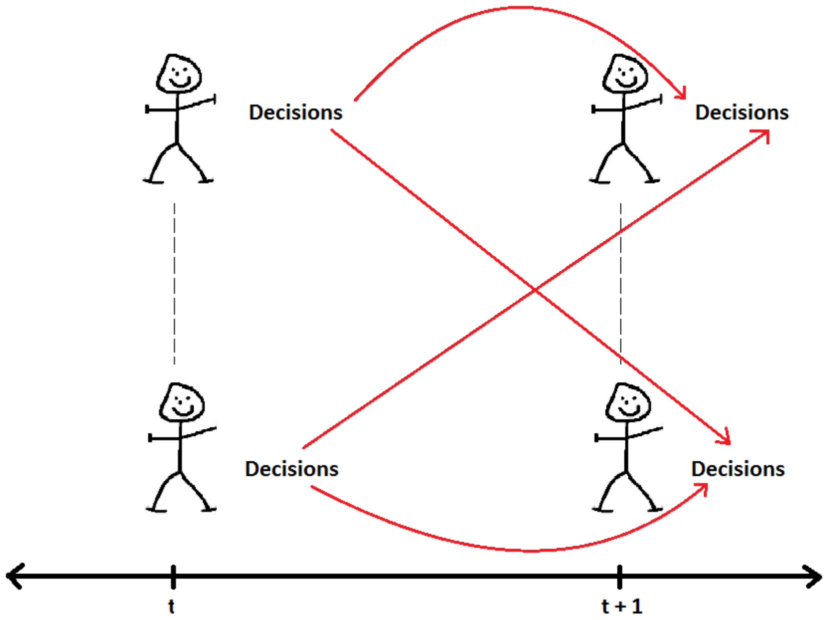

Figure 2.8 : Unilateral dependence of the succeeding decisions on the preceding ones.

The aim of system dynamics is to model a system as 'what it is', not 'what it should be under some ideal situation'. System dynamics is not a tool for 'solving an optimization problem'. It is based on 'control theory' rather than 'game theory'.

System dynamics models aims to explain dynamic phenomena with referring to historical-time, not logical-time. Analyzing a situation as if time is frozen requires a different tool for analysis. System dynamics analyzes the problematic dynamic behavior in a certain system in continuous-time.

One of the major principles of system dynamics is the 'bounded rationality' principle. Accordingly, human decision makers are not 'perfect optimizers'. They follow some rule-of-thumbs which are not necessarily irrational, but rather intendedly-rational. This intendedly-rational behavior is a rational way of behaving for humans because of the unavoidable uncertainty and complexity of the problems they face.

The results of static analysis which assumes that humans are perfect optimizers give useful information for interpreting the reality. However, these results do not represent reality. Reality is both about the laws of structure on a given moment in time and the laws of progress during time. Static analysis aims to explain the first type of laws with a cost of ignoring the other type. System dynamics does not focus deeply on the first type of laws, but aims to explain the second type of laws, which works continuously in time. For this purpose, system dynamics uses the results of static analysis as a tool for explaining the dynamic forces and the motion of the system in time.

3. SYSTEM DYNAMICS

The physical device introduced in the previous chapter uses water tanks and pipes between them to simulate a mathematical model, or a set of differential equations. It was a physical analog computer developed to simulate that model, not a digital computer, because digital computers at that time were not able to make that amount of calculation easily and the visualization properties of those computers were very limited.

However, today we have computers with a very high computational capacity and visualization properties. We don't have to build physical machines to simulate a set of mathematical equation. What we need is a methodology to mimic the idea behind Phillips Machine with computers.

The functioning of the Phillips Machine is based on the flowing mechanism of colored water through pipes between water tanks. The flow rate of water at any time was controlled by the amount of water in tanks at that time. Actually, what the machine did creatively was defining 'stocks' and 'flows' in the system of interest. That methodology is the same thing described by the discipline called 'system dynamics' found by Jay Forrester after the Phillips Machine was built.

3.1 Introduction to System Dynamics

System dynamics is a modeling methodology for explaining dynamic behavior of complex systems. Most of the time, this behavior is non-linear and counter-intuitive. For this reason, it is hard to explore the mechanisms which give rise to this non-linear and counter-intuitive behavior, without defining those mechanisms over time dimension.

The parts of complex systems are defined as stocks and flows in system dynamics. Stocks represent the value of any observable, physical or conceptual, when the time is frozen. In other words, stocks represent the snapshot values, as in the balance sheet of companies. Flows, on the other hand, represent the change in the stocks in a unit time. They are necessarily defined with a time dimension. In other words, flows represent the momentary change and when summed for a time period, they represent the change within that time period, as in the income statements of companies.

It is also a simulation technique for dynamic systems. The simulation is carried on to estimate the true behavior of the differential equation systems by the results of difference equation calculations for small time steps. As the time step gets smaller, the estimates would be more accurate.

Today it is applied to problems in a wide variety of academic disciplines, including economics. Of note is that system dynamics models often generate counter-intuitive behavior which is thought both provoking and insightful. Historically, this has caused many system dynamics models to be evaluated critically, especially by professional economists. However, today economists from several schools of economic thought are beginning to use system dynamics, as they have found it useful for incorporating their non-traditional ideas into formal models.

3.1.1 Causal links

A causal link is an arrow which states the cause and the effect and the direction of the relationship. The direction is either positive or negative assuming other influences do not change (i.e. ceteris paribus). Some examples of causal links are given in Figure 3.1.

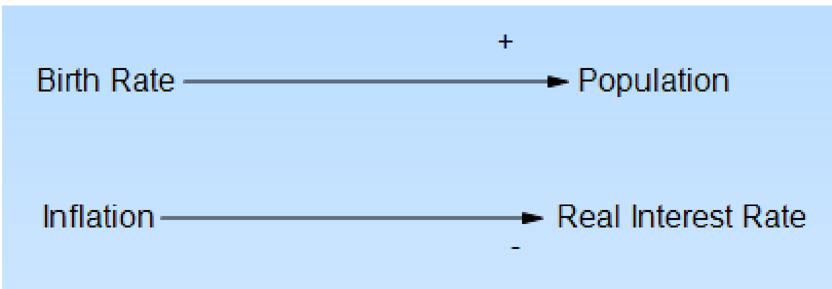

Figure 3.1 : Positive and negative causal links.

The first causal link in Figure 3.1 tells that an increase in the birth rate positively affect the population where other influences are ignored. The second causal link says that an increase in the inflation decreases real interest rate while other influences are ignored (i.e. nominal interest rate is constant). It is important to note that causal links say more than observed statistical correlation, rather it directly states the direction of the causation.

3.1.2 Stocks and flows

In system dynamics, there are stocks and flows, which are digital equivalents of the water tanks and pipes in Phillips Machine. Flows are connected to the stocks in a way to represent the real system under study. Flows are modeled to be a function of other stocks and/or flows. Stocks are accumulated (integrated) values of flows and flows are differentials of stocks. In other words, stocks are defined to have an initial value and flows are defined as functions of other stocks and flows. A stock-flow model is equivalent to a set of differential equations. Where S is stock, i is inflow and o is outflow, we can define the relationship as $S = \int (i-o)dt$. A simple stock-flow representation is given in Figure 3.2.

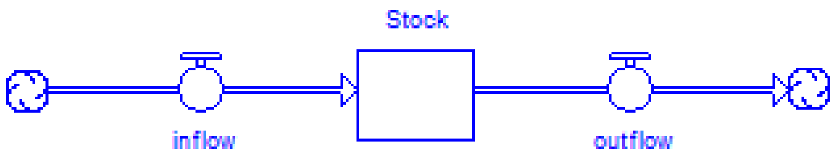

Figure 3.2 : Stock – flow representation in System Dynamics.

Radzicki defines system structure as follows:

> 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. [24, p. 728]

The simplest form of stock-flow representation is the form including one stock and two flows (one inflow and one outflow). Figure 3.3 gives an example of a stock-flow structure where inventory accumulates the difference between production and sales.

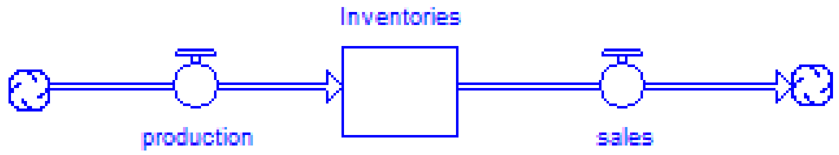

Figure 3.3 : Inventory accumulating the difference between production and sales.

Other than stocks and flows, there are also auxiliary variables in system dynamics models. Auxiliary variables are imaginary variables used as converters or as constants. An example of using auxiliary variables is represented in Figure 3.4. In this example, unit cost is assumed to be a constant and inventory value is just a converter which is equal to the multiplication of inventory and unit cost.

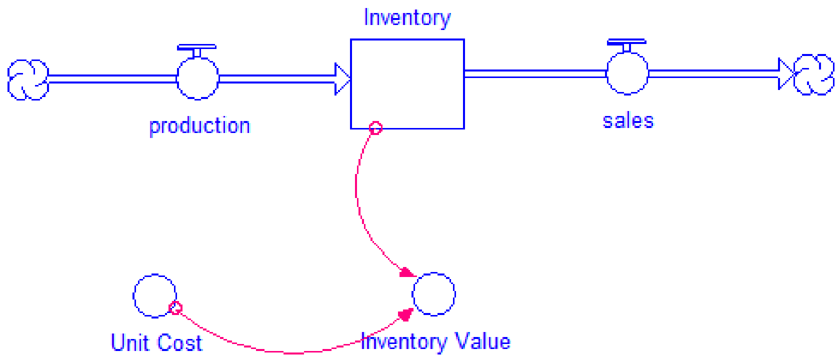

Figure 3.4 : Example of an auxiliary variable.

3.2 Generic Structures

3.2.1 Pipeline structures

A different stock-flow form is in the pipeline form where the there are two stocks following one another and flows connecting them. The unit of measure in the flows should be identical in this situation. Figure 3.5 gives an example of a pipeline.

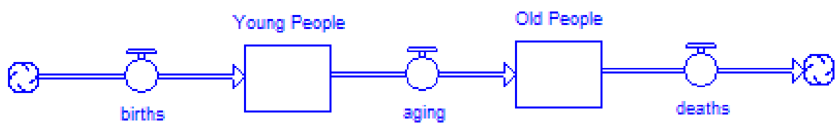

Figure 3.5 : Example of a pipeline structure.

In pipeline structures, it is common to control the flow with auxiliary variables which represents a delay. An example for using auxiliary control variables in pipeline structures is given in Figure 3.6. In this example, 'hiring' accumulates in the stock named 'Inexperienced Workers' and flows again into another stock named

'Experienced Workers' with a delay called 'Experience Gaining Time'. If, for example, experience gaining time is 24 months, the first stock is depleted with a ratio of 1/24 each month. A similar situation is also true about 'Experienced Workers'. If, for example, 'Experienced Workers Working Time' is 120 months, the second stock is depleted with a ratio of 1/120 each month.

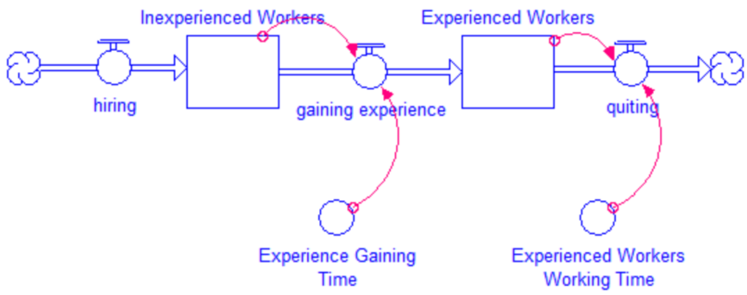

Figure 3.6 : Auxiliary delay variables controlling the flow in a pipeline.

3.2.2 Feedback loops

Radzicki defines feedback loops as follows:

> Feedback is the transmission and return of information about the amount of information or material that has accumulated in a system's stocks. Information travels from a stock back to its flow(s) either directly or indirectly, and this movement of information causes the system's faucets to open more, close a bit, close all the way, or stay in the same place. Every feedback loop has to contain at least one stock. Loops with a single stock are termed minor, while loops containing more than one stock are termed major. [24, p. 728]

Feedback loops can be either positive (reinforcing) or negative (balancing). Positive loops leads to either growth or decline. Population growth or capital depreciation at a fixed rate are examples of positive loops. Negative loops, on the other hand, helps the system to stabilize. When there are more than one feedback loop, the system generates complex behaviour. Figure 3.7 shows a model with more than one feedback loop.

3.2.3 Goal seeking structures

A special case of negative feedback loops is goal seeking structure. Negative feedback loops always try to bring the variables in that loops into equilibrium. These feedback loops may include many variables and causal links between them. In that case, the process of reaching an equilibrium state would include many chains of relations.

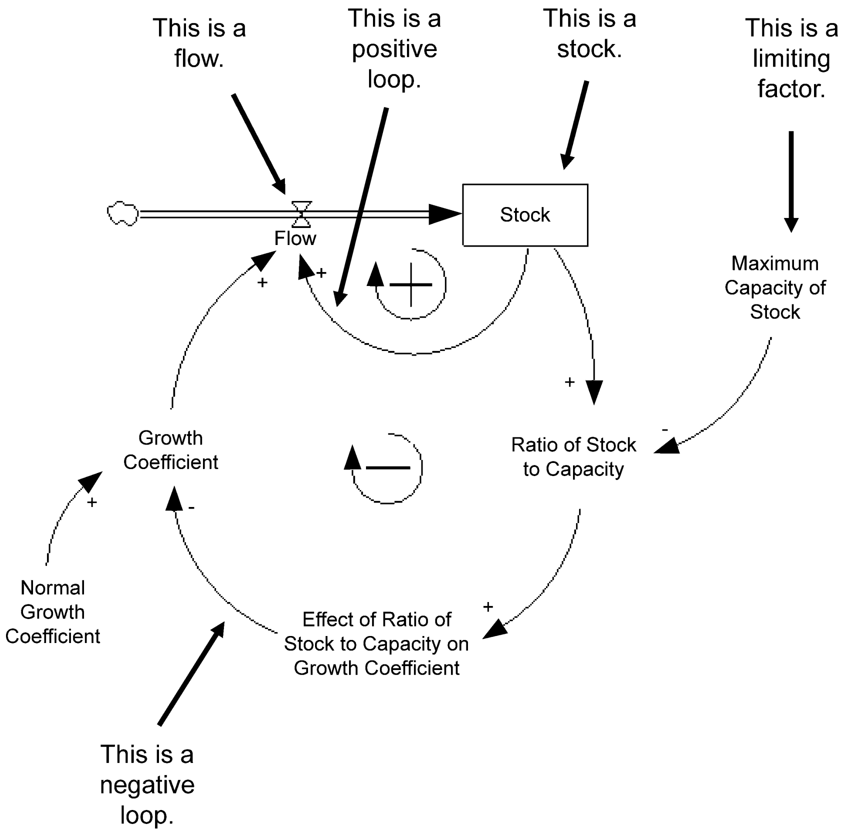

Figure 3.7 : An example containing more than one feedback loop, adopted from [24, p. 729].

However, the scope of the model may not be about all these variables and chains of relations but only one critical variable. In that case, it would be practical to skip those chains of relations which are out of the scope of the model and focus on the path of one critical variable towards its equilibrium. Goal seeking or target seeking structures are suitable for this purpose. If there is a practical way to determine the equilibrium value of the variable of interest, then the modeler may just formulate the change in this variable as if it is following this target value with a delay.

It is a very common practice to use the term ‘target’ or ‘desired’ in order to represent the goal of the variable. An example is given in Figure 3.8. In this example, the average nominal wages in an economy is represented as a stock variable. ‘Target Nominal Wage’ is the goal level of the stock. ‘Average Wage Contract Duration’ represents the time delay of the goal seeking behavior.

It is worth to note the meaning of ‘Target Nominal Wage’. Workers in an economic system make wage contracts with their employer and update the nominal wage in the contract after a period of time. Moreover, not all workers update their contracts at the

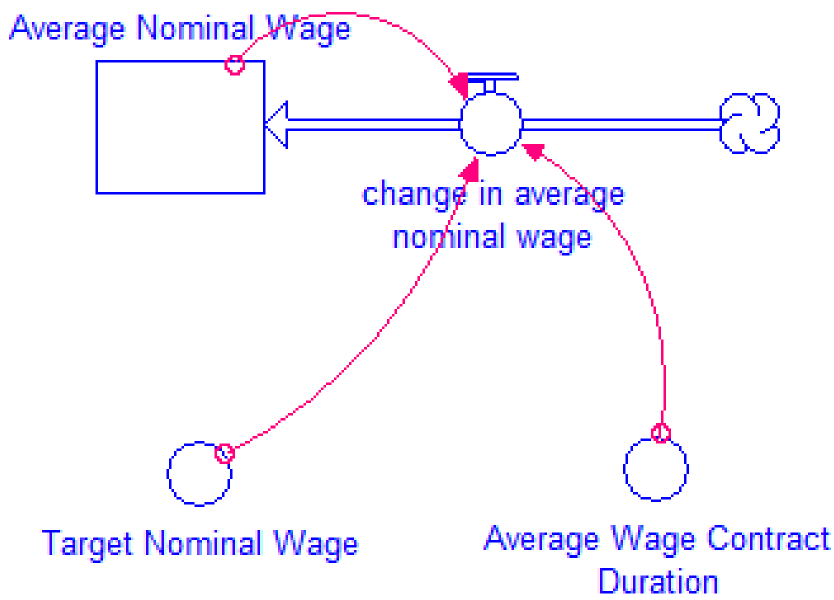

Figure 3.8 : Example of goal seeking structure.

same time. In this case, the value of ‘Target Nominal Wage’ at any instant would be the nominal wage of a worker (an average worker with an average wage) who just signed a wage contract.

All the other workers have outstanding wage contracts and the stock variable called ‘Average Nominal Wage’ represents the average of those outstanding wage contracts. This stock variable is adjusted with a time delay called ‘Average Wage Contract Duration’. If the contract duration is, let’s say, 12 months, the gap between ‘Average Nominal Wage’ and ‘Target Nominal Wage’ will be closed by a ratio of 1/12 at each month. Assuming the values of ‘Target Nominal Wage’ and ‘Average Wage Contract Duration’ do not change (for simplicity), the dynamic behavior of the stock would be a goal seeking behavior. This behavior is represented in Figure 3.9.

Another important point to note about goal seeking structures is the determination of target, or desired values. The gradual adjustment process of the stock variable is not related with the determination of target values. The formulation of this target value is an assumption, or a hypothesis about the underlying mechanism which is skipped for simplicity. For the example just mentioned, ‘Target Nominal Wage’ may be a function of price level, unemployment rate, labor productivity or any other related variable in the economic system. The adjustment process of the stock, however, is always the

Figure 3.9 : Graphical representation of goal seeking behavior.

same. The gap between the actual and the target is eliminated with a ratio, the ratio being the inverse of the delay associated with the goal seeking structure.

3.3 System Dynamics Literature

Jay Forrester is the founder of system dynamics methodology. *Industrial Dynamics* [25] is the first book of Forrester in the field and he analyses how the business cycles occur. After that, Forrester wrote his second book, *Urban Dynamics* [26], about a model for urban planning. Then came *World Dynamics* [27], in which he analyses economy, population and the resources of the world together. Later, Meadows et al. [28] wrote *Limits to Growth* and extend the previous work with *World3* model. These four books are major examples in system dynamics field.

System dynamics is later used in many different disciplines. For studies of system dynamics in business strategy see Gold [29], Snabe and Größler [30], Qureshi [31], Gary et al. [32], Suryani et al. [33] and Größler [34]. For examples of system dynamics models in supply chain management see Schwaninger and Vrhovec [35]. For environmental problems see Vogstad [36] and Winz et al. (2009). System dynamics modeling in biomedical engineering and related fields is recent but growing area of research. See İncioğlu [37] and Hirsch et al. [38] for examples. For an example in project management, see Mashavekhi [39], for accounting see Melse [40], for energy see Ford [41] and for climate modeling see Sterman et al. [42].

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 counter-intuitive behavior. Moreover, aggregate behavior, feedback mechanisms and time delays also make these systems suitable for system dynamics approach.

It will be convenient to state that the first system dynamics modeling study in economics is the study of Phillips [1]. This study is analyzed in detail in Chapter 1. Phillips never uses the phrase 'system dynamics' because it was not born yet at that time. However, the modeling principles of Phillips are consistent with system dynamics by all means.

Another earlier study about system dynamics in economics belongs to Jay Forrester [43]. The main argument in this study is the usefulness of the mental data which is available in people's mind. The author gives the results of his model, SDNM (System Dynamics National Model), to be a basis for his arguments. According to the Forrester [43], the mental database stores a great amount of knowledge about the structures of systems, how the systems are organized with its parts, and how the parts are connected to each other within the system. Information sources for system dynamics models are given in Figure 3.10.

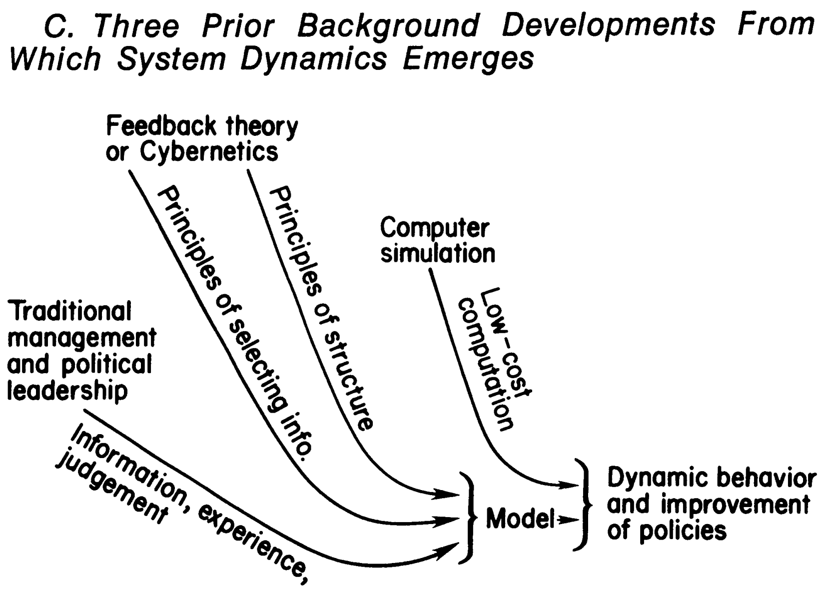

Figure 3.10 : Information sources for system dynamics models, adopted from [43, p. 559].

Principles of integrating system dynamics into economic modeling is given by Smith and Ackere [44]. According to the author, "the policy maker is often interested not only in the equilibrium predictions arising from an economic model, but also in the path taken by policy variables as they move towards that equilibrium" [44, p. 1]. He argues that system dynamics approach is consistent with traditional economic approaches but it uses different terminology. Negative feedback concept in system dynamics is consistent with the equilibrium concept in economics, and positive feedback stands for instability. In the study, the author introduces the problem of the supply-demand relationship for the case of routine non-emergency surgery in the UK National Health Service (NHS). He uses system dynamics approach for modeling the problem.

Atkinson [45], on the other hand, gives the common grounds for institutional economics and system dynamics approach. Firstly, he summarizes the basic differences between institutional view and orthodox view of economics. After that, he argues that the essentials of institutional economics exist in the system dynamics methodology.

Bueno [46] applies control theory and system dynamics approach to the stabilization policy debate. He summarizes the common believes about the short and long run economic movements and mentions that he agrees all of them but defends the control theory approach against game-theoretic approach considering the stabilization problem. He highlights the importance of inventory cycles for understanding the cyclic pattern in economic data and base his ideas on the very early studies of Phillips [47,48]. He concludes that delays in the capital goods industry supply line should not be ignored in the inflationary stabilization models.

Nichols et al. [49] discuss the circular and cumulative structure of administered pricing. The authors criticize the neo-classic view of pricing as a result of the profit maximization. Finally they summarize the dynamics of mark-up pricing and the essentials of system dynamics modeling of pricing.

The study of Wheat [50] discusses the effectiveness of the feedback method of teaching macroeconomics. The author describes the feedback method of teaching macroeconomics using causal loop diagrams and interactive computer simulation models and explains the tests showing its effectiveness (learning performances of students of economics). The model mentioned in the study is the so-called 'MacroLab', a system dynamics model of US economy, used in the undergraduate macroeconomics courses, in the University of Bergen, Norway.

Radzicki [24], in his study, explains the contribution of system dynamics approach to economics and economic modeling. The study gives information about translating the existing economic models to system dynamics format (stock-flow consistent equivalent). The author argues that it is possible to improve existing economic models with system dynamics approach and finally gives the guidelines of creating dynamic economic models from scratch.

A noticeable study Yamaguchi [51], is about debt-free money system. The study begins with a critique of the existing central banking system. According to the author, the government debt is structurally built in the current macroeconomic system of money as debt which is founded by the Keynesian macroeconomic framework, and it is very costly to reduce it. Then he introduces the system of debt-free money that is proposed by the American Monetary Act. In this system, the government has direct control over the issue of money. Based on the output of the system dynamics model, the author argues that government debt can be gradually eliminated in the proposed system. Moreover, the change in the monetary system will, according to Yamaguchi, lead to higher economic growth and better income distribution.

System dynamics has been applied to many economic problems other than the ones mentioned above. See Senge [52] for a system dynamics investment model. See Forrester [53] for a dynamic synthesis of basic macroeconomic theory in system dynamics language. For a monetary policy application, see Machuca [54]. For an economic development system dynamics model with endogenous capital accumulation, see Harvey and Klopfenstein [55]. For a discussion of bounded rationality, see Größler [56]. For a system dynamics study about the human development together with economic development, see Qureshi [57]. Finally, for a more generic economic model, see Forrester [58].

4. INFLATION

4.1 Definition

In economics, inflation is a sustained increase in the overall level of prices. It is measured as the percentage change in a price index and reflects the average change of prices of different goods and services in an economy. Inflation is costly for several reasons, either directly or indirectly. Direct costs are the price adjustment costs, also called ‘menu costs’ and cost of living with short money balances, also called ‘shoe leather costs’. Indirect costs are social costs due to worsened income distribution and reduced economic planning ability due to inflation and price uncertainty.

Besides, low but positive inflation is usually preferred. Especially after recessions, low but positive inflation helps the labor market to adjust new equilibrium. Moreover, it also reduces the risk of liquidity trap [59].

Due to the economic and social costs and risks of hyperinflation and deflation, inflation is desired to be kept at low levels. This is called price stability and is usually the primary objective of central banks. In order to maintain price stability, the dynamics of the phenomenon should be understood perfectly. The knowledge about the dynamics of inflation has been evolving for decades. Understanding this evolution is important to capture the current state of knowledge about inflation.

4.2 Historical Background

There are two milestones in the theory of inflation: i) Phillips Curve and ii) Lucas’ Critique. Before the introduction of Phillips Curve in 1960’s [13], there were 4 basic types of explanations for inflation:

- Cost – push inflation
- Demand – pull inflation

- Wage – price spiral
- Quantity theory of money

Cost-push inflation occurs when an increase in the prices of inputs leads to an increase in the prices of goods and services. Demand-pull inflation, on the other hand, occurs when aggregate demand exceeds aggregate supply. When these two feed each other, a wage-price spiral may occur.

Quantity theory of money (QTM) is a monetarist explanation of inflation. According to the theory, money supply directly determines the price level. In other words, money is neutral and does not affect output. Economists usually agree that this theory holds at least in the long run. For more information about QTM, see Fisher [60] and Friedman [61].

Different schools of thought have different explanation to the phenomenon. Although it is commonly accepted that all of the factors (cost-push factors, demand-pull factors, wage-price spiral and QTM) have an influence on the inflation, the debate is about which of them is the dominant one and in what way determines the inflation. Moreover, the proposed solutions also vary between different schools of thought. While mainstream economists propose to control the money supply, heterodox economists propose a combination of alternative policies (fiscal policy, currency control, direct control on wages and factor prices etc.).

Post-Keynesian school of thought is distinguished from other schools of thought after 1975 by Eichner and Kregel [62]. Post-Keynesian economists follow the ideas of Keynes, and reject the strict equilibrium assumption of mainstream theories. In the case of inflation, Post-Keynesian school rejects the equilibrium interpretations of price determination, and focuses instead on markup pricing behavior of firms [63]. Monetary Circuit Theory, or circulation approach, is associated with Post-Keynesian thinking and emphasizes the non-neutrality of money [64]. For more information on the Post-Keynesian approach to inflation, see Rosenberg and Weisskopf [65], Ateşoğlu [66] and Smithin [67]. For a critical survey, see Cottrell [68].

This section continues with Phillips Curve, Lucas' Critique and New-Keynesian Phillips Curve in a historical manner. Other topics related to inflation are not covered in order to maintain the scope. For a Marxian analysis of inflation, see Saad-Filho [69].

For Austrian theory of inflation, see [70]. For comparison of different explanations, see Gray and Parkin [71], Brunner and Meltzer [72] and Humprey [73]. For different views on money neutrality, see Tobin [74], Cagan [75], Saving [76], Harkness [77], Sheehey [78] and Serletis and Koustas [79].

4.2.1 Phillips Curve

Introduction of Phillips Curve was a milestone in the development of inflation theory. It shows the observed correlation between inflation and unemployment rates. The first observation came from Phillips [13] and Samuelson and Solow [80]. These observations showed a negative correlation between inflation and unemployment rate. This correlation is later named as the Phillips Curve. An illustration of the curve is given in Figure 4.1.

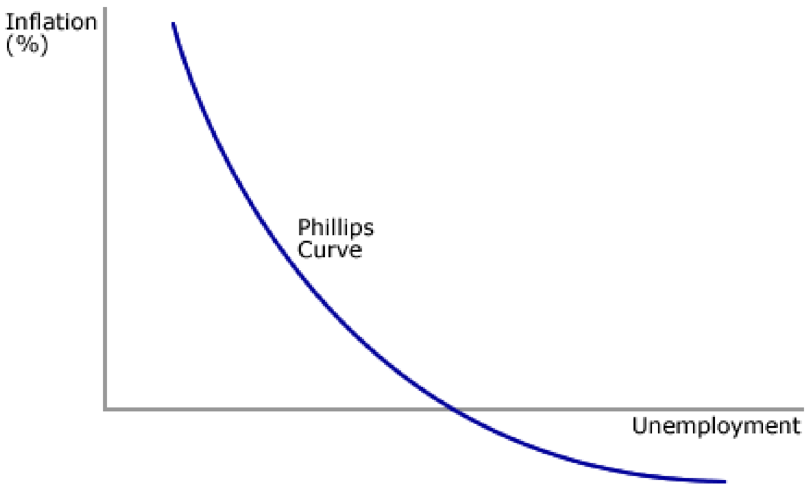

Figure 4.1 : Example of a Phillips Curve.

Later the relation is assumed to be linear for simplification. Where π_t refers to inflation and U_t refers to unemployment rate at time t, the formula is simply as follows:

$$\pi_t = \gamma U_t \tag{4.1}$$

According to equation 4.1, there is a permanent trade-off between inflation and unemployment rate, thus, improving either of them required paying for the other. At that time, the challenging question was the optimal rate of this trade-off.

However, there were two main shortcomings of this formulation. The first is the lack of expectation in the formula. Accordingly, an expectation of increasing inflation does not have anything to do with the actual inflation because it was only a matter of deciding the trade-off between inflation and unemployment rate.

The other shortcoming was seen when policy makers faced with stagflation, which is high inflation and unemployment rate being observed at the same time. This could not be explained with Phillips Curve. The first critics about this issue came from Phelps [81] and Friedman [82].

The study of Friedman [82] gained wide attention and the idea of expectations-augmented Phillips Curve was generally accepted. According to this idea, where π_t, ${\pi_t}^e$, U_t and U^* represent inflation, expected inflation, unemployment rate and natural rate of unemployment, inflation followed the formula in equation 4.2.

$$\pi_t = \gamma(U_t - U^*) + {\pi_t}^e \tag{4.2}$$

The formula relates inflation to the sum of expectation and a portion of the difference between the unemployment rate and the natural unemployment rate. Natural unemployment rate is later called 'Non-Accelerating Inflation Rate of Unemployment' (NAIRU). One result of this formulation is that unemployment can be kept at low levels only with the cost of an accelerating rate of inflation. That is why; this formulation is also called 'Accelerationist Phililps Curve'.

The most important conclusion of the new formulation is the fact that inflation-unemployment trade-off is not permanent. Thus, focusing on an optimal trade-off between inflation and unemployment rate was meaningless. Another implication was that disinflation is costly only in the short-run, and the high unemployment rates after a disinflation period will vanish in the long-run.

The first criticism to the expectations-augmented Phillips Curve was held by Solow [83, 84]. The main idea behind this theory, which is the only temporary trade-off between inflation and unemployment rate, or equivalently 'natural rate hypothesis', was tested based on the formula in equation 4.3.

$$\pi_t = \alpha + \gamma U_t + \rho \sum_{i=1}^{N} \beta_i \pi_{t-i} + e_t \tag{4.3}$$

According to this hypothesis, when the beta's are forced to sum up to one, ρ should be equal to 1 if the hypothesis is true. However, this hypothesis was rejected by the data available at that time. Similar critics are launched at 1970 FED conference [85].

These results led to doubts on natural rate hypothesis, and the idea of permanent trade-off between inflation and unemployment rate gained attention for a few years. However, accelerationist view was soon supported by the studies of Sargent [86], Lucas [87, 88] and Tobin [89]. These studies showed that inflation is mean-stationary, thus, the hypothesis tests could give false rejection. The idea behind this argument is that, since the mean value is changing, the beta coefficients can, in principle, change, thus, with constant beta values, the value of ρ may not be equal to 1 even if the natural rate hypothesis is true. After this new finding, temporary trade-off and natural rate hypothesis gained wider acceptance. See Okun [90] for supportive ideas.

4.2.2 Lucas' Critique and rational expectations

The second milestone in the theory of inflation after Phillips Curve is Lucas' Critique. The critique can be summarized with the author's words as follows:

> Given that the structure of an econometric model consists of optimal decision rules of economic agents, and that optimal decision rules vary systematically with changes in the structure of series relevant to the decision maker, it follows that any change in policy will systematically alter the structure of econometric models. [91, p. 41]

This idea, which had its roots in Lucas' previous study [88], affected the whole econometric forecasting practice. According to Lucas [91], since the parameters of the econometric models were not structural, they would necessarily change whenever policy (the rules of the game) was changed. However, the main implication was about the Phillips Curve. Either the testing of natural rate hypothesis or forecasting the future inflation rate based on the past data was, in principle, wrong. For more details on Lucas' Critique, see also Farmer [92], Alogoskoufis and Smith [93], Lindé [94] and Rudebusch [95].

Following the Lucas' Critique, macro-models should rely on micro-foundations in order to ensure the validity of the model. This fact led the inflation theory to rational expectations. According to the rational expectations theory, economic agents perfectly foresee the future state of the economic system. For this reason, inflationary or disinflationary policies should be foreseen by the economic agents, and the nominal prices and wages should be adjusted accordingly. As a result, real effects of the monetary policies, as in the Phillips Curve case, should not be observed.

However, there was a major problem about this rational expectations theory. Following the observed data, there is a real effect of monetary policy. Rational expectations hypothesis cannot explain this real effect. Stickiness in prices or wages is thought to solve this problem. After that, New-Keynesian approaches began in the inflation theory. For a more information on rational expectations and inflation, see Sargent [96].

4.2.3 New-Keynesian Phillips Curve

After Lucas' Critique, macroeconomic models began to rely on microfoundations. In other words, models assume that macroeconomic phenomena can be explained by aggregating the micro behaviour of all economic agents which are perfectly rational and have perfect foresight about the aggregate result. This type of models are called Dynamic Stochastic General Equilibrium (DSGE) models. See Rotemberg and Woodford [97], Clarida et al. [98], Lane [99], Smets and Wouters [100], Gali [101] and Schorfheide [102] for examples of DSGE applications.

Despite its popularity, there are also some critics to DSGE modeling. First of all, DSGE modeling has little impact on practical macroeconomists who are charged with policy [103]. Secondly, what is learned from DSGE models is not so different from traditional Keynesian analysis [104]. Thirdly, solving and estimating them require great technical and computing capacity [105]. Finally, DSGE models were not very useful for analyzing the financial crisis of 2007 [106].

Unlike more traditional macroeconometric forecasting models, DSGE macroeconomic models should not, in principle, be vulnerable to the Lucas' Critique [107].These models can be divided into two: i)Real Business Cycle models and ii)New-Keynesian models. New-Keynesians, in order to explain the real effect of monetary policy, tried to include nominal rigidities into the model.

At first, stickiness of price and wages, is offered to solve the inflation stickiness (or persistence) problem. See Gray [108], Fischer [109] and Taylor [110, 111] for this kind of frameworks. The theory of inflation using rational expectations together with nominal rigidities is later called New-Keynesian Phillips Curve.

Calvo's study [112] is important in the New-Keynesian literature. The gradual price response in this framework is frequently used later in the literature with the name of

‘Calvo style price adjustment’. The formulation is given in equation 4.4.

$$\pi_t = \beta E_t \pi_{t+1} + \frac{(1-\theta)(1-\theta\beta)}{\theta}(mc_t + \mu) \tag{4.4}$$

The first part of the formula is the discounted future inflation expectation and the second part is the inflationary pressure which is defined as the deviation of real marginal cost from its optimal value. Teta is the ratio of firms which cannot change its price (due to price adjustment costs) in a discrete time period and beta is the discount factor.

Under relatively general conditions aggregate real marginal costs become proportional to the output gap and the formulation becomes as follows [85]:

$$\pi_t = \beta E_t \pi_{t+1} + \gamma y_t \tag{4.5}$$

In equation 4.5, there is no intrinsic inertia. The sources of inflation are the inflation expectation and the output gap. Output gap is defined as the difference between the actual output and potential output. With detrending method, potential output can be calculated by smoothing the actual output.

However, this formulation is not capable of generating enough persistence seen in the data. Different measurement of the output gap and using hybrid-phillips curves are proposed in order to deal with this shortcoming. Other than detrending, labor’s share and production function approach are proposed as a way to measure output gap. See Gali and Gertler [113], Saxena and Cerra [114], Sbordone [115], Woodford and Walsh [116], and Rudd and Whelan [85, 117, 118] for further discussion of these approaches.

Hybrid Phillips Curve is proposed as compensation between the need to model persistent behavior and being invulnerable to Lucas’ Critique. In this framework, a portion of firms are backward-looking while the bigger portion is forward-looking. See Fuhrer and Moore [119], Gali and Gertler [113], Gali et al. [120] for supportive ideas and Rudd and Whelan [85, 117] for critics to this approach. Inflation formulation in a Hybrid Phillips Curve can be described by equatioñ 4.6.

$$\pi_t = \gamma_f E_t \pi_{t+1} + \gamma_b \pi_{t-1} + kx_t \tag{4.6}$$

In equation 4.6, inflation is assumed to reflect three different affects. The first part represents forward-looking effect, where rational agents have perfect insight. The second part represents backward-looking effect, where agents expect previous inflation levels to sustain. Finally, the third part represents an additional inflationary pressure.

4.3 Phillips Curve Revisited

According to Lipsey [121], Phillips' essay on wages and unemployment is one of the seminal articles of the last half of the twentieth century. Phillips Curve became the key element in explaining inflation after Keynesian revolution. Even after the popularity loss of Keynesianism after stagflation period in 1970's, the name 'Phillips Curve' remained its place in the literature although the meaning of the curve drastically changed. Today, Phillips Curve is still the backbone of any discussion about inflation.

In the previous sections, historical background of the inflation phenomenon is given starting from the original Phillips Curve, and continued on the extensions of it. 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 the main motive for accepting the expectations factor in 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 orthodox theory of inflation.

The history given in the previous sections and the interpretations of different Phillips Curve theories are mainly consistent with textbook information. However, careful reading of the studies of Phillips gives us a different history and a different interpretation. Consistent with the motive of the study, a different perspective upon the original Phillips Curve will be presented with the help of focusing on the studies of Phillips as a whole.

4.3.1 Original Phillips Curve

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. [13, p. 283]

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 statistical relationship given by Phillips [13] is shown in Figure 4.2.

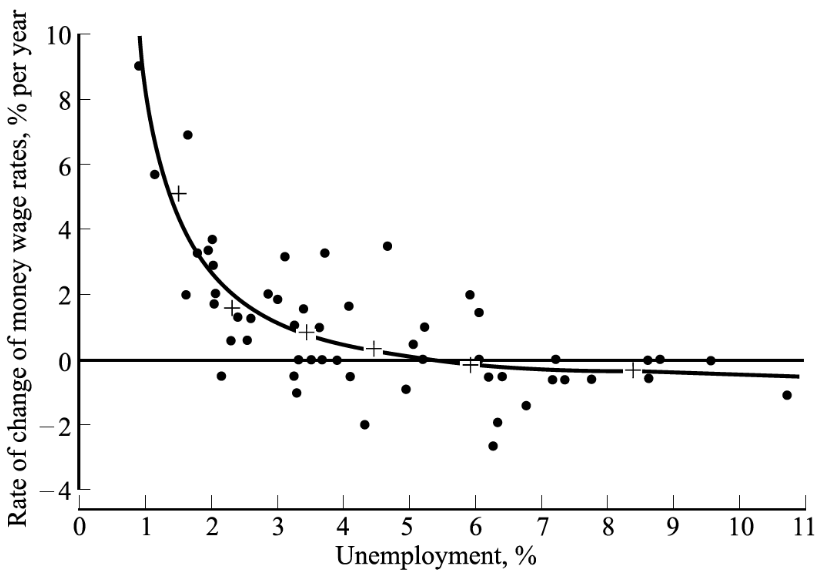

Figure 4.2 : Original Phillips Curve for 1861-1913, adopted from [13, p. 285].

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 [122]. 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" [121, p. 238].

The original work of Phillips about the relation between change in money wage rates and unemployment rate is based on a dynamic disequilibrium viewpoint. This argument becomes clear when we look at his other articles. We can summarize some of the studies of Phillips in four groups. Within the first group, there are dynamic disequilibrium models in continuous-time. 'Mechanical Models in Economic Dynamics' [1] is the first of them, in which he presents the models behind the Phillips Machine. He was still a Ph. D. student at that time. In 1953, he finished his thesis study about 'Dynamic Models in Economics'. 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 [47, 48]. Within the second group, there are two empirical studies about the relation between rate of change of wages and unemployment rate. The first one [13] gained wide attention and lead to the famous Phillips Curve. The second paper [123] was a similar study using data for Australia. Within the third group, there are two modeling studies about employment and growth [19, 124]. In these studies, Phillips combined monetary and real dynamics to analyze stability together with economic growth. Finally, within the forth group, there are econometric studies of Phillips [125–127] and Phillips and Quenouille [128]. Econometric studies are complementary to the stabilization and control studies of Phillips, in which the parameters of the continuous-time models are estimated out of discrete-time data.

If we look at these studies, we see a line of continuity. Phillips was an electrical engineer and his first study [1] clearly shows his engineering approach on modeling. In this study, he utilizes a continuous-time model working through feedback mechanisms, without a concern of equilibrium. We explained this study in detail in chapter 1. Stabilization policy articles [47, 48] are successors to his previous study and to his thesis study on a similar topic. He mainly argues that equilibrating forces, whether a market mechanism or a governmental policy, may be destabilizing. He emphasizes the time lags in the economic system as the source of this instability. Continuous-time thinking is essential in understanding his arguments.

He later applied his stability concerns on more complex economic models. In the paper 'A Simple Model of Employment, Money and Prices in a Growing Economy' [124], Phillips builds a model on which short-term stabilizing objective can be analyzed together with long-run objectives about employment and growth. In the following paper next year, 'Employment, Inflation and Growth' [19], he starts with a few critiques about the recent economic performance of Britain, mostly about fluctuations and high inflation. His emphasize is on quantitative knowledge and understanding how the economic system works. He makes this critique with a 'system scientist' point of view. In other words, he is interested in 'how the system can be made to perform better'.

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. His main concern was stabilization policy in a dynamic environment with continuous-time delays. He was certainly aware that the problem is highly complex and straight-forward stabilization policies indeed will worsen the problem. One of the main challenges of Phillips was that the economic data was in discrete-time while his mental models were in continuous-time. His econometric studies are mainly efforts for solving this problem.

To sum up, the studies of Phillips from 1950 to 1962 have similar economic ideas behind. These studies reflect the ideas of Phillips about how he thinks the economic system works. According to Lipsey, "he saw the economy as a dynamic system whose behaviour could not be understood using neoclassical static analysis" [121, p. 232]. There is no reason that we do not expect the continuity of his beliefs also in his empirical studies about inflation and unemployment. Indeed, the original Phillips Curve article [13] is an empirical complementary to his earlier views [47, 48]. As Lipsay says, "those who interpret Phillips Curve on the basis of this article alone often fail to read the earlier two pieces on stabilisation policy, although all three articles need to be seen as a unit" [121, p. 239]. The following lines of Phillips clear this argument:

> [I]f factor prices have some degree of flexibility, there will be changes in product prices resulting from the changes which take place in factor prices. Even with flexible factor prices, there will be some level of production and employment which, given the bargaining powers of the different groups in the economy, will just result in the average level of factor prices

> remaining constant, this level of production and employment being lower, the stronger and more aggressive the organization of the factors of production. If aggregate real demand is high enough to make a higher level of production than this profitable, entrepreneurs will be more anxious to obtain (and to retain) the services of labour and other factors of production and so less inclined to resist demands for higher wages and other factor rewards. Factor prices will therefore rise. The level of demand being high, the rising costs will be passed on in the form of higher product prices. Factor and product prices will continue to rise in this way so long as the high level of demand and production is maintained, the rate at which they rise being greater, the higher the level of demand and production. [47, p. 306]

The lines above are almost similar to the hypothesis of Phillips in the original Phillips Curve study [13]. He argues that higher production, thus higher demand for labor and lower unemployment rate, will raise factor prices (wage rates). He then adds that this higher factor prices, as costs, will reflect in product prices as long as the demand continues to rise. There is a direct implication of relation between employment and change in factor prices given a constant bargaining power.

In his article [47] Phillips gives a graphical representation between rate of change of factor prices and level of production. This graphical representation is very similar to the empirical relation he presents in Phillips [13]. Figure 4.3 shows his graph.

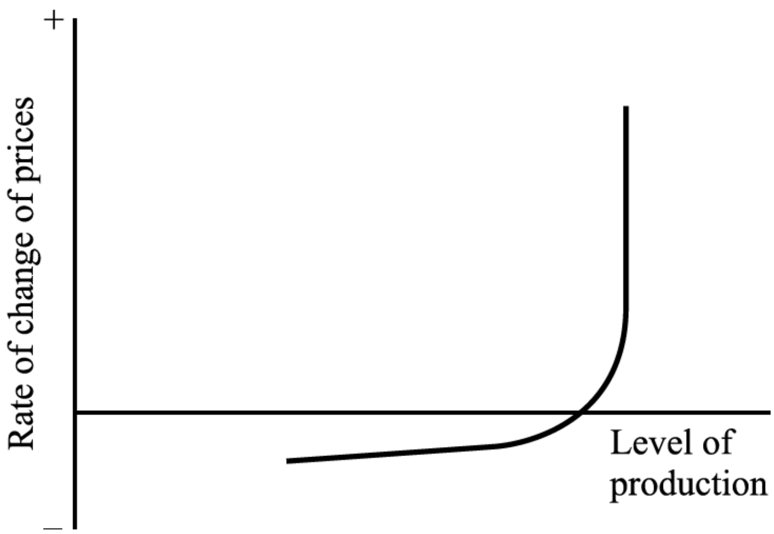

Figure 4.3 : Rate of change of factor prices in response to level of production, adopted from [47, p. 307].

4.3.2 Role of expectations

The empirical work of Phillips [13] gained wider attention and policy makers began to believe that there is a trade-off between inflation and unemployment. Because of that belief, governments treated inflation as an acceptable sacrifice to lower unemployment and boost economic growth. The focus of the econometric works was about determining the parameters about this trade-off.

However, the rise in inflation became permanent while the unemployment returned to its normal value. In other words, the empirical Phillips Curve shifted. The inflation-unemployment trade-off began to be questioned. After Friedman [82], the inflation-unemployment trade-off is modified and the role of inflation expectation is included in the model. The study of Phillips [13] is discredited as a result, for not taking expectation into account.

The criticisms attacking Phillips were due to misunderstanding him. First of all, Phillips never suggested buying additional employment with the cost of inflation. Indeed, he never interpreted the empirical relation as a policy trade-off. According to Leeson, "[f]or 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" [129, p. 160]. However, we certainly know that the original Phillips Curve was a disequilibrium phenomenon. Moreover, neither in the empirical article [13], nor in his previous studies [1, 47, 48], there is a theoretical viewpoint which allows the disequilibrium in the labor market can perpetuate itself. As a result, buying higher employment with a cost of inflation is not, and can never be, a part of his interpretation of the empirical finding.

Secondly, it is not true that Phillips ignored the role of expectations. According to Leeson, "[Phillips's] 1954 theoretical precursor to his scatter diagrams clearly examined the role of expectations about future price changes" [129, p. 166]. The reason why there is no implicit mention in his study [13] is that, during the data period, there was no significant positive inflation on average. That's why Phillips did not mention expectation in the empirical study. According to Fuhrer et al., "[n]ote that all of Phillips's analysis involves money wages or nominal wages, not because Phillips believed that unemployment is related to nominal rather than real wages, but because he lived in a world in which it was reasonable to assume that prices would remain relatively stable, temporary disruptions from import prices notwithstanding" [130, p. 5].

During the transition from the original curve to expectation-included curve, another transition occurred. The causal interpretation of Phillips [13] and Friedman [82] were different. According to Phillips [13, 47] lower unemployment rate leads to wage increases and this increase is passed to prices leading to inflation. However, according to Friedman [82], it is the (unexpected) inflation which causes unemployment to rise.

In other words, in equilibrium models, there is no difference between saying 'A causes B' and 'B causes A'. One way causality can only be meaningful in disequilibrium models. In his empirical study, Phillips did not imply any kind of equilibrium and he argued that unemployment rate causes a change in wage rates. However, his study is misinterpreted and the empirical relation is treated as an equilibrium phenomenon. For this reason, the direction of causality changed and the relation began to be interpreted as if there is a trade-off between them.

To sum up, main concern of Phillips was stabilization policy. He was not thinking in terms of equilibrium, supply and demand, but in terms of feedback loops. He believed that any deviation from stability has the potential of triggering a reinforcing mechanism. Both his empirical works on inflation and unemployment [13, 123] and the theoretical ancestors [47, 48] should be read from this viewpoint.

4.3.3 Lucas' Critique and rational expectations

After the recognition of expectations in the inflation-unemployment relationship, econometric works focused on the parameters of past inflations in the expected inflation formulation. Reduced form solutions estimated by econometrics are then used in stabilization policies. However, shifts in the parameters and the lack of statistical verification of the theory behind were creating trouble. See Rudd and Whelan [85] for details.

However, it was possible to read the Lucas critique from a different point of view. Phillips, in his last published study named 'Models for the Control of Economic Fluctuations' [131], approached the same problem from a different view; control theory view. He summarizes his main point as follows:

> When control is being applied in strict accordance with [the optimal decision rule] the sub-system [econometric model used for parameter estimation] may no longer be identified. By this we mean that new observations generated by the operation of the complete system may give no further information by which to improve the estimates of the parameters of the sub-system. [131, p. 472]

We understand from the passage above that Phillips was aware of the problem before Lucas and claimed similar points before him. Yet the interpretation of the problem was different between Phillips and Lucas. As opposed to Lucas, Phillips was concerned about the data being interpreted from an equilibrium perspective, as happened after he introduced the empirical relation of the Phillips Curve.

5. MODEL DESCRIPTION

5.1 Overview

In this chapter, System Dynamics Model of Inflation is described. The model consists of six sectors, or sub-models, each focusing on a certain dynamical mechanism. These sectors are monetary sector, goods sector, price sector, labor sector, wage sector and investment sector. An illustration of these sectors and their interconnection is given in Figure 5.1.

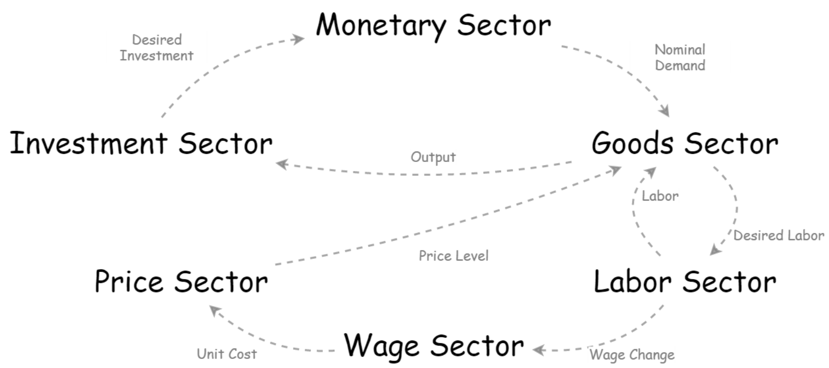

Figure 5.1 : Overview of the System Dynamics Model of Inflation.

In the monetary sector, the concept of circular flow of income in the form of money is illustrated. It gets the information about desired investment from the investment sector, and determines the nominal aggregate demand with the help of interest rate mechanism. This nominal aggregate demand is then used in goods sector to determine real values of aggregate demand with the help of price level.

In the goods sector, real values of aggregate demand and aggregate supply are determined. Aggregate supply is determined by the amount of labor, which is an input from labor sector to goods sector. Aggregate supply and aggregate demand are defined as flow variables and connected with a stock variable in between. Aggregate supply, determined in this sector is used in investment sector to show the effect of economic productivity on investment. Demand pressure is sent to price sector as an information for setting markup rates. Demand pressure is also sent to labor sector in order to determine desired labor.

In the price sector, price level is adjusted following a markup behavior rule. In other words, firms are assumed to be quantity taker and price setter in this model. Markup is determined by the demand pressure information which comes from goods sector. Unit cost is determined by the wage level and labor productivity. The output of this sector, price level, is then sent to goods sector in order to determine the real values of aggregate supply and aggregate demand.

In the labor sector, employed labor is adjusted using the information of demand pressure which comes from goods sector. The amount of employed labor at any time is sent to goods sector in order to determine aggregate supply. The state of labor sector at any time is also sent to wage sector in order to determine the wage level.

In the wage sector, wage level is determined by the labor market conditions. Several variables of labor sector is used in the formulation of wage changes. Wage level is then passed to the price sector, in order to determine price level with a cost-based formula.

In the investment sector, desired nominal investment is formulated using the information of economic output and the forecast of aggregate demand. Output is used directly from the goods sector and demand forecast is formulated based on the aggregate demand information from the goods sector. This desired value is then used in the monetary sector to determine actual nominal investment based on the interest rate, which is endogenously determined within the monetary sector.

5.2 Monetary Sector

Mechanical model (Model 2) of Phillips [1] which is explained in detail in chapter 1 represents the flow of money in an economy. This model, with a few necessary modifications, used as a sub-model in this broader system dynamics model. It explains the circular flow of income (in the form of money) and will be connected with other sectors of the model in order to explain how money affects output. Monetary sector is given in Figure 5.2.

There are three stock variables in this sub-model; *Business Balances*, *Household Balances* and *Loanable Funds*. *Business Balances* is the equivalent of $M1$ in the

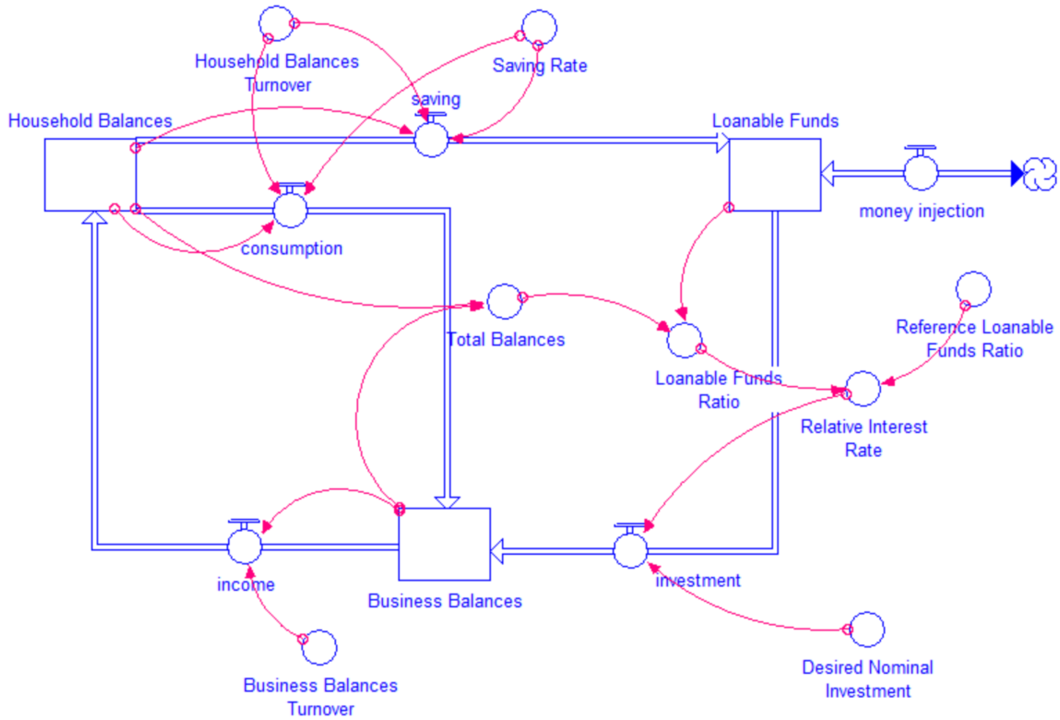

Figure 5.2 : Stock-flow representation of Monetary Sector.

original model. This represents the minimum working balances of the firms. *Loanable Funds*, on the other hand, is the equivalent of $M2$ in the original model. This represents the accumulated saved money by the households, in order to loan to businesses for investments.

A third stock variable named *Household Balances*, which does not exist in the original model, is included in this sub-model, in order to differentiate income from expenditure. In the original model, outflow from $M1$ goes through a long pipe which divides into two along the way, one feeding back to $M1$ representing consumption and the other feeds $M2$ representing savings. This long path of the water flowing out from $M1$ is replaced by this additional stock variable.

The money accumulated in *Business Balances* is the aggregate nominal revenue generated through expenditure, which is composed of *Consumption* and *Investment*. Government expenditure is ignored in this model. The accumulated revenue flows out of *Business Balances* as *Income*, proportional to its level. *Business Balances Turnover* is a constant determining the value of *Income*.

This constant can be interpreted as the ratio of revenues to the required levels working capital, or equivalently, the time required for a unit of revenue to be paid to the owners of input (labor and capital owners). As a reasonable assumption, this constant is set to be $4/year$. This means that firms hold 3 months of revenue as cash in order to continue business activities. From another point of view, this constant represents how frequent the generated income is paid to input owners. Wages are usually paid monthly and dividends are usually paid at the end of each year. On average, $4/year$ seems a reasonable assumption.

When *Business Balances Turnover* is equal to $4/year$, this means that the rate of income per year is $1/4$ of the value of stock. When the value of stock remain unchanged for a period of time, inflow from and outflow to this stock must be equal. Thus, when equilibrium is maintained, *Income* becomes equal to the sum of *Consumption* and *Investment*. *Income* directly accumulates in *Household Balances* in order to be spent as *Consumption* or to be deposited in the financial system. For this reason, *Income* can also be interpreted as disposable income.

Household Balances represents the amount of cash hold by households at any time. It is filled with the flow of *Income* and depleted by *Consumption* and *Savings*. *Household Balances Turnover* is a similar constant to *Business Balances Turnover*, and it represents how many times a year the cash is spent by households. The sum of *Consumption* and *Savings* is determined by the level of *Household Balances* and the turnover constant. This constant is also assumed to be $4/year$, meaning that the sum of *Consumption* and *Savings* at any time is equal to $1/4$ of the level of *Household Balances*.

Saving Rate is another constant which determines both *Consumption* and *Saving*. If H stands for *Household Balances*, s stands for *Saving Rate* and T_H stands for turnover constant, then *Savings* can be calculated as $S = sHT_h$. Similarly, *Consumption* can be calculated as $C = (1-s)HT_h$.

The flow of *Consumption* directly goes to *Business Balances*. *Saving*, on the other hand, fills *Loanable Funds* in order to fund future investments. The value of *Loanable Funds* determines the interest rate and indirectly affects *Investments*. In the original model, *Loanable Funds* is assumed to affect *Saving* as well, through affecting *Saving Rate*. Accordingly, high levels of *Loanable Funds* should decrease interest rates and decrease saving rate. This link is discarded in this model because the relation between saving rate and interest rates is not clear [132].

The cash accumulated in *Loanable Funds* flows out as *Investment*. The level of *Loanable Funds* affects *Investment* through interest rates. Whenever the ratio of *Loanable Funds* to the amount of money in circulation (sum of *Business Balances* and *Household Balances*) increases, interest rates should fall below the equilibrium value (or 'normal' value) and motivate *Investment*. Whenever this ratio decreases, interest rates should be higher and decrease *Investment*.

Normal interest rate conceptually represents a long run average of real interest rate added to expected inflation level. This real interest rate can be a structural variable which is different for each economy. This theoretical model does not capture the dynamics determining this real interest rate. All the model requires to link *Loanable Funds* to *Investment* is that how much higher or lower the interest rate is, compared to a reference value.

The ratio of *Loanable Funds* to *Total Balances* is equal to *Loanable Funds Ratio*. Together with a reference value of this ratio, *Relative Interest Rate* is determined. In equilibrium conditions, *Relative Interest Rate* is equal to 1 and *Investment* is equal to its desired level. When *Relative Interest Rate* is over 1, that means there is a money shortage in the system and *Investment* should decline. When it is below 1, that means there is an excess amount of available money in the system and *Investment* should increase.

When the system is in equilibrium, all the stocks remain unchanged and inflows and outflows should be equal. Accordingly, in equilibrium, *Investment* is equal to *Savings*. However, when there is no equilibrium, *Investment* is determined by several factors, *Relative Interest Rate* being one of them. Other factors affecting *Investment* is captured in *Desired Nominal Investment* and will be explained later. In this sub-model, *Desired Nominal Investment* represents the rate of investments when *Relative Interest Rate* is 1 and there is no interest rate effect on *Investment*.

Finally, there is a flow variable named *Money Injection* and it represents the additional money injected in the system. There is a similar mechanism to inject money in Phillips' original model. Initially, the values of the stock variables are tuned to be in equilibrium and 'money injection' is assumed to be zero. Later, for simulation purposes, this money injection will be used to test how the model behaves.

The initial values of stock variables are calculated so that total expenditure is equal to 1. Thus, *Business Balances* and *Household Balances* are equal to 0.25. *Saving Rate* is assumed to be 0.3 which is thought to be the capital share of income. *Reference Loanable Funds Ratio* is set to an arbitrary value, 0.5. Accordingly, the initial value of *Loanable Funds* is equal to 0.25 as well.

With these initial values of stocks, the sub-model is in equilibrium. The economy produces 1 unit of income and expenditure in nominal terms. 70% of this income is used for consumption and the residual is saved. Investment is also equal to savings and the relative interest rate is 1.

In equilibrium, total money in the system is 0.75 units. For illustration, suppose we injected additional money into 'Loanable Funds' in order to double the amount of money in the system. Simulation for this illustration is given in Figure 5.3.

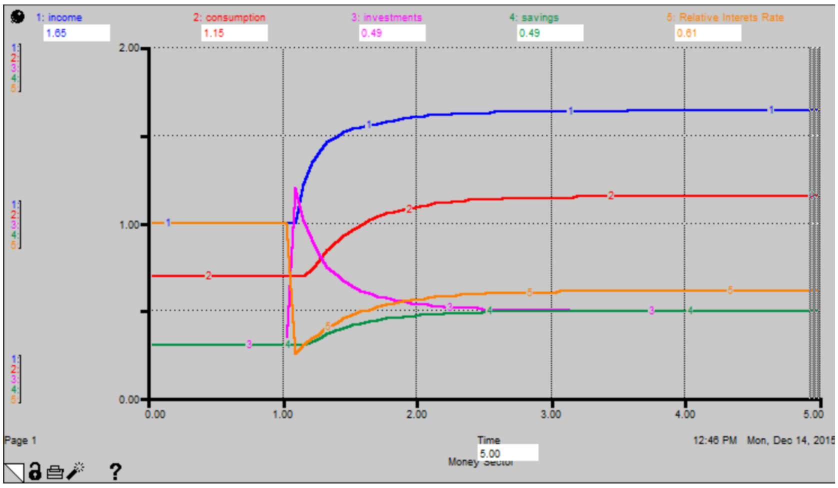

Figure 5.3 : Monetary sector simulation.

According to the simulation results, income, consumption, savings and investments increased after money injection at $t = 1$. However, the equilibrium result is not twice of the initial values. This is because *Desired Nominal Investment* kept constant during simulation and the only effect on 'investments' is interest rates. The system reached its new equilibrium with 'lower than normal' interest rates.

5.3 Goods Sector

The sub-model given in Section 5.2 explains how the income circulates in the economy in the form of money. To link this flow with real counterparts, a model explaining aggregate demand and aggregate supply in real terms is necessary. In this section, 'Goods Sector' of the model will be explained. Stock-flow representation of this sub-model is given in Figure 5.4.

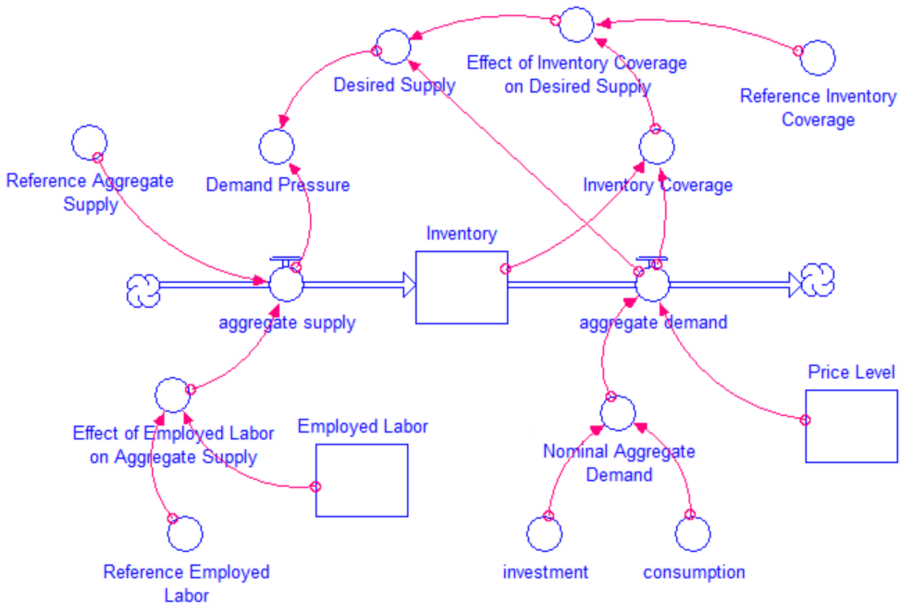

Figure 5.4 : Stock-flow representation of Goods Sector.

In this sub-model, there is only one stock called *Inventory*. *Aggregate Demand* is an outflow from this stock and *Aggregate Supply* is an inflow to this stock. All the variables have real values. *Aggregate Demand* is equal to nominal aggregate demand, sum of *Consumption* and *Investment*, divided by *Price Level*.

Aggregate Supply, on the other hand, is determined by its reference value, and *Effect of Employed Labor on Aggregate Supply*. This effect variable is formulated as $(L/L^{*})^{0.7}$, where L represents *Employed Labor* and L^{*} represents its reference (or initial) value. Both of the reference values are set to 1, thus the formulation reduces to $Y = kL^{0.7}$, where L represents *Employed Labor* and k represents the effect of technology and capital stock in a typical Cobb-Douglas production function, which is assumed to be constant equal to 1 for simplicity. With this formulation of production function, firms can adjust aggregate supply by changing the amount of labor in the short run, but due to the law of diminishing marginal returns, the change in aggregate supply will not be proportional. The exponent of L is chosen to be 0.7 following the common assumption about labor's share of income, and it is in accordance with *Saving Rate*, assuming labors consume while capital owners save all of their income.

Goods sector sub-model transmits the signal of change in demand to the producers so that they can meet demand. Any discrepancy is compensated by inventory. Due to the dynamics explained in Section 5.2, nominal demand may rise without any change in the production capacity of the economy. While price level is constant, this increase in nominal demand also means people can consume or invest goods which cannot be replaced by the producers instantly. Thus, in the short run, people can buy goods which are produced earlier and accumulated in the inventory. However, this cannot be sustained for long periods of time, thus either aggregate supply or price level should increase in order to eliminate the discrepancy between demand and supply. In this model, we assume both mechanisms work at the same time.

Inventory Coverage represents how desirable the level of inventory is compared to the outflow of *Aggregate Demand*. If this value is higher than a reference value, then firms should produce more than they sell in order to replace the depleted inventory. *Effect of Inventory Coverage on Desired Supply* represents this multiplicative effect and formulated as follows:

$$2/(1+e^{c-c^*}) \tag{5.1}$$

According to 5.1, inventory coverage effect is bounded by 2 upwards and by 0 downwards. As inventory coverage gets higher, the effect also increases but in a decreasing rate. On the other hand, as inventory coverage gets lower, the effect also decreases but in a decreasing rate. The formula assures that it is always between 0 and 2. The graphical representation of the function is given in Figure 5.5.

Effect of Inventory Coverage on Desired Supply is multiplied by *Aggregate Demand* in order to calculate *Desired Supply*. The ratio of *Desired Supply* to the current value of *Aggregate Supply* gives *Demand Pressure* which is a signal for increasing supply. *Aggregate Supply* can only be increased by using more labor in the short run. This effect is explained in the labor sector.

5.4 Price Sector

When nominal demand increases, either supply-side of the economy or the price mechanism should adjust in order to close the gap between real demand and

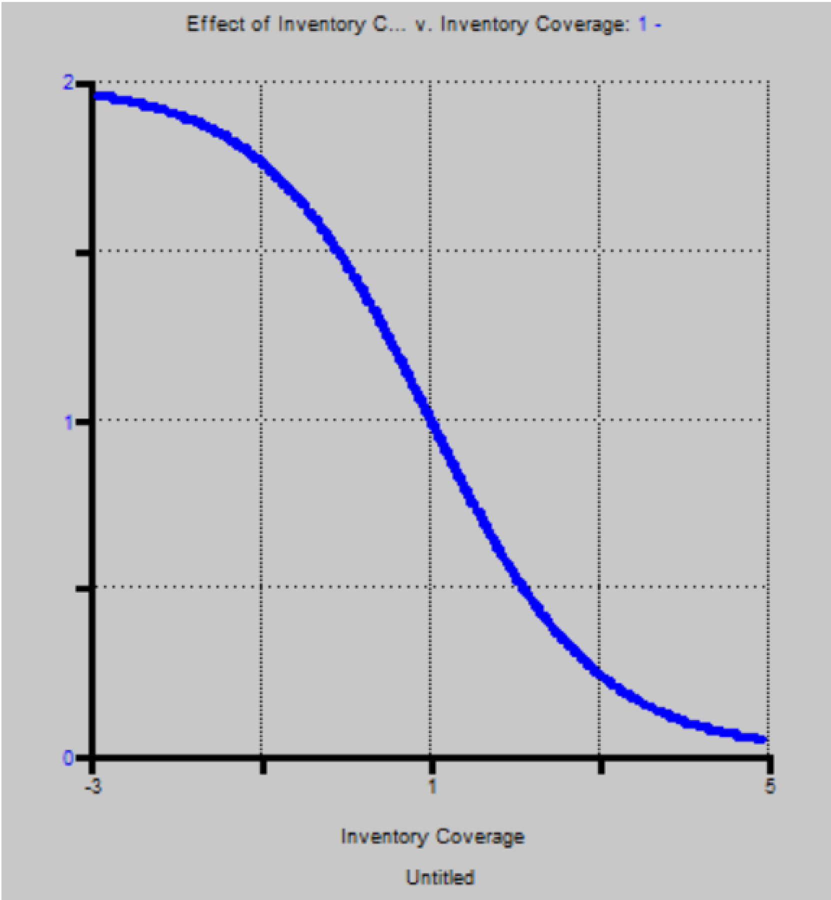

Figure 5.5 : Effect of inventory coverage on desired supply.

supply. Price sector of the model explains how the second one works. Stock-flow representation of this sub-model is given in Figure 5.6.

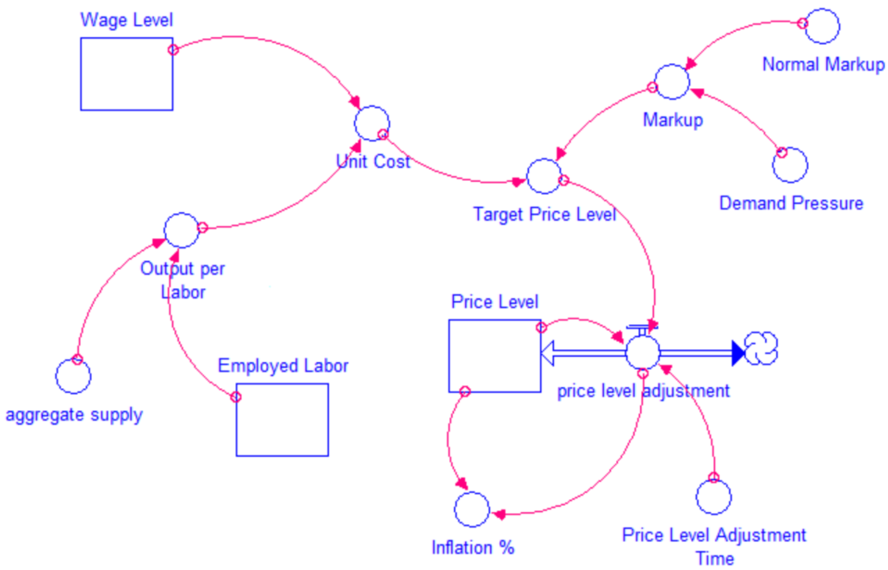

Figure 5.6 : Stock-flow representation of Price Sector.

There is only one stock in this sub-model, *Price Level*. This stock is adjusted to a target value, *Target Price Level*, with an adjustment time called *Price Level Adjustment Time*. However, the adjustment process is somewhat different from ordinary goal-seeking formulation; it also includes a trend correction. Where P denotes *Price Level*, P^* denotes *Target Price Level*, T denotes adjustment time and f denotes the built-in 'TREND' function of STELLA software, price level adjustment can be formulated as in 5.2.

$$dP/dt = (P - P^*)T + f(P^*)P \tag{5.2}$$

In the formula of price adjustment, trend correction part assures that there will be no systematic gap between price level and its target value. Without this trend correction, price setter would always be fooled in an environment of positive inflation. With the help of trend correction, unless inflation itself is constantly increasing, price setters will eventually set the right prices.

The built-in trend function estimates the rate of change in any variable of the model. The stock-flow representation of a simple trend estimation is given in Figure 5.7. Accordingly, the delayed value of the chosen variable is calculated with a time delay, similar to the goal-seeking adjustment mechanism. Later, rate of change is estimated by the difference between actual and delayed values divided by the delayed value. Time delay in this formulation represents the time horizon within which the trend is estimated. In the proposed system dynamics model, time delay is assumed to be 2 years for all trend functions.

The effect of trend correction can be demonstrated with a simple example. Assume that 'Target' is linearly increasing and there are two following variables; 'Follower 1' and 'Follower 2'. 'Follower 1' is adjusted with ordinary goal-seeking structure while 'Follower 2' is adjusted using goal-seeking with trend correction. The simulation result is shown in Figure 5.8 . According to the results, 'Follower 1' systematically remain below its target while 'Follower 2' eventually closes the gap between itself and its target.

Target Price Level represents the markup pricing behavior of price setters. Accordingly, unit cost is multiplied by $1+\mu$, where μ represents the markup rate. There is a normal rate of markup under equilibrium conditions, meaning when there

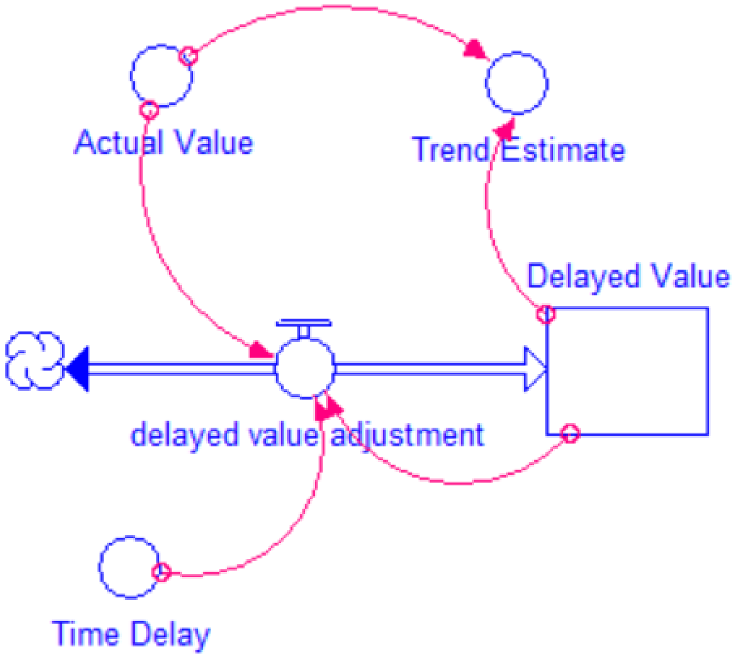

Figure 5.7 : Stock-flow representation of trend estimation.

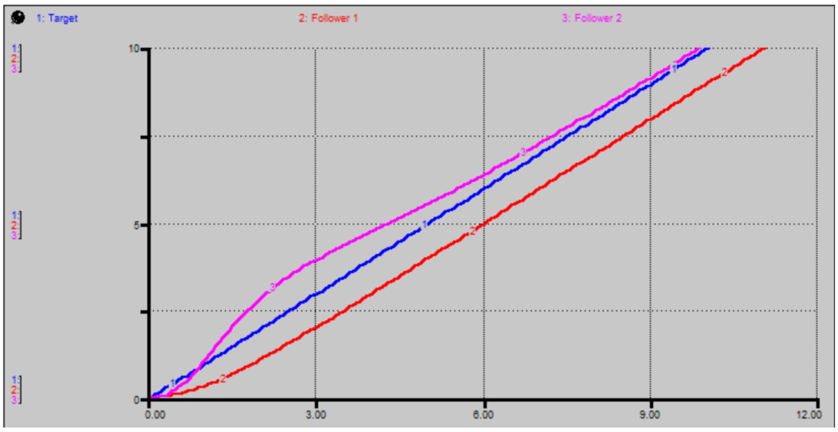

Figure 5.8 : Example of adjustment with trend correction.

is no demand pressure. Markup is the multiplication of this normal rate with demand pressure, meaning that markup rate is linearly correlated with demand pressure.

Unit Cost represents the unit labor cost of producers. Firms usually have costs other than labor as well, like energy, raw material, or semi-finished goods. However, since they are also goods produced by other firms, labor cost is assumed to be the only cost at the macro level.

Unit Cost is defined as the ratio of *Wage Level* to *Output per Labor*. *Output per Labor* is defined straightforward as the ratio of *Aggregate Supply* to *Employed Labor*. Following the assumed production function, supply will increase as more labor is used but not linearly. Thus, labor-oriented supply increase will lead to a higher unit cost, triggering a cost-push raise in prices.

Monetary sector, goods sector and price sector can be simulated together in order to see how money affects output until price mechanism corrects it. Aggregate supply is set to 1 without being effected. Initial value of *Wage Level* is set to 0.7 which is consistent with the assumed labor's share of income. *Normal Markup* is also assumed to be 0.3/0.7 so that the initial price level is consistent with the target value. Total money in the system is doubled as done before. The simulation results is given in Figure 5.9.

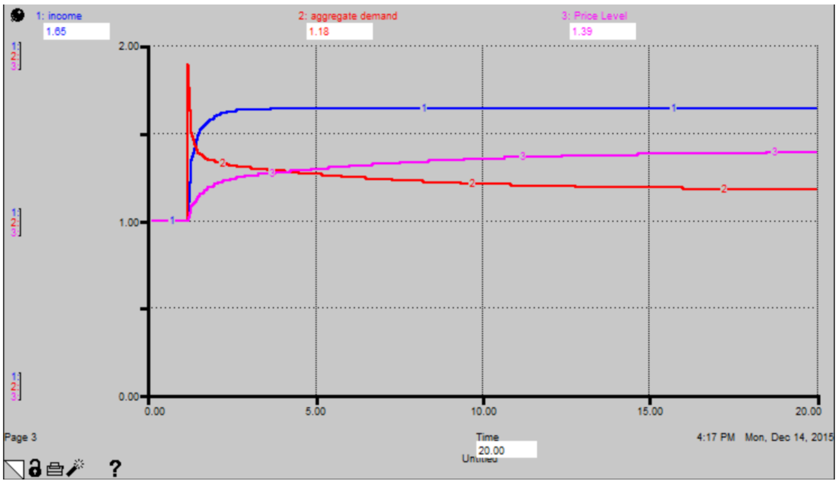

Figure 5.9 : Simulation of monetary sector, goods sector and price sector.

According to the simulation results, *Income* (in nominal terms) reaches to 1.65 after a few years. *Aggregate Demand*, in real terms, is also increasing after the money shock. *Price Level* gradually reaches to 1.40 as the demand pressure accumulates. However, the increase in price level is not enough for *aggregate demand* to return to its initial value. That is because *Wage Level* is assumed to be constant, thus, costs do not increase during this monetary expansion. When supply side of the economy responds to the monetary expansion, wages will increase as a result, and the monetary expansion will be offset by prices.

5.5 Labor Sector

When new money is injected into the system, nominal values of the economic aggregates, such as income and expenditure rises. Until the prices respond to this change, aggregate demand in real terms also rises. As explained in Section 5.3, this increase in demand triggers a signal to the supply side of the economy in order to increase production. This signal is represented as *Demand Pressure*.

When demand pressure becomes greater than 1, firms tend to hire more labor. This additional labor should come from *Unemployed Labor*. This dynamic is explained in the labor sector of the model, which is given in Figure 5.10.

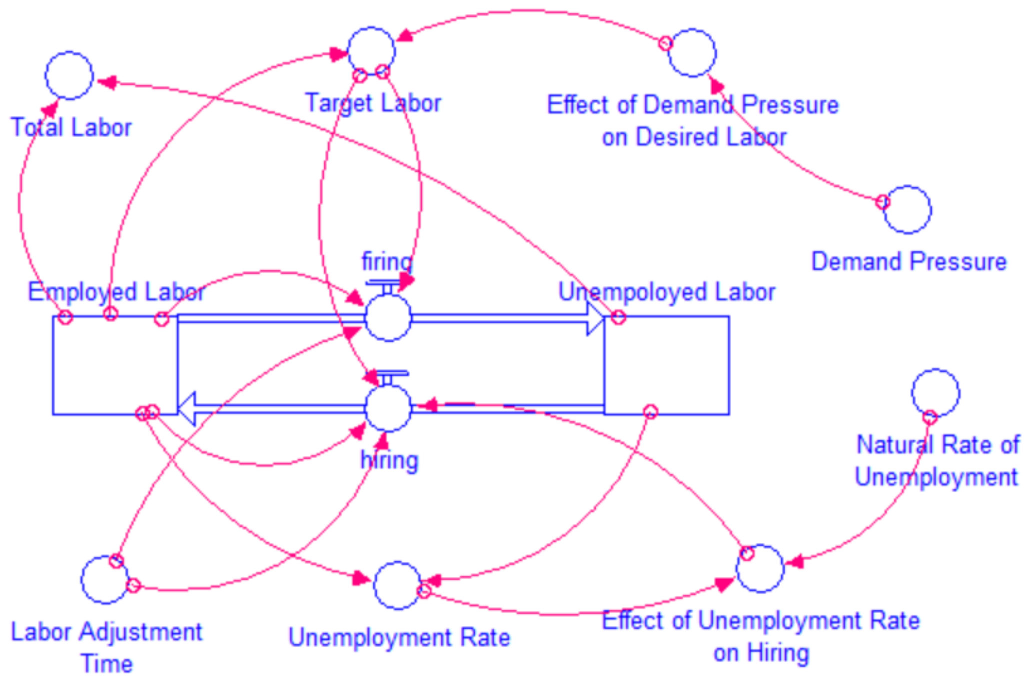

Figure 5.10 : Stock-flow representation of Labor Sector.

There are two stocks in this sub-model: *Employed Labor* and *Unemployed Labor*. The ratio of *Unemployed Labor* to the total workforce is *Unemployment Rate*. There is a normal or reference value of unemployment rate, which is called *Natural Rate of Unemployment*. In literature, there is a similar term for this normal value, which is called NAIRU (Non-Accelerating Inflation Rate of Unemployment). In this model, *Natural Rate of Unemployment* is constant equal to %10, assumed to be a structural variable which can be different in each economy. In equilibrium, unemployment rate is set to be equal to this constant, and bargaining powers of capitalists and labors are equal so that wages do not change.

There is a target value for *Employed Labor*, called *Target Labor*. This target value is the multiplication of *Employed Labor* with *Demand Pressure*. In other words, if the demand pressure is 2, then that means the firms would like to hire twice the labor they already have hired. Adjustment of *Employed Labor* occur with the flows of *Hiring* and

Firing. The formulation of *Firing* is straightforward, the same as other goal-seeking structures. *Labor Adjustment Time* is assumed to be 2 years.

Formulation of *Hiring* is a little bit tricky, because firms cannot hire any more labor if the value of *Unemployed Labor* is zero. Moreover, *Hiring* should be more difficult when *Unemployed Labor* is very low but positive. For this reason, another variable to determine *Hiring* is included in the model, called *Effect of Unemployment Rate on Hiring*. This effect is simply assumed to be the ratio of actual unemployment rate to the natural rate. As a result, when unemployment rate is higher, it becomes easier for the firms to find new employees, and when there is no unemployed in the economy, it becomes impossible.

The effect of unemployment rate on hiring can be interpreted in another way. The adjustment time of *Employed Labor* to its target value is used for both positive and negative adjustments. In other words, hiring and firing are assumed to take the same amount of time for simplicity. However, when unemployment rate is too low, it would be difficult for firms to find the right person to hire, thus adjustment of *Employed Labor* to its target value would take more time. It would be more accurate for modeling purposes, to consider the constant adjustment time to be 'normal adjustment time' for positive adjustments and the actual adjustment time to be a function of this normal value and the effect of unemployment rate. However, during simulation, if the value of *Unemployed Labor* falls to zero, hiring adjustment time should be infinitive so that net hiring would be zero. This can cause a computational problem. As a result, for only computational purposes, the level of *Unemployment Rate* is assumed to directly affect *Hiring* without being linked to the adjustment time. Model readers should consider this, and interpret 'Labor Adjustment Time' as the normal value of positive adjustments which is true under equilibrium conditions, and changes as *Unemployed Labor* changes.

According to this sub-model, demand pressure occurred in goods sector transmits a signal to the firms to hire more labor to meet the demand. As more labor is hired, there will be an upward pressure on wages. This pressure may occur because unemployment rate is below the natural rate, or firms try to hire more labor in a period of rising business activity. These two reasons may seem identical, since when firms try to hire more labor, unemployment rate decreases. However, this is only true when labor market adjusts. During a disequilibrium state, both mechanisms work at the same time. As a result, during a period of rising business activity with an unemployment rate higher than the natural rate, two mechanisms work in opposite ways and may cancel each other out.

The idea behind this is apparent in the empirical study of Phillips [13]. As the data shows, even though unemployment rate is high, wages still increase during a period of rising business activity which represents a higher demand for labor. Phillips explains this 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. [13]

An illustrative simulation can be prepared in order to see if two effects in labor market together can generate similar behaviour given in the data for original Phillips Curve. For simulation purposes, two kinds of cycles are assumed to exist in the system, which are exogenous to this sub-model. The first cycle is a short-wave, which is represented as a sinus-wave with a frequency of 7 years. The second cycle is a long-wave, which is also presented as a sinus-wave, this time with a frequency of 25 years. The sinus waves are assumed to affect 'Target Labor' at %5 at most. The frequencies of the waves are choosen to be relatively prime, so that $7x25$ years of non-repeating pseudo-data can be generated. The behaviour of *Target Labor* for a 100-year period is given in Figure 5.11.

Since the business cycles are assumed to be exogenous in this simulation, other sectors of the model are discarded. Rate of change of wage rates, in Phillips' terminology, is temporarily added to the model and it is assumed to be a linear function of the ratio of

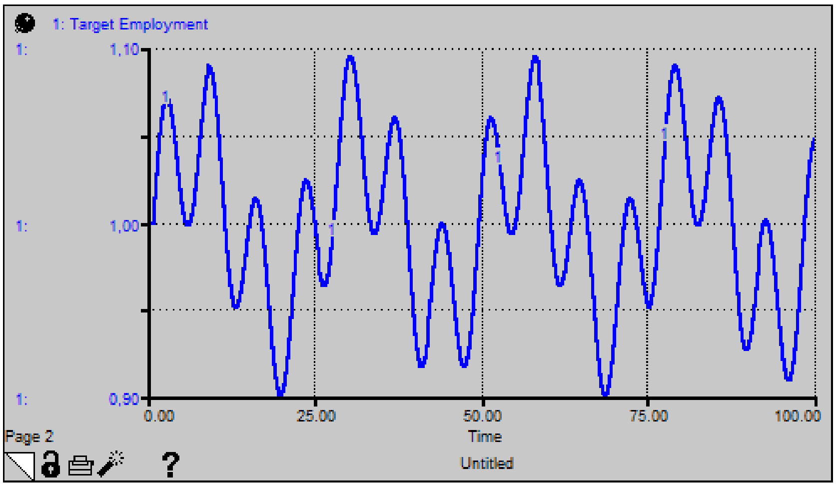

Figure 5.11 : Exogenous cycles containing two sinus waves.

Target Labor to *Unemployment*, being zero when it is equal to a reference equilibrium value. Simulation results for 100 years is given in Figure 5.12.

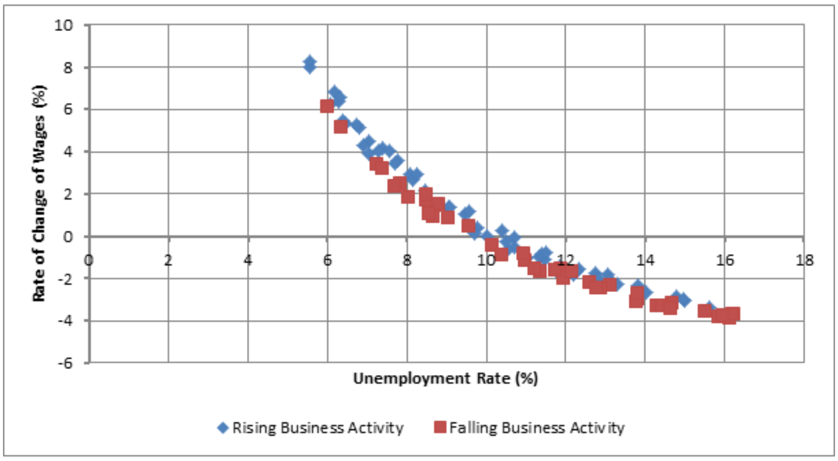

Figure 5.12 : Simulation of the original Phillips Curve.

The result 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 non-linearity in the simulated relation similar to the original curve. This is apparent in the scatter diagram of Phillips [13] and his interpretations. In other words, wages rise faster than they fall. Stock-flow structure given in Figure 5.10 explicitly gives rise to this nonlinear behavior due to the causality beneath.

Finally, and most importantly, the relation is asymmetric. As seen in Figure 5.12, 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 [13]. Figure 5.13 shows that yearly data moves around the curve during a cycle.

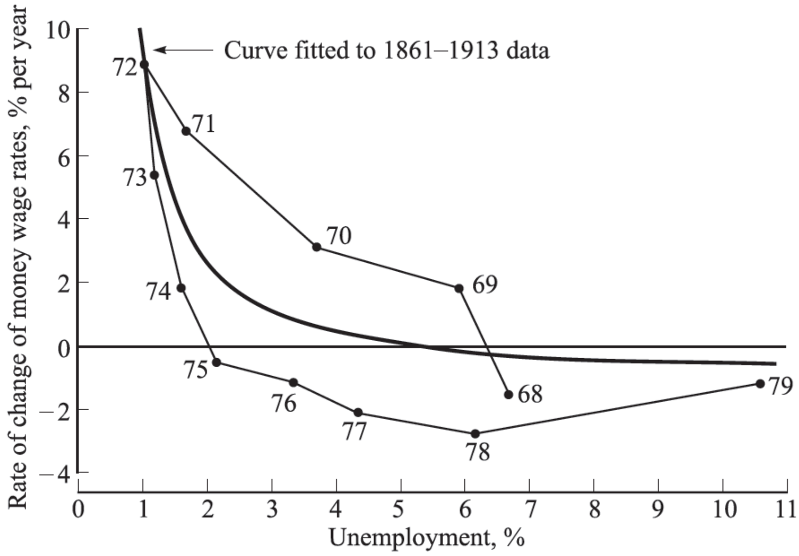

Figure 5.13 : A cycle around the original Phillips Curve, adopted from [13].

Similar cyclical patterns exist for other periods as well [13]. 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 exhibit the same type of behavior along cycles.

Figure 5.14 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 Figure 5.13. In other words, the unemployment – wage change relation is different than it would be if the unemployment rate remained unchanged.

To sum up, this illustration shows that the original Phillips Curve is a disequilibrium phenomenon. The nonlinear and cyclic behaviour of the empirical data can be simulated by a system dynamics model. The results of this simulation are given in detail by Sansarcı et al. [133].

Figure 5.14 : A cycle around the simulated Phillips Curve.

5.6 Wage Sector

Wage sector of the model represents the dynamics affecting wage level as a result of the changes in labor sector. It is assumed that, whenever capital owners desire to hire more labor or unemployment rate is low, wage level should increase. Likewise, whenever capital owners desire to hire less labor or unemployment rate is high, nominal wage level should decrease. Stock-flow representation of wage sector is given in Figure 5.15.

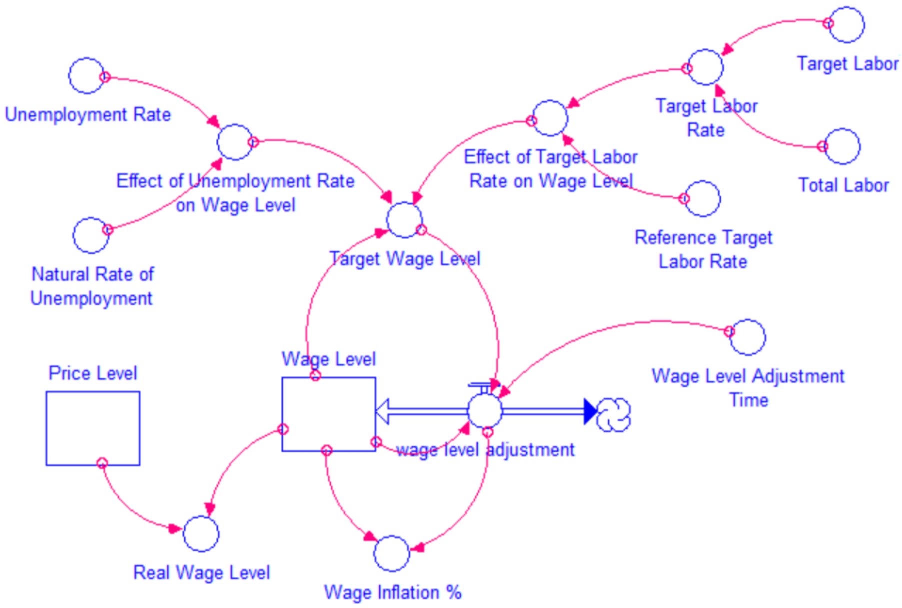

Figure 5.15 : Stock-flow representation of the Wage Sector.

There is only one stock variable in this sub-model; *Wage Level*. It is adjusted to a target value, with a trend correction, similar to price level adjustment. *Wage Adjustment Time* is assumed to be 1 year. *Target Wage Level* is determined using the actual value, and two additive effects. The first one is *Effect of Unemployment Rate on Wage Level* and it says that whenever unemployment rate falls below the natural (or normal) rate, wages should rise. The second effect is *Effect of Target Labor Rate on Wage Level* and it says that whenever *Target Labor Rate* (simply target labor divided by total labor) exceeds its reference (or normal) rate, wages should rise. The term 'rate' may seem confusing, since these variables are not flow variables and should not be called 'rates' in system dynamics terminology. However, *Unemployment Rate* is simply referring to a ratio in economics, thus all other related variables are labeled with this meaning.

Effect of Unemployment Rate on Wage Level is assumed to be a linear function of the difference between and the natural unemployment rate and the actual unemployment rate. *Effect of Target Labor Rate on Wage Level* is also assumed to be a linear function of the difference between 'Target Labor Rate' and its reference value, which is the ratio of labor under equilibrium conditions. Where U, U^*, T, T^*, W and W^* represents unemployment rate, the natural rate, target labor rate, the reference value of target labor rate, wage level and target wage level respectively, the effects of unemployment rate f_u and target labor f_t can be formulated as follows:

Effect of Unemployment Rate on Wage Level is assumed to be a linear function of the difference between and the natural unemployment rate and the actual unemployment rate. *Effect of Target Labor Rate on Wage Level* is also assumed to be a linear function of the difference between 'Target Labor Rate' and its reference value, which is the ratio of labor under equilibrium conditions. Where U, U^*, T, T^*, W and W^* represents unemployment rate, the natural rate, target labor rate, the reference value of target labor rate, wage level and target wage level respectively, the effects of unemployment rate f_u and target labor f_t can be formulated as equation 5.3.

$$f_u = U^* - U \tag{5.3a}$$

$$f_t = T - T^* \tag{5.3b}$$

$$W^* = W(1 + f_u + f_t) \tag{5.3c}$$

Accordingly, wages respond only to the changes in labor sector. In a zero-inflation environment, this sounds reasonable. However, after Phillips Curve is transformed into 'Expectations Augmented Phillips Curve', it is believed that wages rise due to an expectation of inflation, even if there is no disequilibrium in labor market, meaning that unemployment rate is at its natural level. From this perspective, wage setting equations may seem incomplete.

However, the effect of expected inflation on wages is captured by the trend correction in *Wage Level Adjustment*. Consider an economic system in equilibrium with zero-inflation. When, by the monetary authorities, it is decided to constantly inject new money into the system, the first response is seen as an increase in total sales, in real terms. Neither *Employed Labor* nor *Wage Level* is adjusted to this new equilibrium at this point. Firms have two tools to cope with increased sales; setting a higher price due to a higher markup, and increase labor in order to meet the increased sales. The initial increase in wages is due to this desire of firms to hire more labor. At this point, there is no trend in *Wage Level*; it only responds to the changes in the bargaining power of labor and capital owners.

As the money injection continues, unemployment rate remains below its natural value for some time and *Wage Level* systematically remains below its target value, because the target itself is constantly increasing as well. When the trend in this target value is perceived by the economic agents, *Wage Level* begins to respond not only labor market conditions, but also the trend. When *Wage Level* closes the systematic gap due to this trend effect, prices begin to reflect this trend as well since firms are using a 'markup rule' in price setting. After all adjustments are complete, unemployment rate rises back to its natural rate, real economic aggregates reach their equilibrium values, and the constant increase of money in the system begins to be reflected to nominal values of prices and wages. In other words, sustained money injection causes the economic agents to expect a constant rate of inflation (assuming that production factors and their productivity remain unchanged), and adjust prices and wages accordingly without any disequilibrium in labor market.

5.7 Investment Sector

In this model, *Aggregate Demand* is assumed to be composed of *Consumption* and *Investment*. *Consumption*, in nominal terms, is determined by the circular flow of income, in the form of money, which is explained in Section 5.2. *Investment*, is formulated as a function of *Relative Interest Rate* and *Desired Nominal Investment*.

Desired Nominal Investment reflects the rate of investment when there is no interest rate effect.

In economics, investment is assumed to be affected by various reasons. If, for any reason, output per capital rises, that means investment becomes profitable and should rise as well. Moreover, in the short run, an increase in sales or an expectation of it, is also assumed to increase investment. Any risk factor is also considered to negatively effect investment.

In this model, the risk factor is ignored, and investment is assumed to be affected by the interest rates, productivity of capital, and expected sales. Interest rate factor is explained in Section 5.2. The other two effects, which are captured in *Desired Nominal Investment*, are explained in the stock-flow model given in Figure 5.16.

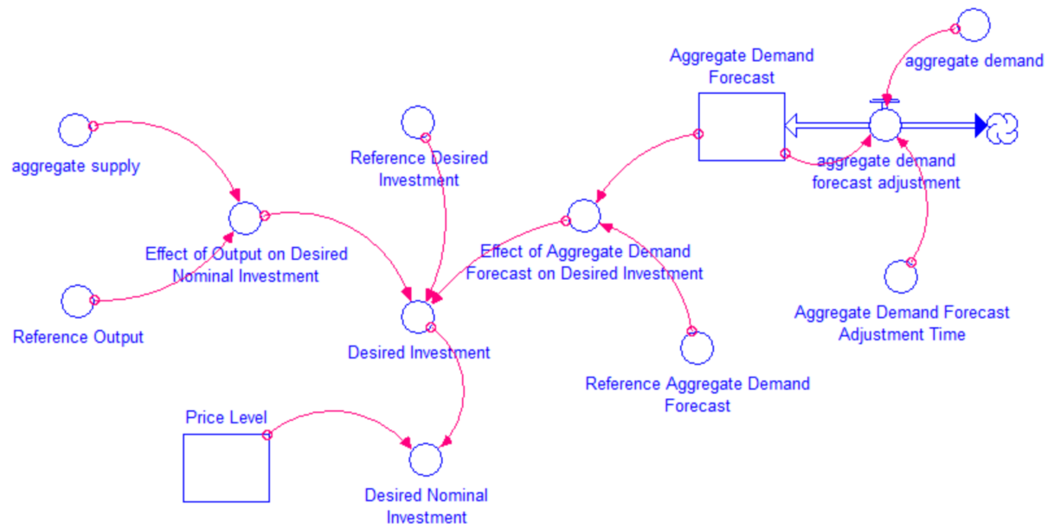

Figure 5.16 : Stock-flow representation of Investment Sector.

There is only one stock variable in this sub-model, called *Aggregate Demand Forecast*. It is adjusted to *Aggregate Demand* with an adjustment time of *Aggregate Demand Forecast Adjustment Time*. Adjustment process also includes a trend correction so that the forecast would not systematically fail.

The first effect determining *Desired Nominal Investment* is *Effect of Aggregate Demand Forecast on Desired Investment*. It is the ratio of *Aggregate Demand Forecast* to its reference (or initial) value. Accordingly, as the *Aggregate Demand Forecast* increases, *Desired Nominal Investment* also increases proportionally.

This effect could be defined in terms of *Aggregate Demand*, other than its forecast. However, since *Desired Nominal Investment* effects *Aggregate Demand* instantly (without a delay), there appears a circular causation and the model becomes impossible to simulate. In order to avoid this circular causation, the effect is assumed to be based on the forecast, which includes a delay in itself.

There is positive feedback loop in this formulation. An increase in investment increases aggregate demand by definition, and aggregate demand increases investment again which further increase aggregate demand. In economics, this is called the accelerator effect of investment and may generate instability. For details, see Goodwin [9].

The other effect on *Desired Nominal Investment* is called *Effect of Output on Desired Investment*. The idea behind is that, when output increases capital investment becomes more profitable and investors tend to invest more. The relation is assumed to be proportional.

Although there are many variables in this sub-model, it is only because every step of calculation is reflected as a variable with its meaning. The idea behind it can be presented by a very simple formula. Where Y_d^e and Y_s stand for demand estimate and output respectively, and k is a constant which captures all the constants and reference values in the stock-flow model, investment (I) can be formulated as in 5.4.

$$I = kY_d^e Y_s \tag{5.4}$$

The output of this sub-model is *Desired Nominal Investment* and it is used in monetary sector. In the monetary sector, the final value of nominal investment is determined by taking the interest rate effect into account. Later this nominal investment is divided by price level and used to calculate aggregate demand in goods sector.

5.8 Discussion

5.8.1 Equilibrating mechanism

The initial values of the variables of the model are set to equilibrium conditions. On equilibrium, aggregate demand is equal to aggregate supply, and saving is equal to investment. Price level and wage level are equal to their target values. Unemployment rate is equal to natural rate. All the inflows from the stocks are equal to corresponding outflows and the stocks are expected to remain stable.

When additional money is injected into the system, no matter how much, the equilibrium will be disturbed. According to the textbook version of this scenario, when nominal money supply increases, assuming that prices are sticky in the short run, real money supply increases as well and interest rates decline. Investment increases as a result of low interest rates, and shifts aggregate demand curve (which is assumed to be a function of price level) to right. In order to clear the goods market, aggregate supply and aggregate demand should meet at a new price level. At this new price level, real money supply and interest rates move back to their previous value. Also when this new price level is reflected to wages, aggregate supply curve shifts upwards, to cross the aggregate demand curve again at the previous quantities with this new higher value of price level. After all these adjustments take place, nominal money increase is proportionally reflected to price level and the economic activity returns to its previous values. Theoretically, if the prices can adjust quickly, these all happen at the same time. If the prices are assumed to be sticky in the short run, these adjustments take time. How much time these adjustments take time and in what order these adjustments complete is a matter of interpretation of the theory.

A similar mechanism can be defined based on the proposed system dynamics model. When new money is injected into the system, interest rates fall and investment rises. As a result, aggregate demand increases and leads to a demand pressure in the goods market. This pressure is a signal for labor market to increase aggregate supply by hiring more labor.

Aggregate demand and aggregate supply are defined as individual points on the price-quantity surface, as opposed to curves in the conventional interpretation. However, similar curves can be conceptually defined for the model as well. Aggregate demand is inversely related to price level, by definition, so the conceptual aggregate demand curve is straightforward. Aggregate supply curve, on the other hand, would have a different interpretation. Mainstream economic theory defines aggregate supply curve as it shows the optimal supply quantities for different values of price level. Conceptual aggregate supply curve for the model would be, on the other hand, about the desired price level reflecting the unit costs for the sustained supply of the corresponding quantities. In other words, in order to supply larger quantities, desired price level should be higher to cover the increased costs due to declined labor productivity. As a result, the conceptual aggregate supply curve of the model is similar in shape to the conventional curve, however, its interpretation is completely different in the sense that, firms are assumed to be quantity takers (realized quantities of aggregate demand) and price setters (with markup pricing rule).

When aggregate supply is increased by hiring more labor, unit costs increase due to decreased productivity and price level is adjusted to its new higher value. As a result, aggregate demand falls, demand pressure vanishes, and after every adjustment mechanism is completed, the model reaches its new equilibrium, only at a higher price level. The balancing mechanism explained above can be visualized by a balancing feedback loop, as given in Figure 5.17.

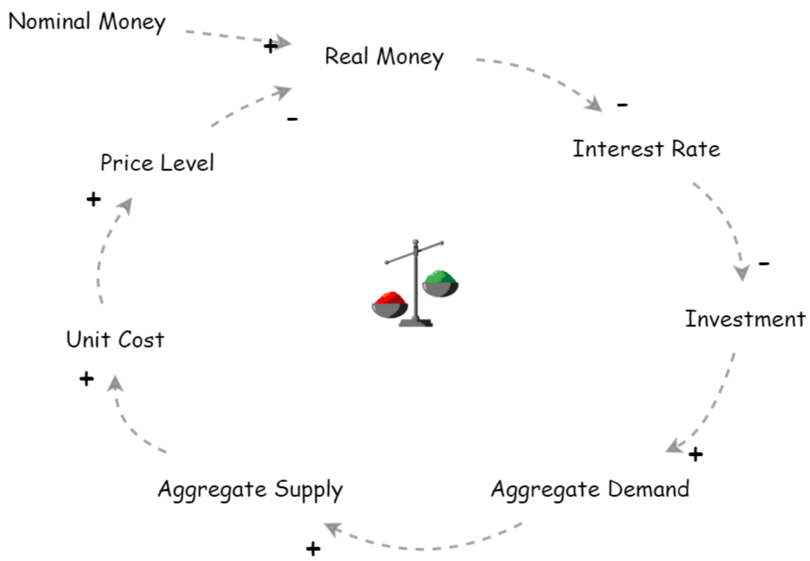

Figure 5.17 : Main balancing loop in the proposed system dynamics model.

The equilibrating mechanism of the model and the textbook version of equilibrium mechanism are similar, except the sequence of events, adjustment times, and the interpretation of adjustment processes. However, there is another mechanism in the model which actually works during the explained equilibrating mechanism, but skipped in both the story and the feedback loop. In order to complete the equilibrating mechanism, rises in the price level should be reflected proportionally to wage level, so that the real values of economic variables be the same as the previous equilibrium state.

In the textbook scenario, if nominal rigidities are ignored, the whole adjustment mechanism completes instantly and price increase is reflected to wages immediately, because every agent in the economy is super-rational and perfectly calculates the equilibrium values of everything. Or, if the wages are sticky in the short run, these agents are super-rational again and perfectly calculate the equilibrium values of everything, this time with including the adjustment costs of changing the nominal wages, and decide to adjust them slowly to the equilibrium points they already have calculated. In either case, why, how, when and to what extend the wage level is adjusted to its equilibrium value is unclear.

It is known empirically that an increase in money supply boosts aggregate demand and real economic activity rises for more than a year. During this time, unemployment rate is found to be decreasing, and wage inflation is found to be increasing. On the other hand, it is also empirically known that real wages are higher when unemployment rates are lower. This inverse relation between real wages and unemployment rate is named as Wage Curve by Blanchflower and Oswald [134]. This means that, the increase in wages should not solely be about the reflection of price level increases to wage level. The empirical regularity states that there is a connection between wage level and labor market conditions.

In the proposed system dynamics model, this connection is captured in labor sector and wage sector of the model. In other words, nominal wages change due to the labor market conditions, instead of reflecting the changes in the price level as stated by the textbook model. Accordingly, whenever unemployment rate is lower or declining, wage level rises more than it should otherwise. Likewise, whenever unemployment rate is higher or increasing, wage level declines more than it should otherwise. It is worth to note that, labor market conditions determine the rate of change in wages, not the wages themselves. This formulation is consistent with the empirical relation between unemployment rate and wage inflation. As a result, during the overall equilibrating process, unemployment rate falls behind its natural value and leads to a positive rate of change in wage level. This effect may contribute to the equilibrating mechanism, but also may over-shoot the equilibrium value of wage level, and generate cycles.

5.8.2 Extensions and limitations

The extent of System Dynamics Model of Inflation is bounded considering the purpose of the model. From a set of alternative models explaining the rules of an economic system, the simplest version which is complex enough to explain the related empirical behavior is chosen to be reported. However, it is worth to mention the possible ways of extending the model, in order to give a research direction for a generic economic model.

The proposed system dynamics model captures the dynamics in short and medium run. In other words, it explains the adjustment processes of prices, wages and output. During these processes, the potential output is assumed to be constant, and the only change in output is due to the temporary changes in the labor market. However, in the long run, the potential output may also change, due to the changes in total workforce, technology level, and capital stock. For this reason, in an extended model, workforce changes, technological improvement or changes in the capital stock can be included.

Another extension can be in the monetary sector. The turnover constants in the monetary sector are assumed to be constant. However, for very high levels of inflation, as in the hyperinflation case, businesses and households may tend to hold lower amounts of cash because it is loosing its value in high inflation environment. Similarly, when there is instability in the prices or overall economic activity, they may tend to hold higher amounts of cash to cover the uncertainty. These formulations have the potential to extend the set of behavior mods generated by the model. However, considering the scope of the proposed model, these effects are not included in the model.

In an extended model, a detailed monetary sub-model can be formulated to include credit mechanisms and reserve banking system. In the real system, the loans given to businesses for investments accumulate. If the generated income of businesses grow at a lower rate than total loans, investments will be restricted. Hypothetically, when the accumulated loans become too much and a payment risk occurs, the economic system may not recover on its own, no matter how much money is injected into the financial system. In that case, fiscal authority can intervene to recover the economic system, as happened in the great depression in 1930's and in the recent mortgage crisis after

2007. The effect of accumulated loans may be important for a more generic model, but ignored in the proposed model.

Finally, the policy of fiscal and monetary government can also be included in an extended model. Monetary policy can be defined as a Taylor rule, which aims to stabilize economy by monitoring the growth rate and inflation. Fiscal policy can be included in the model by defining direct taxes as outflow of money from household balances, indirect taxes as outflow of money from business balances, and government expenditure as inflow to business balances representing government expenditures.

The proposed model is initially set to represent zero-growth and zero-inflation environment. It is clear that this environment is not observed in reality. In reality, economic activity grows with a positive rate in the long run, and inflation is controlled by the monetary authority to be around a small but positive value. The behavior of this model can be interpreted as the behavior of the economic variables during their deviations from long-run trajectories.

6. MODEL BEHAVIOR

Model description of the proposed model is given in Chapter 5. Before the simulation phase, variables and parameters needs to be tuned, so that the model will be in equilibrium. After that, several shocks can be applied in order to see how the model responds. The aim of the model is to explain how money affects output. For this reason, only monetary shocks are analyzed. Two types of monetary shocks are designed. Firstly, money is injected for once inside *Loanable Funds*. Secondly, money is injected at a constant rate, representing the target inflation rate of the monetary authority.

6.1 Simulation Setting

Before the simulation phase, the model needs to be set to equilibrium conditions, so that simulation results can be meaningful. Equilibrium, in system dynamics models, means that value of stocks do not change. As a reference point, *Aggregate Supply* and *Aggregate Demand* are set to 1. The unit of these variables are 'real \$ per year' where '1 real \$' represents a unit of 'set of goods' which can be bought by \$1 at $t = 0$. *Price Level* is also set to 1, with a unit of '\$ per real \$', and represents the price of a unit of 'set of goods'. Moreover, *Employed Labor* is also set to 1.

Setting initial values for these stock variables is enough to calculate the initial values of other stock variables and the reference values. The initial values of *Business Balances* and *Working Balances* are set to \$0.25 so that *Income* equals to \$1 per year, being consistent with *Aggregate Supply*. *Loanable Funds* is set to \$0.25 considering to *Reference Loanable Funds Ratio*, which is arbitrarily set to 0.5. With these initial values, total amount of money in the system is divided equally to three stock values.

Reference Inventory Coverage is assumed to be 1 year, meaning that *Inventory* should cover one year of sales. Accordingly, the initial value of *Inventory* is set to 1 real \$. In equilibrium, a unit of labor corresponds to a production of a unit good, and the initial value of *Wage Level* can be calculated as \$0.7 to be consistent with *Price Level* and the labor's share of income (0.7). Labor's share of income comes from the exponent of the production function and consistent with saving rate, assuming that labor consumes all the income share while capital owners save.

Unemployed Labor is calculated based on *Natural Rate of Unemployment* and the initial value of *Employed Labor*. Since the natural rate is assumed to be 10%, the initial value of *Unemployed Labor* becomes $1/9$. All these calculations are done with the modeling software 'STELLA 7.0.3' by defining the initial values of stock variables as separate variables and linking them in order to make backward calculations. Other reference variables which are not mentioned here are also calculated in this manner.

Model is simulated in this equilibrium settings. Time horizon is set to be 10 years but for scatter diagrams, the model is simulated for 100 years in order to show more data points in the graphs and to easily define the properties of the graphs. Simulation step is set to be $1/256$, which is small enough considering the adjustment time parameters in the model. According to the simulation results, model is in equilibrium. The graph of *Aggregate Supply* and *Aggregate Demand* is given in Figure 6.1. Accordingly, both *Aggregate Supply* and *Aggregate Demand* preserve the initial state and the model is in equilibrium.

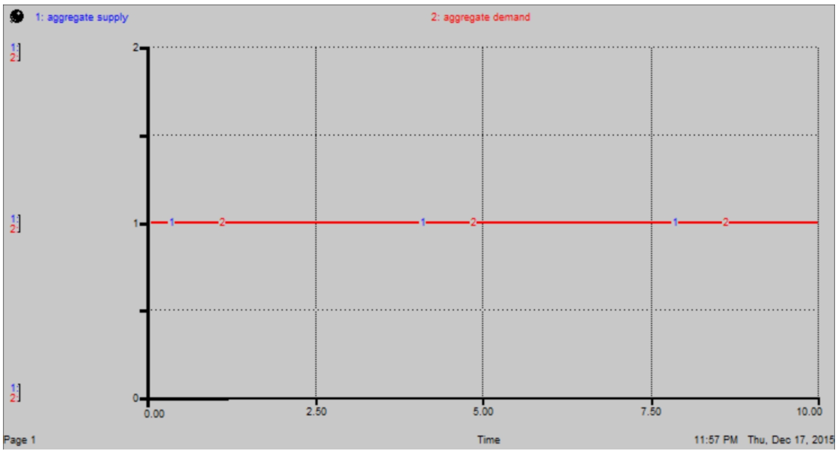

Figure 6.1 : Aggregate Demand and Aggregate Supply in equilibrium.

6.2 Money Shock

The first experiment is designed to inject additional money only once, at the beginning of the simulation. Initially, there are \$0.75 in circulation. 5% of this money is added to *Loanable Funds* at $t = 0$. The behavior of *Aggregate Demand* and *Aggregate Supply* is shown in Figure 6.2.

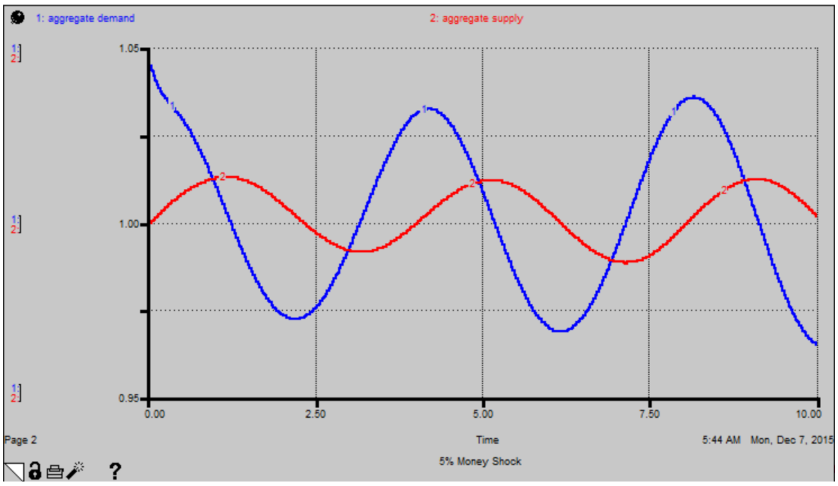

Figure 6.2 : Aggregate Demand and Aggregate Supply after 5% money shock.

According to the simulation results, the effect of the initial shock do not fade away. The cycle of *Aggregate Demand* has a larger amplitude than *Aggregate Supply*. The frequencies of both cycles are approximately 4 years. The peak of *Aggregate Supply* occurs approximately one year later than the peak of *Aggregate Demand*.

The amplitude of both cycles seem to rise in time. This may be a problem for the model, if the amplitude continues to rise forever. Simulation is run for 200 years in order to see if the cycles will converge to a path. Simulation step is doubled for this example, because of the computation capacity of the software. The behaviour of the variables in 200 years is given in Figure 6.3.

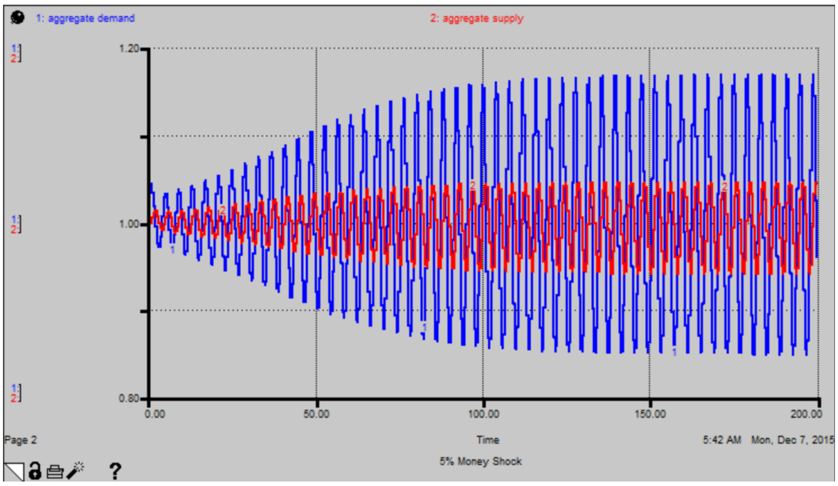

Figure 6.3 : Aggregate Demand and Aggregate Supply after 5% money shock - 200 years.

As seen in Figure 6.3, the cycles converge to a path at the end. *Aggregate Demand* moves approximately 17% and *Aggregate Supply* moves approximately 5% from the baseline at most. The results of this 200-year simulation should not be interpreted as the 200-year effects of the initial shock. Rather, the results show that the cycle generated by the initial shock does not grow forever. Moreover, it may be argued that an economic system may show cyclic behavior at all times because this type of monetary shocks are unavoidable and may occur anywhere in a 200-year time horizon.

Other than *Aggregate Supply* and *Aggregate Demand*, the behaviour of *Saving*, Investment and *Relative Interest Rate* can be analyzed. The results are given in Figure 6.4.

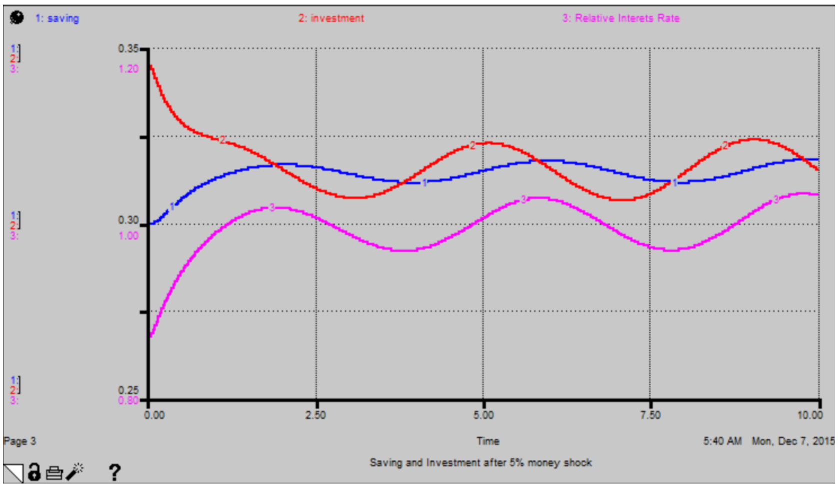

Figure 6.4 : Saving and Investment after 5% money shock.

The equilibrium values of *Saving* and *Investment* are set to 0.3. Because of the money shock at $t = 0$, *Investment* is 0.34 at the beginning of the simulation. This is due to the fact that, interest rates are too low, which can be monitored by *Relative Interest Rate*. All three variables cycle around the equilibrium but the cycles do not overlap. In other words, *Saving* and *Investment* are not always equal although their equilibrium values are.

After new money is injected to the system, price level is expected to rise eventually. *Price Level* and *Aggregate Supply* can be monitored together in order to see the relation between them. Figure 6.5 shows the simulation results.

As seen in Figure 6.5, *Price Level* reaches its equilibrium value (5% above the initial value) in approximately a year. After that, it continues to cycle similar to other economic aggregates. However, the cycles of *Price Level* and *Aggregate Supply* do not overlap. Instead, the period of price increase follows the period of economic growth.

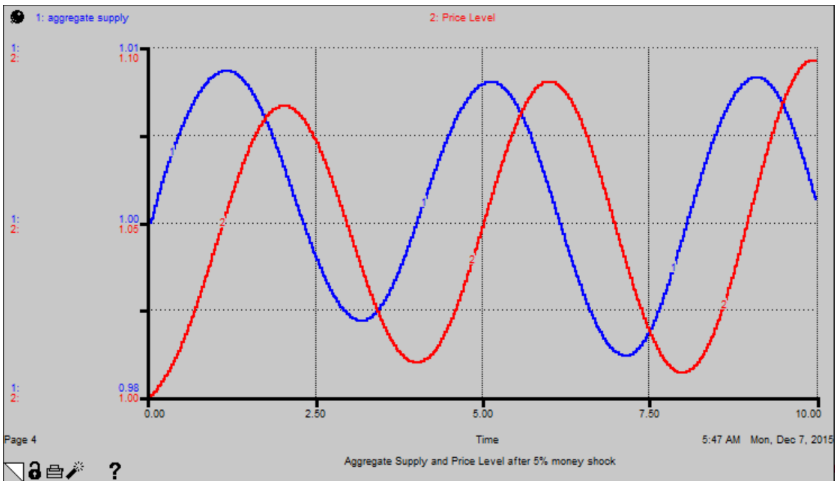

Figure 6.5 : Aggregate Supply and Price Level after 5% money shock.

A possible explanation of the simulation result that price increase follows economic growth with a delay is that economic growth may lead to an increase in factor prices, which is later reflected to prices. This explanation is supported by the behavior of *Wage Level*. As seen in Figure 6.6 , following a period of economic growth, *Wage Level* responds before *Price Level*. For this reason, *Real Wage Level* remain higher in this period.

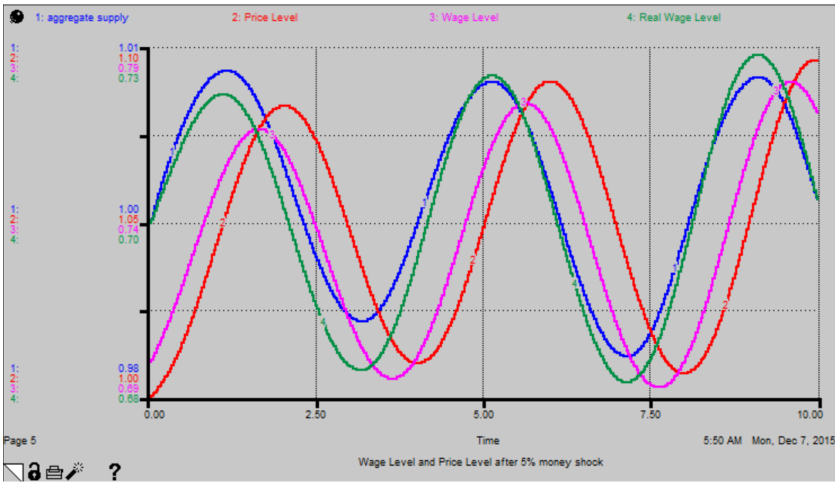

Figure 6.6 : Wage Level and Price Level after 5% money shock.

One of the concerns of this model is Phillips Curve. Phillips Curve originally refers to the relation between *Unemployment Rate* and *Wage Inflation*. An illustrative simulation is prepared in Section 5.5, to show that labor sector, isolated from the other sectors of the model, is capable of generating this relation, with similar properties of the empirical curve. With simulating the complete model, a similar relation appears, as shown in the scatter diagram in Figure 6.7. The value of *Wage Inflation* is given as percentage.

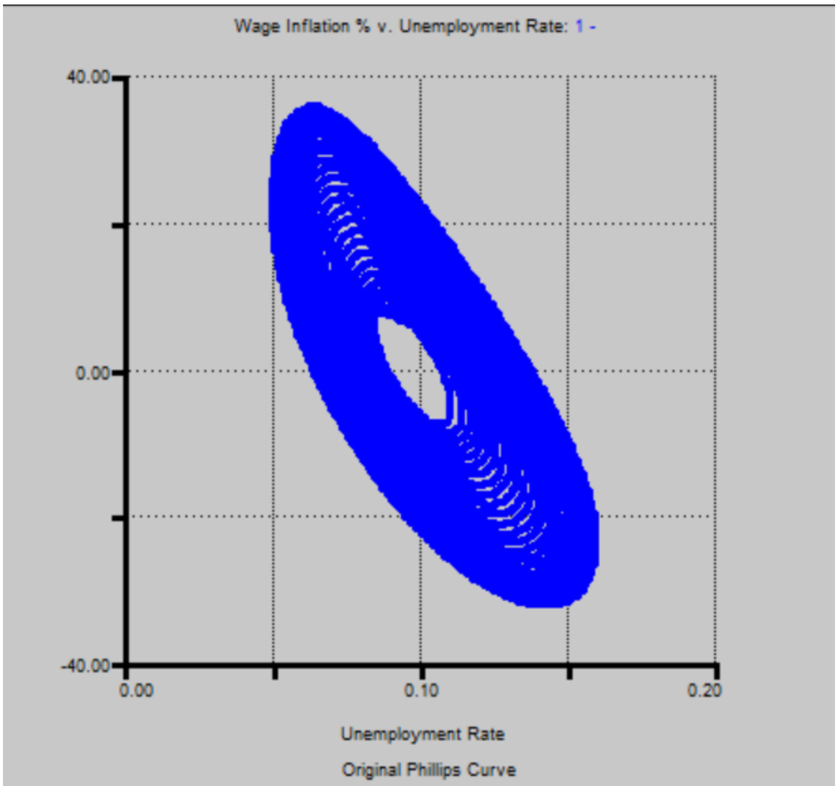

Figure 6.7 : Scatter diagram of unemployment rate and wage inflation.

The scatter diagram shows that the relation between *Unemployment Rate* and *Wage Inflation* is inverse and slightly non-linear. Moreover, when simulated slowly, the counter-clockwise cycle is apparent. Figure 6.8 shows the data for the first 3 years, representing this behavior.

The original Phillips Curve, is later interpreted as the relation between *Inflation* and *Unemployment Rate*. The model is expected to show this relation as well. Figure 6.9 represents a scatter diagram of *Inflation*, the value of which is given in percentage, and *Unemployment Rate*.

The simulated Phillips Curve shows an inverse relation as expected. The data points are less scattered around the average curve, compared to Figure 6.7. A slight non-linearity is seen as well.

The relation between *Real Wage Level* and *Unemployment Rate* may also be concerned. In economics, it is believed that there is a negative relation between them. This relation is supported by empirical data, and it is called 'Wage Curve' [134]. Figure 6.10 shows the scatter diagram of these two variable. Simulation horizon is set to 100-years, in order to generate more data-points in the diagram.

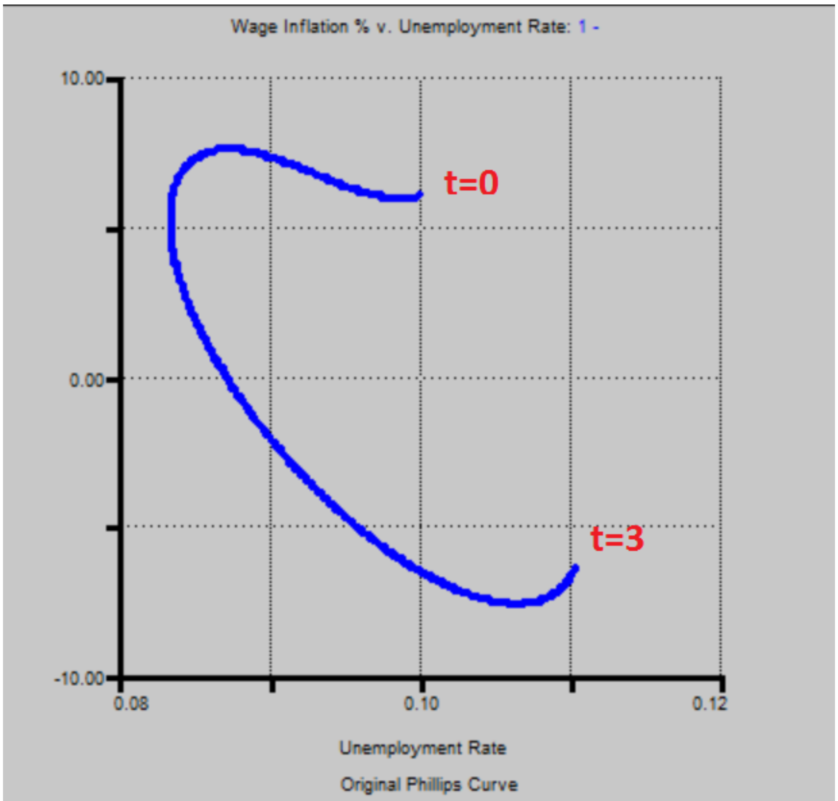

Figure 6.8 : Scatter diagram of unemployment rate and wage inflation for the first 3 years.

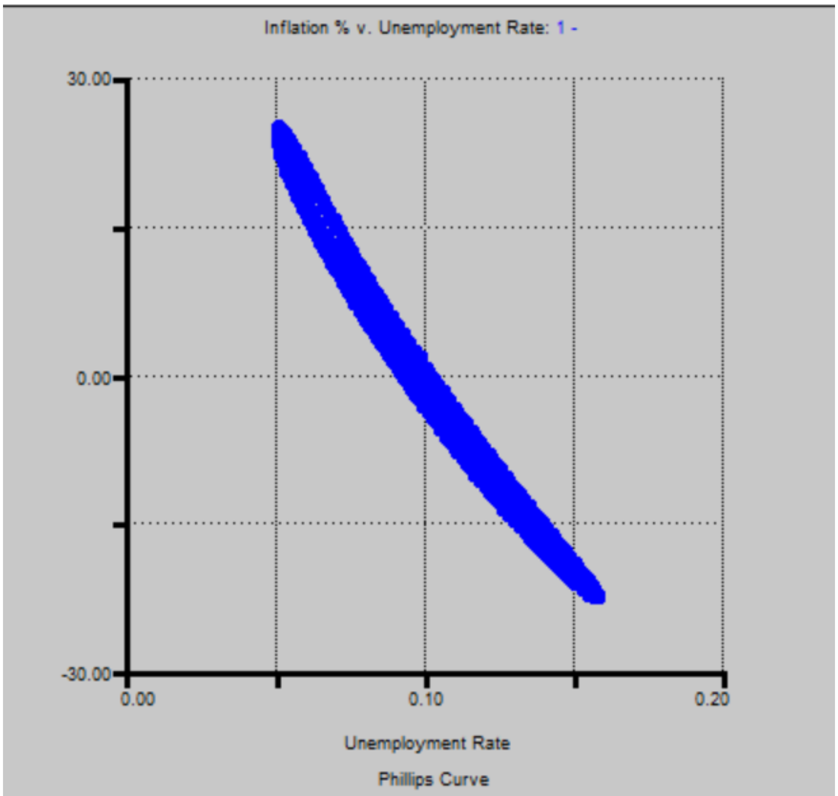

Figure 6.9 : Scatter diagram of unemployment rate and inflation.

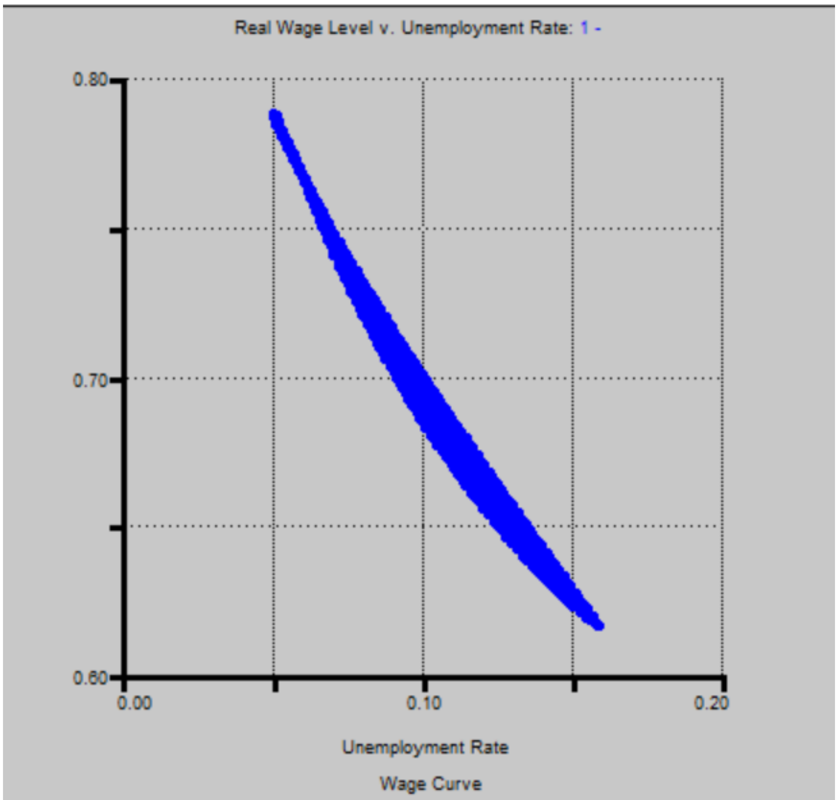

Figure 6.10 : Simulated Wage Curve appear after 5% money shock.

According to the scatter diagram, there is a negative relation between *Real Wage Level* and *Unemployment Rate*. It is worth to note that, such a relation is not directly implied in any formulation of the model. Rather, the stock-flow structure gives rise to this dynamic behavior due to the causality beneath. In other words, the proposed system dynamics model is capable of generating a 'simulated wage curve' which is similar to the empirical one.

As explained before, the relation of *Aggregate Supply* and *Price Level* illustrated in Figure 6.5 shows that there is a delay between the cycles. This delay can be interpreted as the delay between *Inflation* and Growth Rate. The delay between them, or the late response of *Inflation* compared to *Growth Rate*, is called 'Inflation Persistence' by Fuhrer and Moore [119] and Mankiw [14]. This persistence is shown in Figure 6.11.

Trend function is used to estimate the growth rate because *Aggregate Supply*, considered to represent GDP, is a flow variable and momentary change cannot be calculated directly. *Inflation* is also estimated with the same trend function, with another temporary variable *Inflation Rate*, in order to make the comparison meaningful. As seen in the graph, there is a delay less than a year, between the peak

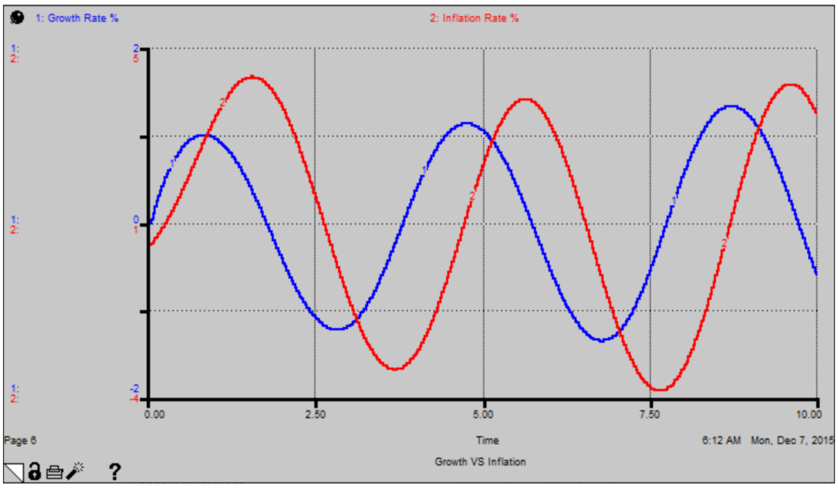

Figure 6.11 : Delayed response of inflation to growth rate.

points of the variables. In other words, *Inflation* is persistent in the proposed system dynamics model, consistent with the empirical fact.

In this section, the effect of money injection on an economic system is explored. Money injection appears to be triggering a cycle in the model, with the assumed parameter values, which converges to a path in the very long run. The behavior of selected variables, such as *Aggregate Supply*, *Price Level*, *Wage Level*, *Unemployment Rate* and *Inflation* are explored during this cycle, and the results are consistent with the stylized facts. Empirical relations such as 'original Phillips Curve', 'Phillips Curve' and 'Wage Curve' can be observed in the simulation results.

This simulation experiment can be interpreted in another way. In this model, it is assumed that the amount of money, is strictly controlled by the monetary authority. However, in practice of current monetary system, monetary authority can control the amount of money only indirectly. In other words, central banks provide as much money as wanted by the banks in daily transactions, and control this money flow through different tools as policy interest rates and reserve ratios.

During the control process, there are delays in measurement, forecasting and decision making. Thus, such a money shock assumed in this experiment, can happen anytime in reality, and that would be unavoidable. For this reason, even if the effect of a money shock dissolves in time with different parameter values, the economic system may always show a cyclical behavior due to various unavoidable shocks. In other words, cycles generated by money shocks can be a built-in property of the economic system.

During the model generation phase, different parameter settings are tested. Although each parameter setting leads to a different results, the main behavior in cycles do not change significantly. However, for some parameter values, cycles fade away after some time. In other words, there are two distinct behavior of the proposed model, one representing business cycles and the other representing only temporary effects.

Labor Adjustment Time is a crucial variable which affect the mode of behavior. This parameter is assumed to be 2 years initially. Only for generating a different mode of behavior, this parameter is set to be 10 years. Figure 6.12 shows the graph of *Aggregate Supply* for 10 years.

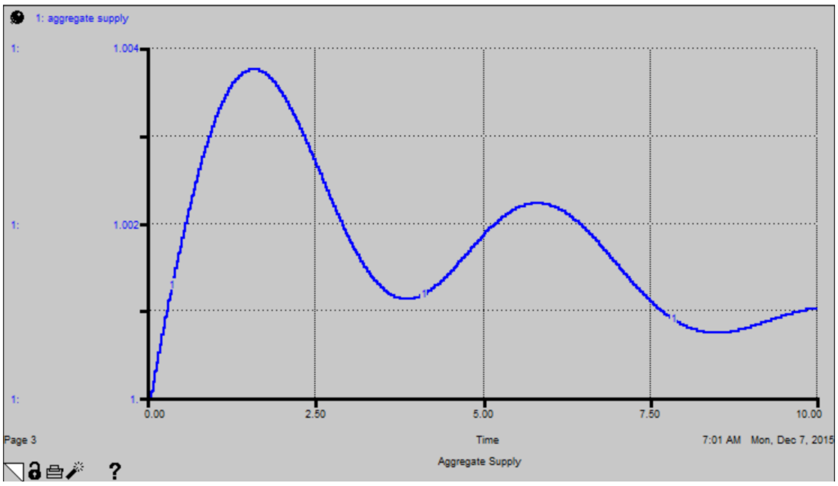

Figure 6.12 : Response of *Aggregate Supply* to money shock when L^* = 10 years.

Accordingly, *Aggregate Supply* increases more than 0.4% after 1.5 years, and slowly and cyclically goes down to equilibrium value. The effect of money shock is still above 0.1% after ten years. When simulated for 100 years, the cycle appears to fade away as seen in Figure 6.13.

The behavior of *Aggregate Supply* is consistent with the stylized fact that money has a real affect in the short-run but is neutral in the long-run. This short-run effect gets smaller as time passes, but still visible after 10 years. This result is also consistent with empirical result, which is discussed by Mankiw [14].

6.3 Inflation Shock

The second experiment is designed to inject additional money at a constant rate, at the beginning of the simulation. Initially, there are $0.75 in circulation. Using the flow variable of *Money Injection*, which flows into *Loanable Funds*, the amount of money

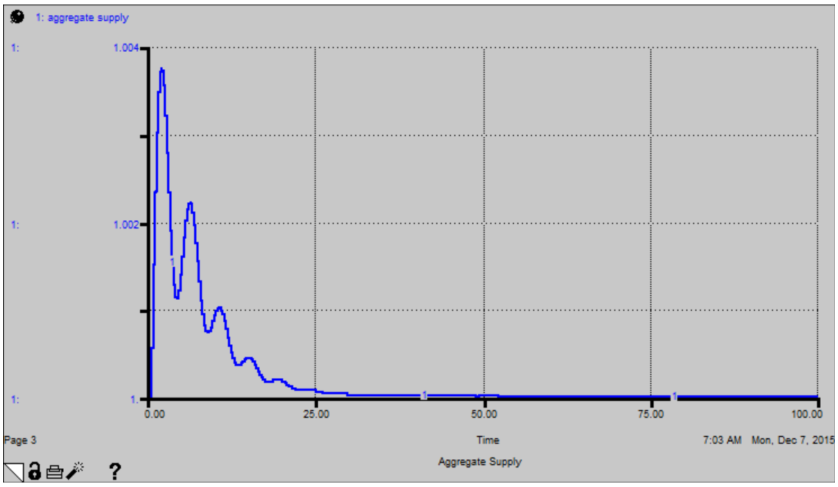

Figure 6.13 : Response of *Aggregate Supply* to money shock when L^* = 10 years (simulated for 100 years).

is increased with a rate of 5% per year. Following the assumption of money neutrality and QTM, *Inflation* is expected to be 5% in the end, although there may be real effects in the short-run.

Simulation is run for 10 years. The behavior of *Aggregate Supply* is given Figure 6.14, in comparison with the behavior in the first experiment. Blue line shows the effect of money shock while red line shows the effect of inflation shock. Accordingly, *Aggregate Supply* is positively affected by inflation shock and reaches its peak value approximately after 2 years. Then it begins to cycle around the equilibrium value. The response time is slightly larger compared to money shock experiment.

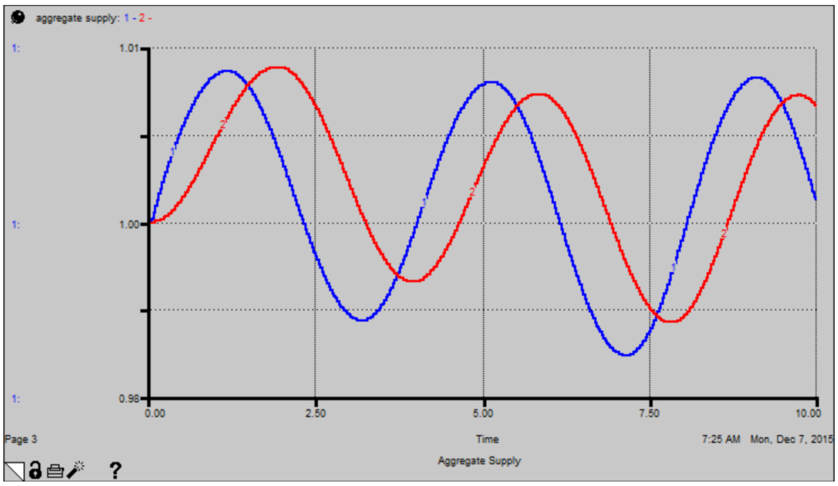

Figure 6.14 : *Aggregate Supply* after money shock (blue) and inflation shock (red).

A similar cycle occurs in *Aggregate Demand* as well. Figure 6.15 shows *Aggregate Demand* and *Aggregate Supply* together after inflation shock at $t = 0$. Vertical axis is scaled to be between 0.96 and 1.04. *Aggregate Demand* responds relatively faster and there is a difference between cycle phases approximately 1 year. The amplitude of *Aggregate Demand* is also larger compared to *Aggregate Supply*.

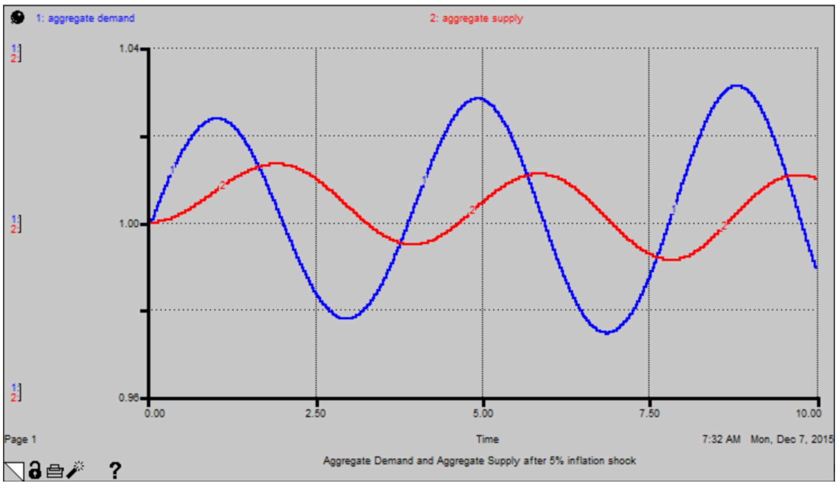

Figure 6.15 : *Aggregate Supply* and *Aggregate Demand* after inflation shock.

In order to see if the cycle generated by inflation shock is a limit cycle, the model can be simulated for 200 years. To simulate for such a long time period, simulation step is set to be $1/128$ due to limitation of the software. According to Figure 6.16, the cycle converges to a path.

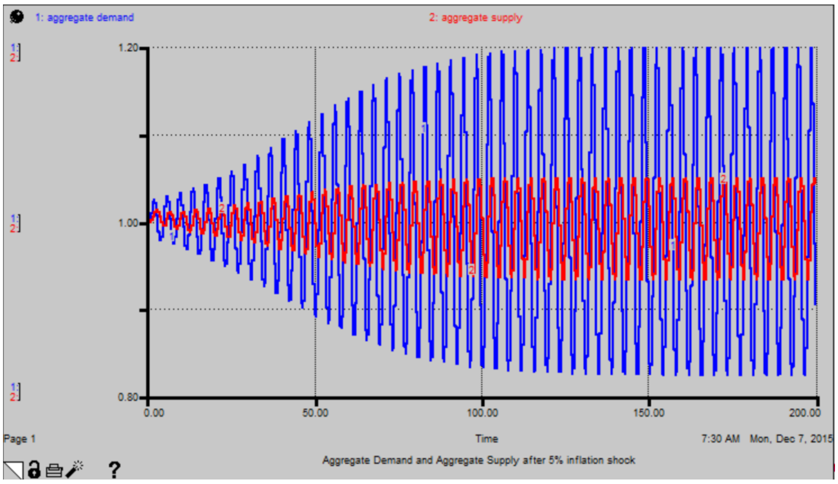

Figure 6.16 : Aggregate Demand and Aggregate Supply after 5% inflation shock - 200 years.

The relation between *Unemployment Rate* and *Wage Inflation* may be concerned after the inflation shock. The scatter diagram in figure 6.17 shows that *Wage Inflation* is inversely related to *Unemployment Rate* and this relation is slightly non-linear. This simulated Phillips Curve is similar to one in Figure 6.7.

Although not apparent in the scatter diagram, the rotation of the simulated data points are counter-clockwise. This cyclic behavior is similar to the money shock case. It is

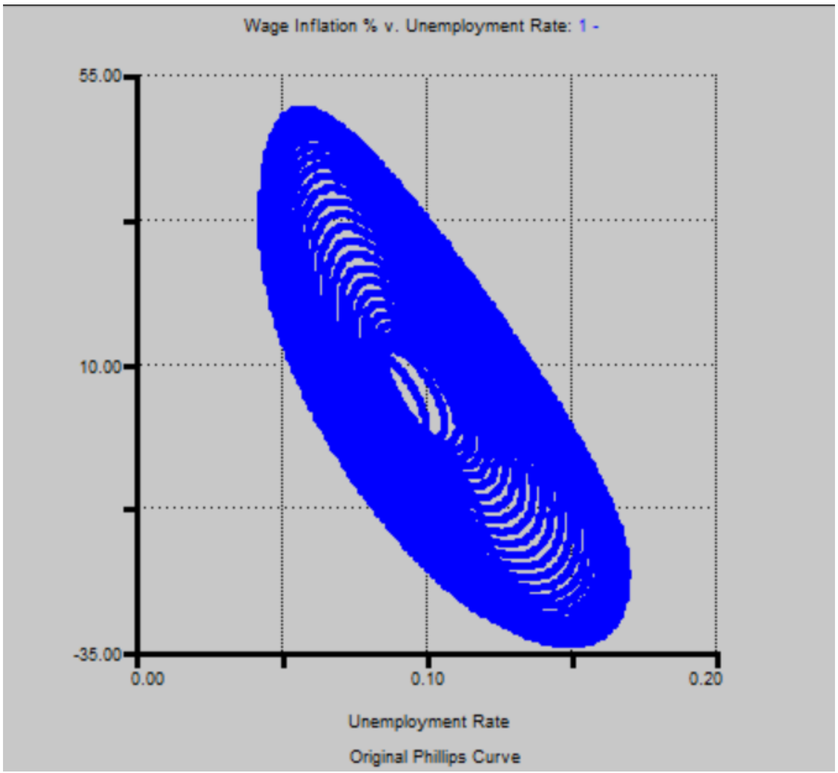

Figure 6.17 : Scatter diagram of unemployment rate and wage inflation after inflation shock.

also similar to the empirical data of Phillips [13]. In other words, when unemployment rate is falling, wage inflation is higher than it would be otherwise. Similarly, when unemployment rate is rising, wage inflation is lower than it would be otherwise. Not only the rate of unemployment, but also the direction of change of it affects the rate of change of wage level.

This cyclic behavior can be shown with a simulation of limited time period. Figure 6.18 shows the first 3 years of the simulation. The data points for $t = 0$ and $t = 3$, and the curve between them clearly indicates a counter-clockwise cycle around the average.

The model is expected to show the relation between *Inflation* and *Unemployment Rate* as well. This is the common interpretation of Phillips Curve. Figure 6.19 represents the concerned scatter diagram and unit of *Inflation* is given as percentage. The shape of the curve is similar to the scatter diagram in Figure 6.9.

The inverse relation between *Real Wage Level* and *Unemployment Rate* which is observed after 5% money shock has been given in Figure 6.10. This relation can be called Wage Curve. Inflation shock generates the same inverse relation as well.

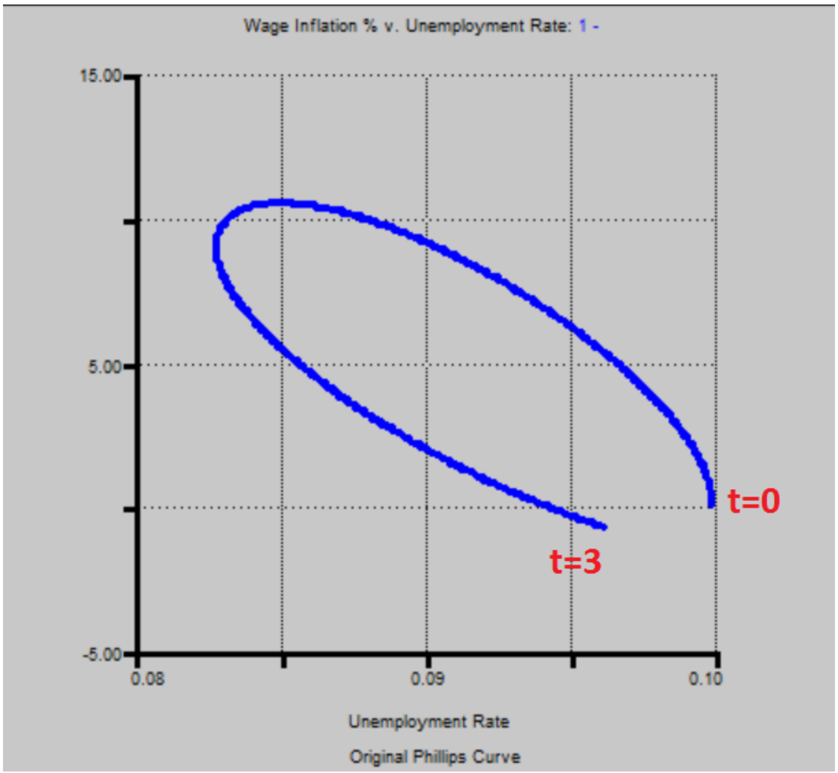

Figure 6.18 : Scatter diagram of unemployment rate and wage inflation for the first 3 years, after inflation shock.

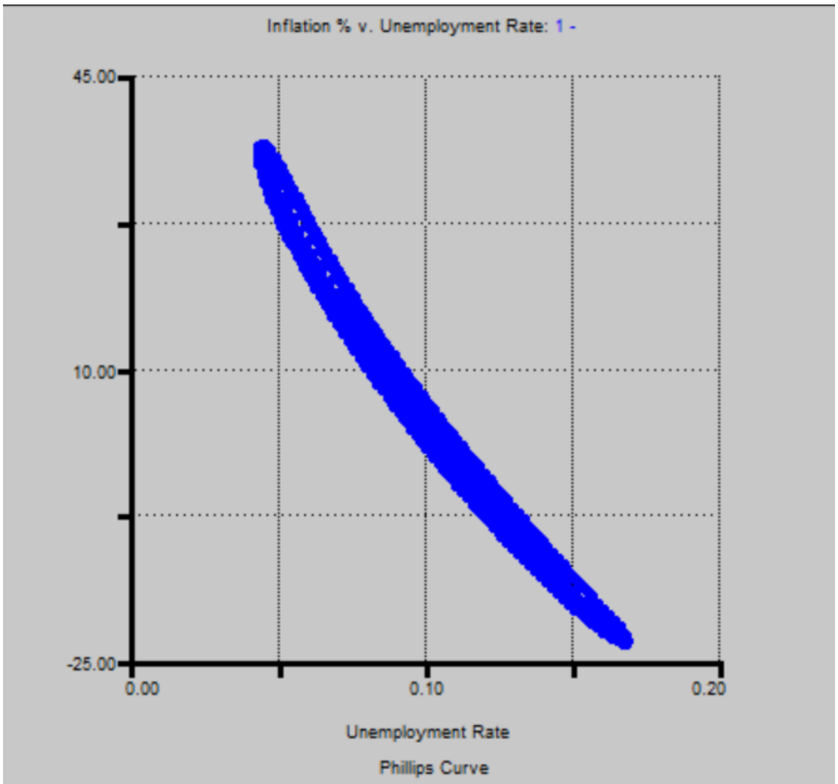

Figure 6.19 : Scatter diagram of unemployment rate and inflation after inflation shock.

Figure 6.20 shows the related scatter diagram. Accordingly, *Real Wage Level* rises when *Unemployment Rate* is below its natural rate and declines when it is above.

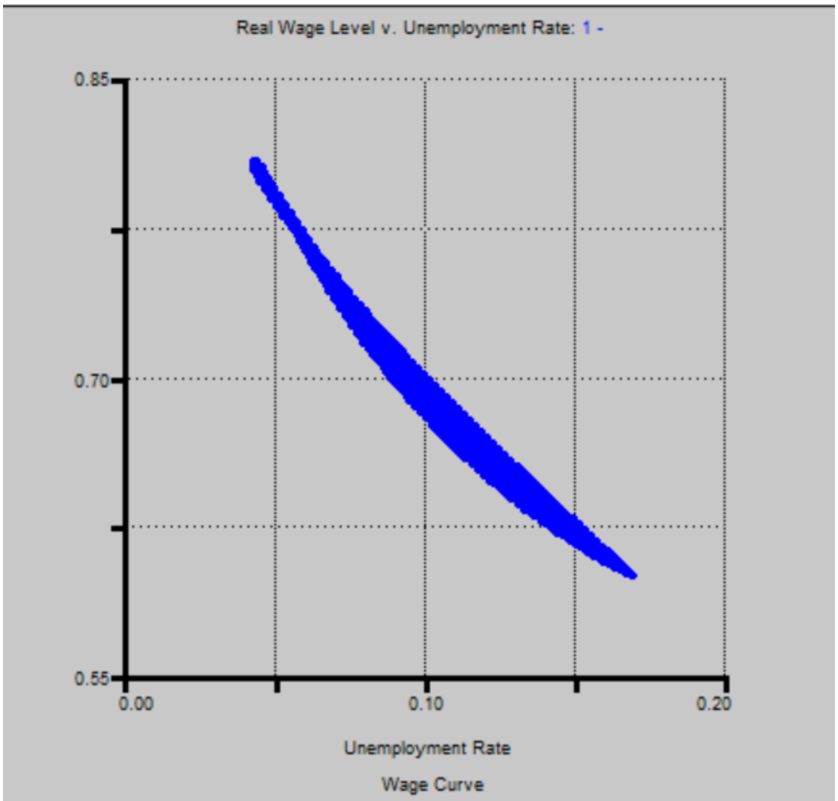

Figure 6.20 : Simulated Wage Curve after 5% inflation shock.

Effect of 'Expected Inflation' is later included in the Phillips Curve relation and is called 'Expectation-Augmented Phillips curve'. If the shock had not created a cycle, expected inflation would be 5% in equilibrium. However, since the shock generates a cycle, *Inflation* and its expectation may change from time to time. In order to see if the model generates a similar relation, the model requires two additional variables called *Expected Inflation* and *Unexpected Inflation*. Figure 6.21 shows the stock-flow representation of *Expected Inflation* and *Unexpected Inflation* is simply the difference between *Inflation* and *Expected Inflation*. Expectation about inflation is assumed to be backward-looking, standard adjustment structure with an adjustment time of 1 year.

Figure 6.22 shows the scatter diagram of *Unexpected Inflation* and *Unemployment Rate*. Accordingly, the relation is inverse and slightly non-linear. These properties are similar to the original Phillips Curve.

It is important to note that, all the versions of Phillips Curve can be virtually generated by the proposed model. It seems that, they are all valid representations of reality, if the percentage change of the amount of money is constant. However, in an environment

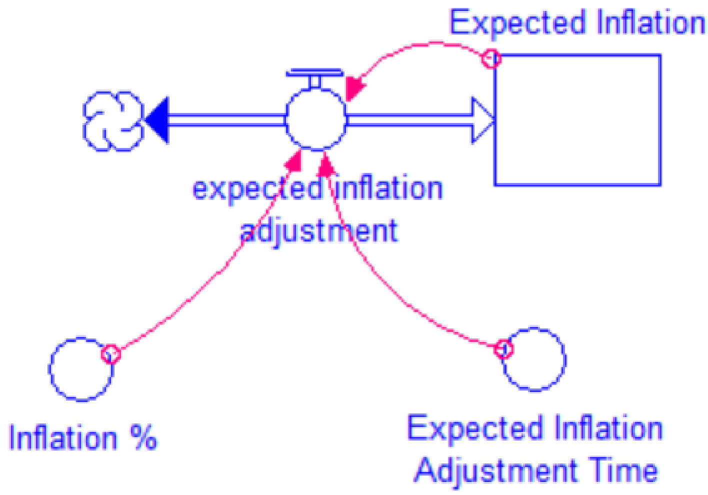

Figure 6.21 : Stock-flow representation of *Expected Inflation*.

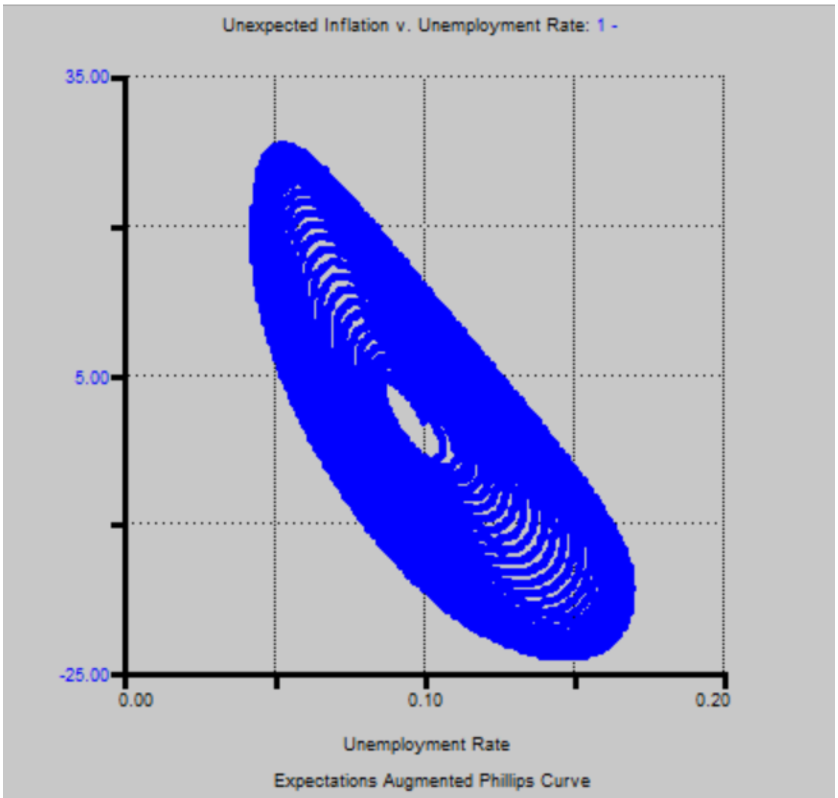

Figure 6.22 : Expectation-Augmented Phillips Curve after 5% inflation shock.

where the percentage change of the amount of money is volatile, this conclusion may not hold.

The delayed response of *Inflation* to *Growth Rate*, or in other words 'Inflation Persistence', may be concerned as well. Figure 6.23 shows the simulation results for 10 years. Both of the variables are estimated using TREND function of the software, in order to make the comparison meaningful.

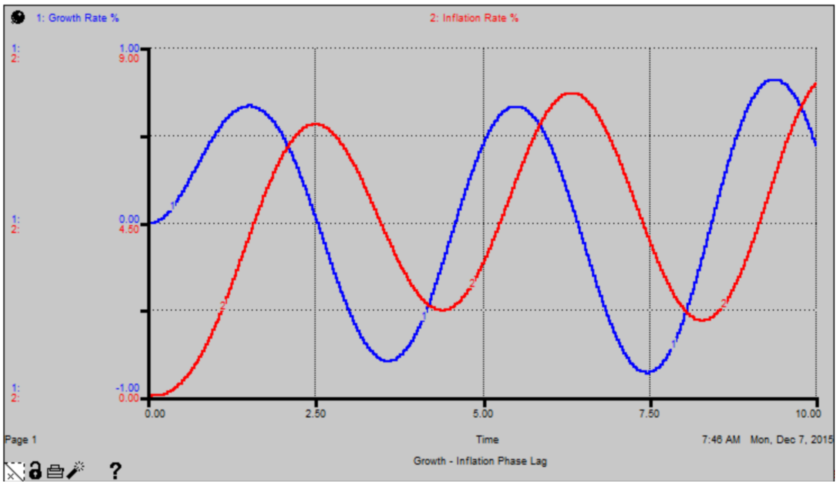

Figure 6.23 : Delayed response of *Inflation* to *Growth Rate*, after inflation shock.

According to Figure 6.23, the real effects of money injection appears before the monetary effects. Both variables cycles around the equilibrium value with the same frequency, but the peak points to not overlap. In other words, there is a time delay between the cycles, which is approximately a year.

In Section 6.1, increasing the constant of *Labor Adjustment Time* to 10 years, resulted the cycle to vanish in the long run. In order to see if inflation shock leads to the same result, adjustment time is set to 10 years again. Figure 6.24 shows two simulation results of *Aggregate Supply*; one with money shock and the other with inflation shock.

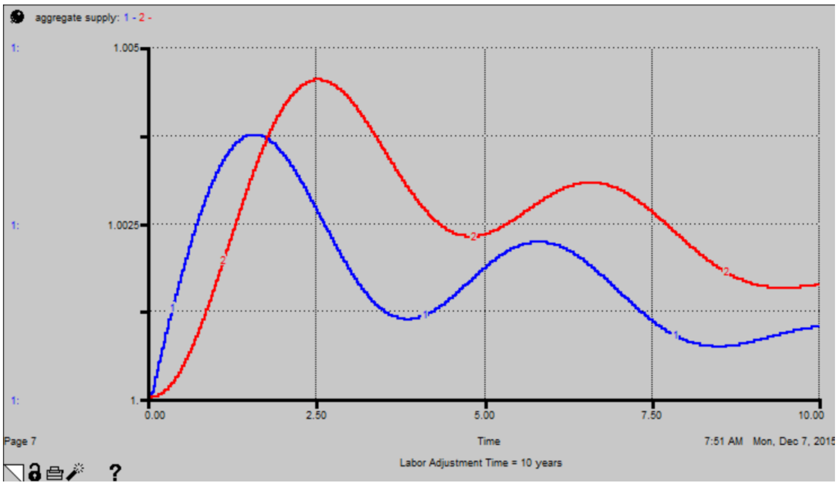

Figure 6.24 : Response of *Aggregate Supply* to money shock (blue) and inflation shock (red) when $L^* = 10$ years.

Accordingly, *Aggregate Supply* rises approximately 0.5% as a result of inflation shock, after approximately 2.5 years. In the money shock case, the rise is approximately 0.4% after approximately 1.5 years. In both cases, *Aggregate Supply* tends to fall back to its initial value. In order to see if that happens eventually, the model is simulated for 100 years. The simulation result is given in Figure 6.25.

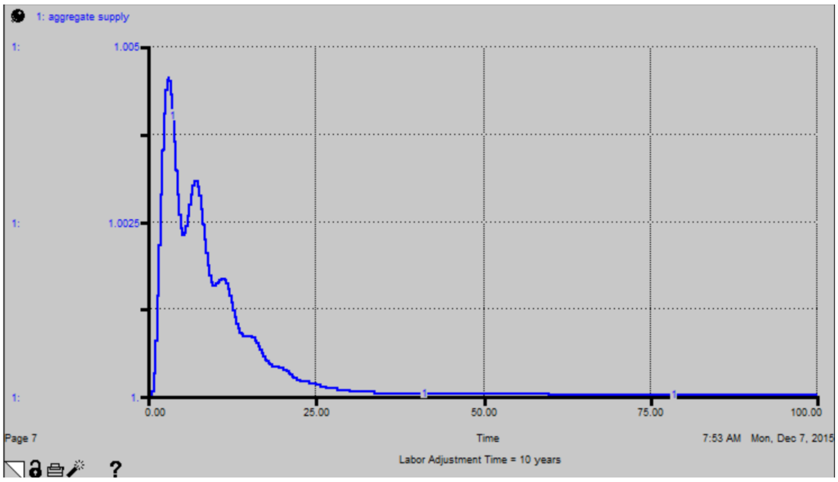

Figure 6.25 : Response of *Aggregate Supply* to inflation shock when L^* = 10 years (simulated for 100 years).

According to the simulation result, the cycle vanishes quickly. *Aggregate Supply* converges to its initial value after 100 years. In other words, rate of change of money has real effects in the short run, but neutral in the long run. This conclusion is similar to the money shock case.

7. MODEL VALIDATION

In Chapter 5, System Dynamics Model of Inflation is introduced. It is a theoretical model which uses the ideas, concepts and even other models of the Keynesian and Post-Keynesian school. The proposed model aims to explain how money affects output.

In Chapter 6, behavior of the model is explained with some simulation results. These results are discussed under the lights of previous empirical and theoretical findings in the literature. The similarities between the behavior patterns of the simulations and empirical findings are presented as indicators of model validity.

In this chapter, validity of the model will be further analyzed. The aim of this procedure is not to conclude that the model is valid or not, because such a clear distinction is not possible for system dynamics models. Barlas defines validity as “usefulness with respect to some purpose” [135]. For this reason, validation procedure is used to discuss ’how useful’ the model is, considering its purpose.

This chapter begins with a verification test, namely integration error test, in order to show that the behavior patterns produced by the model are not caused by computational errors. Later, several validation tests will be applied. Validation procedure is divided into two; namely structural validation and behavioral validation. Structural validity is about the internal structure of the model itself while behavioral validity is about the output it produces.

7.1 Verification

The mathematical formulations of system dynamics models include differential equations. However, for simulation purposes, these formulations are treated as difference equations. Simulations are carried out for small time steps, so that the results of difference equations can be similar to the differential equations.

For the purpose of model verification, integration error test is applied. This test is carried out in order to see if the right simulation step is chosen. If the simulation step is too high, then the computation time would be small, but the results would be different than the ideal differential equation results. If the simulation step is too low, then the results would be similar, but the computation time would be long. For the purpose of model validity, integration error should be avoided, and the simulation step should be small enough. In practice, if the results change significantly, simulation step is halved until the the successive results are similar.

To avoid computation errors, simulation step should be in the form of 2^{-n}. Initially, $1/32$ is chosen as the simulation step. However, the model turned out to be too sensitive to this simulation step. It is halved until it is $1/256$, for which the simulation results do not change significantly. As an example, *Aggregate Demand* and *Aggregate Supply* after %5 money shock is simulated with a time step of $1/128$ in Figure 7.1 and a time step of $1/256$ in Figure 7.2. There is no significant difference between these simulation results and $1/256$ is considered to be small enough simulation step.

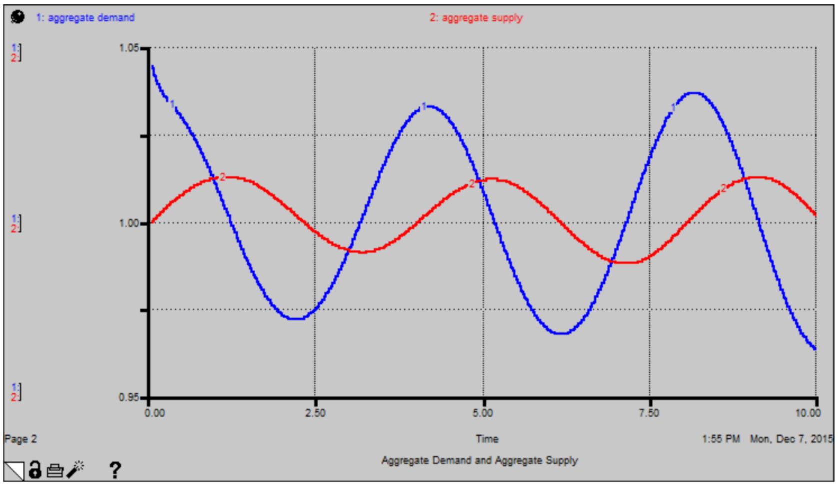

Figure 7.1 : *Aggregate Demand* and *Aggregate Supply* when time step is $1/128$.

In Chapter 6, model is shown to produce a limit cycle, for some parameter values. It may be of concern that whether this limit cycle is caused by computation error. In order to check this possibility, even smaller simulation steps are required. Simulation step of $1/256$ is the smallest simulation step that the software Stella 7.03 allows for a 100-year-simulation.

In order to simulate the model for smaller time steps, an algorithm is written in C# language. Simulation is run five times for 200 years, and simulation steps are chosen

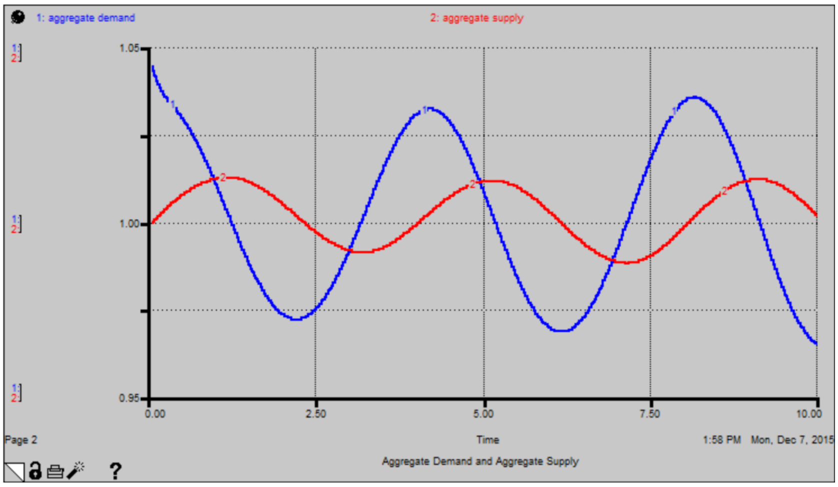

Figure 7.2 : *Aggregate Demand* and *Aggregate Supply* when time step is $1/256$.

as $1/256$, $1/512$, $1/1024$, $1/2048$ and $1/4096$ respectively. In each case, 1% money injection leads to a limit cycle. The maximum value of *Growth Rate* is found to be approximately 11% for small simulation steps. Values of *Growth Rate* at the end of each year in the simulation for 200 years is given in Figure 7.3, where simulation step is $1/4096$. These simulations ensure that limit cycle is not the result of a computation error, but the very property of the model itself.

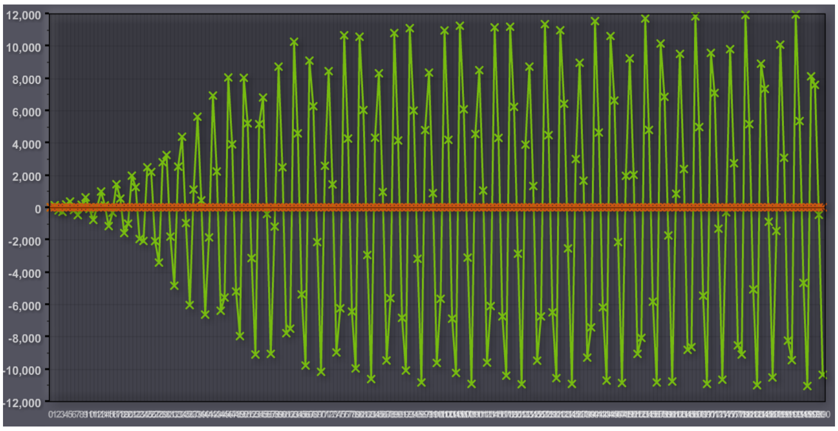

Figure 7.3 : Limit cycle of *Growth Rate* in 200 years when time step is $1/4096$.

7.2 Structural Validation

7.2.1 Structure confirmation test

'Structure Confirmation Test' concerns whether the individual relations within the model represent the relations in the real system. If it is carried out as an empirical test, the relations or mathematical equations in the model should be observed in the empirical data. On the other hand, if it is carried out as a theoretical test, the relations or mathematical equations in the model should be consistent with the knowledge in the theoretical literature.

The proposed model includes many sub-models and formulations, some of which are directly adopted from theoretical models and others are justified by empirical findings. For instance, monetary sector of the model is directly adopted from an earlier model of Phillips [1], which is consistent with the theoretical knowledge of the circular flow of income. On the other hand, labor sector and wage sector are formulated in accordance with the arguments given in the empirical paper of Phillips [13], and can be justified by empirical observations. For this reason, this test is carried on without making a theoretical-empirical distinction.

7.2.1.1 Structure of monetary sector

In the monetary sector of the model, income is assumed to flow circularly within economic system in the form of money. In equilibrium, total expenditure will be equal to income, which is consistent with the theory. Moreover, when part of the income is used for consumption by the households, the remaining part will be saved in the banking system to be used for funding investments. Thus, in equilibrium, saving will be equal to investment, which is again consistent with the theory.

On the other hand, there are also missing parts in this sub-model, if we compare it to real economic system. In reality, households can invest the money they earned, without lending it to the banking system. Even the firms can invest a portion of their revenue, without paying the dividends back to the shareholders. Moreover, today's banking system not only funds investments but also funds consumption. For this reason, the real structure of money flow is far more complex then the model explains. However, economics discipline does not conceptualize the macro-economic system with a high level of detail and theories are defined with many necessary simplifications and assumptions. For this reason, the simplifications of the monetary sector are consistent with the theoretical knowledge.

7.2.1.2 Structure of goods sector

In the goods sector of the model, a stock variable called *Inventory* is necessarily used, in order to allow *Aggregate Demand* and *Aggregate Supply* be loosely coupled and dynamically adjusted to each other. As explained in Chapter 1 and Chapter 2 in detail, when these two variables are defined to be equal at all times, then the model becomes a game-theoretical optimization model. In order to make the model truly 'dynamic', this stock variable between them is used. In reality, production and sales are not equal at all times. A similar assumption is used by Goodwin [9] to explain business cycles. Separately determining *Aggregate Supply* and *Aggregate Demand* is therefore consistent with disequilibrium theories in economics.

There is a subjectively defined variable in the goods sector called *Effect of Inventory Coverage on Desired Supply*. This kind of 'effect' variables are common in system dynamics models. However, such a variable is never mentioned directly in the economics field. In equilibrium-oriented theories, markets clear instantly and aggregate supply necessarily equals to aggregate demand at all times. However, the disequilibrium nature of the proposed model required to differentiate between aggregate supply and aggregate demand. For this reason, a signal is to be defined in order to let the supply-side responds to the demand-side. The accumulated change in the aggregate demand is represented by the loss (or gain) of inventory in the model. For this reason, this effect variable which relates the inventory loss, in other words previously accumulated change in the demand, to the supply side of the system.

The idea behind the formulation of *Effect of Demand Pressure on Desired Supply* is that, when sales exceeds the production capacity of the economy due to monetary reasons (more than enough money leading to lower interest rates), the difference is tolerated by *Inventory*. Later, the firms should produce not only the goods they are expecting to sell, but also the goods necessary to replenish the inventories to the desired values. However, the effect of inventory should be limited on extreme conditions. For instance, when there is too much inventory, firms would desire to produce less, but not below zero. Even zero production is meaningless since firms would logically desire to continue business activities in a minimum rate. For this reason, this effect is bounded on the extreme values so that it cannot be below 0 and above 2. These limitations are also common in system dynamics models, and also necessary to make the models stable. Usually, the limitations are defined by a graphical S-shaped functions, but a mathematical formula which generates a similar S-shaped graph is also considered to be valid.

On the other hand, there are weaknesses in the goods sector as well. Firstly, economic system not only produces goods which can be stored in an inventory, but also produces 'services' which cannot be stored. For this reason, the model does not represent all the economic activities. However, this assumption is unavoidable because classifying economic activities in a theoretical model has the potential to break all the connections between the theoretical background and the model.

Secondly, the level of inventories cannot be negative in real life. If the stocks totally deplete, probably a different economic behavior would emerge, in which only few people can buy goods at extremely higher prices and some transactions may not occur even if the buyer has the money required. In free-market economies this is not an expected situation and the common theoretical knowledge do not capture the economic behaviors of such situations. In an ideal system dynamics model, the situation of near-zero inventory level should be defined to have a counter-effect on the outflow, which is *Aggregate Demand*. In other words, if there are no goods in inventories, people should not be able to buy even if they have money to buy it. But this definition would harm the simplicity of the structure of Monetary Sector, which has the ability to communicate dynamic relations with the usually-equilibrium-oriented theoretical knowledge in economics. Changing the formulation of *Aggregate Demand* would harm the explanatory power of the model and make it a non-sense for economics discipline.

Tens of different formulations in Goods Sector is applied during the model building procedure, but none of them solved problems more than they created. As a result, the simplest formulation is used in the model and it is noted that if *Inventory* falls systematically below zero in the simulations, then the simulation results may be invalid. It is worth to note that, in the simulations results given in Chapter 5, this issue is considered. Neither money shock experiments nor inflation shock experiments have resulted the *Inventory* to fall below zero.

To sum up, in the goods sector, it is assumed that *Aggregate Demand* is determined in the monetary sector, while *Price Level* is stable. In other words, when there are too much money in the system (and real money supply rises), interest rates fall and nominal demand rises. *Aggregate Supply* is determined by the level of *Employed Labor* while other factors affecting supply are stable. Supply side should respond to the demand side, by employing the required amount of labor to meet demand. This response is transmitted by the inventory adjustment system. This mechanism is the reason behind the observation that, when additional money is injected into the system, unemployment rate falls and economy grows.

7.2.1.3 Structure of price sector

In the price sector of the model, *Price Level* is assumed to reflect the markup pricing behavior of firms. With this formulation, the changes in *Wage Level* is transferred to *Price Level* because costs are directly related with wages on aggregate level. Markup pricing is a common assumption in the Post-Keynesian literature. See Nichols et al. [49] for a review of markup pricing.

The value of markup ratio is strictly related with other parameters in the model. The assumed production function implies that workers should get 70% of the income while capital owners should get the rest in equilibrium. For this reason, the cost of goods should be 70% of the prices since the costs are the income of workers and the markup is the income of capital owners. Furthermore, if we assume that workers spend all the income for consumption and capital owners save, which is a common assumption in Post-Keynesian literature, saving rate should be equal to the ratio of markup to price. For this reason, these parameters are assumed to be consistent with each other.

The adjustment of *Price Level* includes a simple goal-adjustment formulation which is common in system dynamics model. This type of adjustment is also similar to Calvo-style adjustment [112]. However, price setters should not be systematically fooled, in an inflationary environment. For this reason, a trend correction is included in the adjustment process, which is consistent to the theoretical knowledge that firms reflect their expectations about future inflation to their price decisions.

7.2.1.4 Structure of labor sector

In the labor sector of the model, there is an adjustment between *Employed Labor* and *Unemployed Labor*, based on *Demand Pressure*. The adjustment is assumed to take some time, which is also a reasonable assumption and do not contradict to the theoretical knowledge. *Unemployment Rate*, is defined as the ratio of unemployed labor. *Natural Rate of Unemployment* is defined in economics as the ratio of unemployment rate in equilibrium.

The formulations in this sector are mostly straightforward, if we assume that *Desired Supply* determines the the target for *Employed Labor*. This assumption is consistent with Keynesian and Post-Keynesian theories which claim that, demand-side of the economy affects unemployment rate, at least in the short-run. The ideas behind the formulations is also apparent in the empirical work of Phillips [13].

7.2.1.5 Structure of wage sector

The wage sector of the model, together with the labor sector, represents the informal theory behind the empirical work of Phillips [13]. Accordingly, when unemployment rate falls, labor would bargain for higher wages and *Wage Level* increases as a result. This is also consistent with the bargaining-power theories within Post-Keynesian literature.

The formulation of *Target Wage Level* is determined arbitrarily. In other words, this effect exists in real life, apparently, but the value of this effect cannot be determined. The bargaining powers of labor and capital owners cannot be measured directly. For this reason, the effect of the deviation of unemployment rate from its natural rate, or the deviation of target labor from its normal value, may be either higher or lower than defined, in real life. However, considering the model behavior, the effect does not seem to make any significant difference in the key results of the model.

7.2.1.6 Structure of investment sector

Most of the macroeconomic textbooks say that *Investment* is affected by the interest rates and 'sales', in the short-run. However, it is not clear that how much these affects are. What the textbooks say is that, in equilibrium, *Investment* is equal to *Saving* and the interest rate is the value which equalize these two.

For this reason, two assumptions are made in the model. First, it is assumed that, *Investment* proportionally responds to *Aggregate Demand Forecast*. In other words, if total sales doubles, so does investment in real terms, when other effects are ignored. This is consistent with the fact that, if the economy grows systematically, either by the increase of technology level or workforce at a constant rate, investment has to grow too, in order to maintain the (dynamic) equilibrium.

The other assumption is that, *Investment* is inversely proportional to *Relative Interest Rate*, thus proportional to *Loanable Funds Ratio*. This assumption solves many problems in Monetary Sector. For the model to be stable, each outflow should be controlled by its own stock somehow. In other words, if the value of a stock is too high, the outflow should be high as well. Defining *Investment* in such a way simplifies the Monetary Sector of the model, and still consistent with the textbook definitions.

7.2.2 Parameter confirmation test

In this test, it is discussed if the parameter values of the model are consistent with the empirical observations or theoretical knowledge in the field. The difficulty for this economic model is that, some of the parameters are hard to measure in real life. Moreover, some other parameters have not previously been defined within theory. These difficulties will be discussed later.

7.2.2.1 Parameters of monetary sector

Within monetary sector, there are four parameters called *Business Balances Turnover*, *Household Balances Turnover*, *Saving Rate* and *Reference Loanable Funds Ratio*. *Business Balances Turnover* defines the ratio of outflow of *Income* to the stock variables *Business Balances*. In a sense, it is the reverse of the circulation time of the money hold by firms.

The outflow of money from *Business Balances* represents the payment of income to the production factor owners; labor and capital owners. Labor get wages and capital owners get dividends for the ownership of capital. Wages are usually paid once a month, and dividends are usually paid once a year. Since these two payments are not differentiated for simplicity, it can be initially assumed that circulation time should be between a month and a year.

In theory, the share of income is usually explained by the parameters of Cobb-Douglas production function, and these parameters are assumed to be approximately 0.7 for labor and 0.3 for capital. For this reason, the amount of wages should be higher than the amount of dividends. As a result, the average circulation time should be closer to a month.

According Machlup [8], the average circulation time of working balances (which is a similar term for *Business Balances* should be between 3 and 4 months. In the paper introducing Phillips Machine, Phillips [1] also assumes these approximate values. As a result, the value of 4 for *Business Balances Turnover* seems to be valid approximation of reality.

The analog computer of Phillips [1] does not include a stock variable representing *Household Balances*, thus does not give an estimate for the circulation time. It is also difficult to obtain an empirical data for the value of *Household Balances Turnover*. For this reason, it is a necessity to assume a reasonable approximation for this parameter value.

Workers, when paid monthly wages, spend this money for a month. So in average, half of this monthly wages is expected to be at hand, and the circulation time becomes half a month. Similarly, for yearly paid dividends, the circulation time can be estimated as half a year. With the same reasoning as done before, the turnover can be estimated to be 8 (twice the turnover of business balances). However, it is also reasonable to assume that, households may also keep money for other reasons, such as a cover for financial risks. For this reason, this turnover parameter is also assumed to be 4, which is the same as *Business Balances Turnover*.

The two turnover parameters determine the amount of money held by firms and households. The amount of money in the financial sector is, on the other hand, defined by the *Reference Loanable Funds Ratio*. In the original model of the Phillips Machine, the amount of money in the *Loanable Funds* stock is assumed to be similar to the amount of money in *Business Balances*. Since the proposed model is adopted from the work of Phillips [1], the equilibrium value of *Loanable Funds* is assumed to be the same as other stock variables. This assumption also makes it easier to compare the levels of stock variables during simulations.

When the equilibrium values of the stock variables are the same, then each stock is expected to hold $1/3$ of the money in circulation. This makes the value of *Reference Loanable Funds Ratio* equal to $1/2$. In reality, it is difficult to have an empirical estimate for this variable, because the circulation of money is far more complex than the description of the model. Even the definition of money is far more complicated than an analogy of water, flowing through pipes. The model structure of monetary sector is only a simplified version of reality, which is helpful for dynamically formulating how money determines the aggregate demand. Thus, although this is a weakness for the model, the assumption regarding this parameter value does not harm the validity of the model structure, if this value does not significantly change the overall model behavior.

The final parameter in the monetary sector is *Saving Rate*. The value of this parameter is assumed to be 0.3 which is a common assumption in Post-Keynesian literature. The reason is that, workers earn 70% of the generated income and it is assumed that they consume all of it because the earning is so low for each worker. Moreover, capital owners earn 30% of the generated income and it is assumed that they save all of it because they are already rich people and the ratio of consumption would be negligible. As a result, although there may be different values of saving rates in different countries, 30% seems to be acceptable within Post-Keynesian theory.

7.2.2.2 Parameters of inventory sector

The only parameter in this sector is *Reference Inventory Coverage*. This parameter represents how much inventory is held by firms on aggregate level, compared to their sales. A similar model is used by Goodwin [9], in which he assumed the level of inventory to be equal to one year of aggregate demand.

From a different perspective, *Reference Inventory Coverage* is equal to the inverse of 'average production time'. Although the model simply defines production (or *Aggregate Supply*) as an instantaneously determined flow variable, in reality this process takes time. Thus, on aggregate level, the amount of inventory represents semi-finished goods and raw materials as well. For this reason, the production time of a good defines the time from the beginning of the production chain, to the time it is delivered to the end customer, and includes the time required for transportation. Although some products can be produced within weeks and some other require years (buildings, cars, vehicles etc.), one year is a reasonable estimate of 'average production time'. As a result, the unitless estimate of 1 for *Reference Inventory Coverage* seems to be reasonable assumption.

7.2.2.3 Parameters of price sector

There are two parameters in price sector; *Normal Markup* and *Price Level Adjustment Time*. However, there is another parameter in the trend formulation, which is not separately defined in the model but can be considered as a parameter. It is the adjustment time of the trend estimate, which defines how smooth the trend is estimated. These three parameters are set to be $0.3/0.7$, 1 year, and 2 years respectively.

The value of *Normal Markup* is directly related to the initial value of *Wage Level*, and consecutively to the Cobb-Douglas function parameters and *Saving Rate*. The value of $0.3/0.7$ is the result of direct calculation. For this reason, it cannot be freely determined.

In literature, there is no consensus for the average value of *Price Level Adjustment Time*. It is assumed to be 1 year in the theoretical models, by Taylor [111] and Calvo [112]. Later, various numbers are given. It is estimated to be between 4 and 13 months by Carlton [136], 9 months by Blinder [137], 5.5 months by Bils and Klenow [138], 20 months by Eichenbaum and Fisher [139] and 8.6 months by Nakamura and Steinsson [140].

Apparently, it may be different in different countries and may change in time. Moreover, the estimations may also differ based on the method used. In this model, *Price Level Adjustment Time* is assumed to be 1 year. This assumption does not conflict with the assumptions of other theoretical models and empirical estimates.

The adjustment parameter of the trend function is assumed to be 2 years. There is no empirical or theoretical information about the value of this parameter. Moreover, it is difficult to measure it directly. However, logically speaking, trend adjustment time should be higher than the adjustment time of the concerned variable. When the target is measured to be different than the actual value, the first response would be to consider this as an error, and close the gap. Only later, if the gap continues to be observed systematically, then an economic agent would consider this as a trend. For this reason, only based on logical thinking, trend adjustment time is set to be twice of the *Price Level Adjustment Time*, 2 years.

There are other trend functions in the model as well. To maintain the consistency, the same 2 years value is used in all trend functions. This is based on the assumption that, an economic agent would adjust the perceived trend with the same delay if she receives information about the variables with the same frequency.

7.2.2.4 Parameters of labor sector

The first parameter in labor sector is *Labor Adjustment Time*. This parameter is used for both hiring and firing. Based on the common knowledge and direct observation, it may be argued that finding a labor with the required skills may take time between a few months to a year. However, this estimate at the micro level may not represent the macro level adjustment time correctly. Because a newly hired worker can possibly be working for another employer at that time. In that case, the overall employment levels do not change.

The overall outcome will depend on whether the newly hired worker is unemployed at that time. Although both cases are possible, it is more likely that newly hired worker is already working in another firm, since the unemployed workers are usually lower than employed workers. For this reason, the adjustment time of macro-level labor increase should be much more higher than the average hiring time at the micro-level.

For firing, it is more difficult to have an estimate. For some jobs, it does not take more than a day to fire a worker. However, although the action of 'firing' completes very fast, the decision of firing would take time. An ideal firm would not fire workers instantly, when it observes that the required number of workers is less than already hired. Shortly, hiring a labor the day after another is fired would be too costly.

Moreover, for some jobs, it may not be legally possible, or may be too costly, to fire a worker because of the type of employment contracts. However, it is not easy to estimate how common this situation is. Thus, it is necessary to make an educated guess.

For the reasons explained above, 2 years seems a reasonable assumption on average, for several reasons. First, it is higher than the adjustment time of prices, which is meaningful since it should be harder to hire or fire a worker compared to change the price tag of a product. Secondly, it is higher than the covering time of inventory (1 year), which is meaningful since an ideal firm would use inventories as a buffer for changes in sales, before considering to adjust production by hiring or firing a labor. Finally, it is an observed reality that corporations usually plan their employment processes a year in advance. If we assume that they may or may not successfully execute their employment plans, adjustment of labor should be more than a year. Thus, *Labor Adjustment Time* being 2 years is a meaningful and reasonable assumption.

The other parameter in labor sector is *Natural Rate of Unemployment*. This parameter is a structural parameter which largely differs across countries. Moreover, since it is purely a theoretical concept and cannot be observed or measured directly, different estimation models may give different results. Since the aim of the proposed model is explaining a behavior rather than making a point prediction, the value of this natural rate does not have to be precisely correct. Rather, an average and sensible value would be enough considering the purpose of the model.

According to Fabiani and Mestre [141], NAIRU (Non-Accelerating Inflation Rate of Unemployment) for the Euro area is estimated to be 9.4% for the years between 1984-1998. It is also known that unemployment rate is around 10% in developed and developing countries after the year 2000. As a result, 10% is a reasonable and valid assumption for the value of *Natural Rate of Unemployment*.

7.2.2.5 Parameters of wage sector

In the wage sector of the proposed model, *Wage Level Adjustment Time* is the only parameter and it is assumed to be 1 year. This assumption reflects the observation that wages are usually adjusted once a year. In some countries with high levels of average inflation, like Turkey, wages can be adjusted twice a year as well. On the other hand, in the countries with low levels of average inflation, like USA, 2 years of wage contracts are also common.

According to Barattieri et al. [142], the probability of a nominal wage change in a quarter is estimated to be between 21.1% and 26.6%. This probability means that average adjustment time of nominal wages is approximately 1 year. For this reason, 1 year estimate can be considered reasonable.

7.2.2.6 Parameters of investment sector

There is only one parameter in the investment sector of the proposed model; which is *Aggregate Demand Forecast Adjustment Time*. This is a necessary parameter for a system dynamics disequilibrium model, because the effect of sales on investment cannot be directly formulated. *Investment* is theoretically assumed to be determined by sales (which is equivalent to *Aggregate Demand* in the proposed model) and sales is by definition contains investment. In an equilibrium-oriented model, where the both sides of the equations are determined at the same time, this may not be a problem. However, for a system dynamics model, this creates circular causation. For this reason, an additional variable is necessarily used, which represents a forecast of the observed variable.

Aggregate Demand Forecast Adjustment Time represents the adjustment time of this forecast. Although there is not an empirical information about this parameter, it is reasonable to assume that adjustments which are more frequent than 1 year would not be reasonable because of the seasonal effects on the sales at micro-level. For this reason, the assumption of 1 year would be a reasonable assumption that does not harm the validity of the proposed model.

In this test, all the parameter values are explained and justified by empirical findings or theoretical knowledge if possible. The parameters which are difficult to measure, estimate or even define are chosen to be consistent with other parameters of the model or logically selected to be meaningful and consistent with the common knowledge. The limitations in this test are believed to be harmless considering the purpose of the proposed model.

7.2.3 Direct extreme condition test

In direct extreme condition test, model equations are tested in extreme conditions, in order to see if the results represent what would happen in reality under similar circumstances. This test is applied on each equation in the model. In a proper system dynamics model, it is expected that model equations do not give meaningless results which cannot be observed or anticipated in reality.

A necessary assumption should be made before applying this test to each equation of the model. The model aims to represent a simplified version of the real economic system. This system works with currency, or money, flowing within the system and this money is controlled by a monetary authority. The amount of money determines the nominal values like prices and wages, in the long run. Hypothetically, if an extreme amount of money is injected into the system, the nominal values will inevitably be extreme as well. On the other extreme case, when all the money is extracted from the economic system, it cannot work as it is assumed to, within the theoretical framework. A different system, a barter economy, will possibly emerge in that case, which the theoretical background of this model is insufficient to represent. As a result, it is only possible to test the extreme-conditions of the model with the assumption that the amount of money cannot be extremely determined.

In the monetary sector of the proposed model, outflows are directly controlled by their stocks. For instance, *Income* is directly proportional to *Business Balances*. With this first-order control structure, the value of the flow variables are smooth in time and cannot change dramatically in a meaningless way.

Saving Rate can be between $[0-1]$ by definition, so that *Saving* and *Consumption* are always non-negative. The sum of their values are also directly controlled by their stock variable. Since the sub-model is a closed-circuit and the flows are directly controlled by the stocks, all the stock variables are guaranteed to be positive, unless the total amount of money is extracted from the system. In that case, of course, the model will not work, similar to the anticipated behavior of the real economic system which cannot work without any currency flowing inside.

Investment is also directly controlled by its stock. Suppose, for instance, the value of *Loanable Funds* suddenly doubles after the equilibrium state. *Loanable Funds Ratio* will double as well, and *Relative Interest Rate* will be 0.5. Since *Investment* is defined to be inversely proportional to *Relative Interest Rate*, its value will suddenly double as well. As a result, when other variables are stable, *Investment* is directly controlled by the level of *Loanable Funds*.

All the equations in monetary sector are valid, in terms of extreme-condition test. The only exception is that, when there is no money in the system, *Loanable Funds*

Ratio will be undefined. In that case, of course, the model will not work, similar to the anticipated behavior of the real economic system which cannot work without any currency flowing inside. In all other cases, whenever there is a small unit of currency flowing within the system, *Loanable Funds Ratio* is perfectly determined, the stocks are guaranteed to be positive, and the equations are guaranteed to be meaningful.

In goods sector, there is an inflow, an outflow and a stock variable decoupling them. *Aggregate Supply* is directly defined as a function of *Employed Labor*, thus cannot have extreme values unless *Employed Labor* has an extreme value itself. When the value for this stock variable rises, the value of *Aggregate Supply* also rises, following the law of diminishing returns, which is reasonable bases on the theoretical knowledge. For this reason, the value of *Aggregate Supply* is guaranteed to be positive, finite and within reasonable ranges.

The value of *Aggregate Demand* is defined by *Nominal Aggregate Demand*, which is determined in monetary sector, and *Price Level*. Direct extreme condition test for the monetary sector assures that *Nominal Aggregate Demand* will not have extreme values, unless an extreme amount of money is injected into the system. *Price Level*, on the other hand, is guaranteed to be positive by its formulations. Since *Aggregate Demand* is formulated as the ratio of *Nominal Aggregate Demand* and *Price Level*, it can only change proportional to *Nominal Aggregate Demand* and inversely proportional to *Price Level*. Changes in both directions are meaningful and reasonable. For this reason, *Aggregate Demand* is guaranteed to be positive, finite and within a meaningful range.

Effect of Inventory Coverage on Desired Supply is a dimensionless variable, which transmits the signal of change from the demand-side to supply-side. This effect variable is mathematically defined to be within the interval of $[0-2]$. This S-shaped definition is similar to manually drawn graphical functions to bound the value within acceptable limits. As a result, all the equations in this sector are valid for extreme-conditions.

The value of *Price Level* is adjusted to a target value, which is determined by a markup pricing behavior, which adds *Unit Cost* with a markup value. *Markup* is defined as the multiplication of *Normal Markup*, which is a constant, and *Demand Pressure*. If *Unit Cost* suddenly increases extremely, *Price Level* gradually increases as well, but only proportionally. This proportional increase is reasonable and meaningful. On the other extreme case, if *Unit Cost* falls to zero, *Price Level* gradually falls to zero as well, according to model equations. However, this is only possible when there is no money in the system, which is an initially excluded case.

If *Demand Pressure* extremely increases, *Price Level* gradually increases as well. This increase is guaranteed to be less than proportional with the markup price formulation. The smallest possible value of *Demand Pressure* is zero, according to model equations. This case is only possible when *Aggregate Demand* falls to zero. In that case, *Price Level* decreases but only to the value of *Unit Cost*, which is also reasonable and meaningful.

There are two equations preventing *Price Level* having extreme values. First, *Aggregate Demand* is inversely proportional to *Price Level*, so that when it is 'too high', an increase *Price Level* instantly offset this effect. In other words, the balancing loop between *Price Level*, *Aggregate Demand* and *Demand Pressure* prevents the over-reaction of *Price Level*. Secondly, *Effect of Inventory Coverage on Desired Supply* is bounded by the interval $(0-2)$, so that *Demand Pressure* cannot get extreme values because of the changes in *Inventory*.

The adjustment parameter *Price Level Adjustment Time* is non-negative by definition. If it is zero as an extreme case, *Price Level* is expected to change instantly and become equal to *Target Price Level*. In another extreme case, if it is assumed to be extremely high, then *Price Level* remains stable, which is also a reasonable and meaningful result.

The amount of total labor is contained by two stocks. Inflow of additional labor from outside of the model is ignored. *Target Labor* is defined to be proportional to *Employed Labor*. Since *Demand Pressure* cannot fall to zero whenever there is money in the system, *Target Labor* remains positive and *Employed Labor* cannot fall to zero. For this reason, the values of the stocks and flow of labor between them are guaranteed to be within reasonable range.

As an extreme case, if *Labor Adjustment Time* is equal to zero, then the *Employed Labor* instantly becomes equal to its target value. In another extreme case, if the adjustment time is extremely high, then the values of the stocks remain the same. In both extreme cases, the equation results are viable.

In the wage sector of the proposed model, *Wage Level* is adjusted to a target value. The formulation of *Target Wage Level* includes two additive effect variables. Both effect variables can either be positive or negative, but finite for positive levels of *Natural Rate of Unemployment*. When added together, *Wage Level* can increase or decrease proportionally.

When the addition of these two effect variables is equal to (-1), *Target Wage Level* becomes zero, which cannot be justified. Regardless of how high *Unemployment Rate* is or how low *Target Labor* is, *Wage Level* should not fall to zero. For this reason, the formulation of *Target Wage Level* is artificially modified to be above some very small but positive fraction of *Wage Level*. This fraction is chosen arbitrarily as 1%. This artificial lower bound has no practical value for any reasonable simulation setting because the effect practically never gets close to this lower bound. However, it is a necessary modification in order to make the model valid for extreme conditions.

Wage Level Adjustment Time determines how rapid the *Wage Level* adjusts to its target. If this adjustment time is close to zero as an extreme case, the adjustment becomes instant and *Wage Level* becomes equal to its target. If the adjustment time is assumed to be too large, then adjustment never occurs and *Wage Level* remain stable. These behaviors are reasonable and meaningful behaviors for extreme conditions.

In the investment sector of the proposed model, *Desired Investment* is determined by two effect variables, which represent the effect of output and *Aggregate Demand Forecast*, relative to their reference values. The reference values are defined to be the initial values of these variables which are calibrated to provide equilibrium for the whole model.

If these effects variables increase extremely, *Desired Investment* also increases proportionally. This result totally consistent with expectations. For instance, imagine an economy grows in time and *Aggregate Demand* become twice as before. If all other effects are ignored, *Desired Investment* should be twice as before as well to be consistent with this new equilibrium. On the other hand, if capital productivity rises for any reason, more investors should be willing to invest. As a result, this proportional increases are not only logically meaningful, but also necessary to satisfy equilibrium conditions.

Similarly, if one of these variables becomes close zero, *Desired Investment* proportionally falls close to zero as well. These results make sense as well, since no economic agent would invest when the produced goods cannot be sold or when investments are not productive. To sum up, the equations in investment sector are meaningful for extreme conditions.

7.2.4 Dimensional consistency test

In this test, each individual formulation is controlled to see if the units are consistent. If two sides of an equation do not match, that means there is something wrong about the model formulation. In a valid system dynamics model, all the parameters with their defined units are expected to be meaningful.

In the monetary sector of the proposed model, the units of the stock variables *Business Balances*, *Household Balances* and *Loanable Funds* are \$. The unit of *Total Balances* is also \$. The flows in and out of these stock variables are \$ / year. When the flows are integrated over time dimension, there will be no inconsistency in the units.

The unit of the turnover parameters are 1/year. *Saving Rate*, *Loanable Funds Ratio*, *Reference Loanable Funds Ratio* and *Relative Interest Rate* are dimensionless, and only define ratios. When the formula for each flow is calculated, the units are seen to be consistent.

In the goods sector, the unit of *Inventory* is 'real \$'. The flows in and out of this stock are defined with the unit of 'real \$ / year'. When integrated over time, the units become consistent.

The variable *Inventory Coverage* and parameter *Reference Inventory Coverage* are defined in 'years'. *Effect of Inventory Coverage on Desired Supply* is the ratio of them and is dimensionless. The unit of *Desired Supply* is the same as the flow variables, 'real \$ / year'. *Demand Pressure* is defined as a ratio and is dimensionless.

Nominal Aggregate Demand has a unit of 'real \$ / year' while *Price Level* has a unit of '\$ / real \$'. When calculated to find *Aggregate Demand*, the units are consistent. Likewise, *Employed Labor* and its reference value are defined as 'labor' and *Aggregate Suppy* and its reverence value are defined as 'real \$ / year'. The effect variables are dimensionless.

In the price sector, *Price Level* has a unit of '$ / real $'. It shows how much is the nominal $ value of a set of goods is at some time, where the nominal value of this set of goods is a unit $ at the reference time, $t = 0$. Consequently, 'real $' is defined to be a unit set of goods which has a unit $ nominal value at the reference time, $t = 0$.

Price Level Adjustment is defined as the change in *Price Level*, so its unit is '($ / real $) / year)'. *Target Price Level* has the same unit with *Price Level* and *Inflation* is a percentage variable with a unit of 1 / year'.

Output per Labor has a unit of '(real $ / year) / labor' and represents how much 'real $' of goods can be produced in a year by a unit labor. *Wage Level* is defined in terms of '$ / (year x labor)' and *Unit Cost* becomes '$ / real $'. *Markup* and *Normal Markup* are dimensionless.

In the labor sector, the stock variables have the unit of 'labor'. The flows between them are defined as 'labor / year'. *Target Labor* and *Total Labor* have the same unit with the stock variables. Other parameters and variables are dimensionless and only represent ratios.

In the wage sector, the stock variable *Wage Level* and its target *Target Wage Level* have the unit of '$ / (year x labor)'. *Wage Level Adjustment Time* is defined in 'years' and the flow variable is defined as the yearly change of the stock variable. *Real Wage Level* has the unit of 'real $ / (labor x year)' which is also consistent the unit of *Price Level*. All other variables and parameters are dimensionless.

In the investment sector, *Desired Nominal Investment* has the unit of '$ / year' and *Desired Investment* has the unit of 'real $ / year'. *Aggregate Demand Forecast*, *Reference Aggregate Demand Forecast*, *Aggregate Demand* and *Reference Desired Investment* are all defines in terms of 'real $ / year'. The adjustment time parameter is defined as 'years'. Finally, the effect variables are dimensionless.

To sum up, all the formulations in the model have dimensional consistency. The parameters have meaning with their defined units and there is no scaling parameter without a meaning. Both sides of the equations are shown to have the same units.

7.2.5 Extreme condition test

Extreme condition test aims to determine how the model behaves in extreme conditions. This test is different from direct extreme condition test, which aims to test how each formulation of the model is affected at extreme conditions. Extreme condition test, on the other hand, does not consider each formulation of the model separately, but considers the behavior of the overall model in extreme conditions.

7.2.5.1 Extreme money injection scenario

In this scenario, the amount of money in the system is suddenly doubled. The additional money is injected into *Loanable Funds* once at $t = 1$. Figure 7.4 show how *Aggregate Supply*, *Price Level* and *Unemployment Rate* behave after extreme money injection.

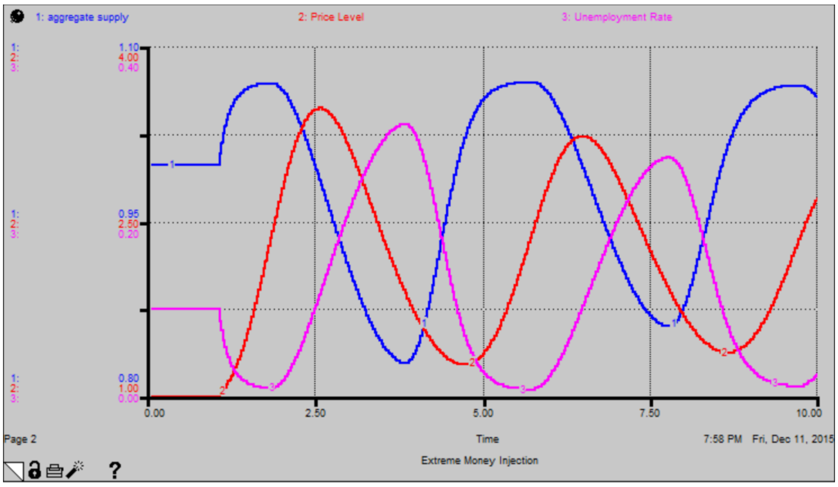

Figure 7.4 : *Aggregate Supply*, *Price Level* and *Unemployment Rate* after 100% money injection at $t = 1$.

According to the simulation result, *Aggregate Supply* and *Price Level* begins to increase and *Unemployment Rate* begins to decrease. In the second half of the second year, *Aggregate Supply* has its highest value and remains there for some time. *Unemployment Rate* falls to approximately 1%, and remains there for some time. *Price Level*, on the other hand, continues to rise until $t = 2.5$. The extreme money injection shock creates a boom at first and then a recession. The first recession is so severe that *Unemployment Rate* rises up to 31%. The following recessions are relatively moderate. The cycle continues with a diminishing amplitude.

Although such a case is not likely in real life, an extreme amount of money injection is expected to create an economic growth at the beginning together with a price level increase. Moreover, once the increase in the *Price Level* begins, it has a tendency to continue to increase, so that it decreases the purchasing power of money, and *Aggregate Demand*. As a result, the initial rise in the *Aggregate Supply* does not continue forever and economic activity slows down.

7.2.5.2 Extreme money extraction scenario

In this scenario, the amount of money in the system is suddenly halved. In order to simulate this scenario, half of the money is extracted from all the stocks in the monetary sector at $t = 1$. Figure 7.5 show how *Aggregate Supply*, *Price Level* and *Unemployment Rate* behave after extreme money extraction.

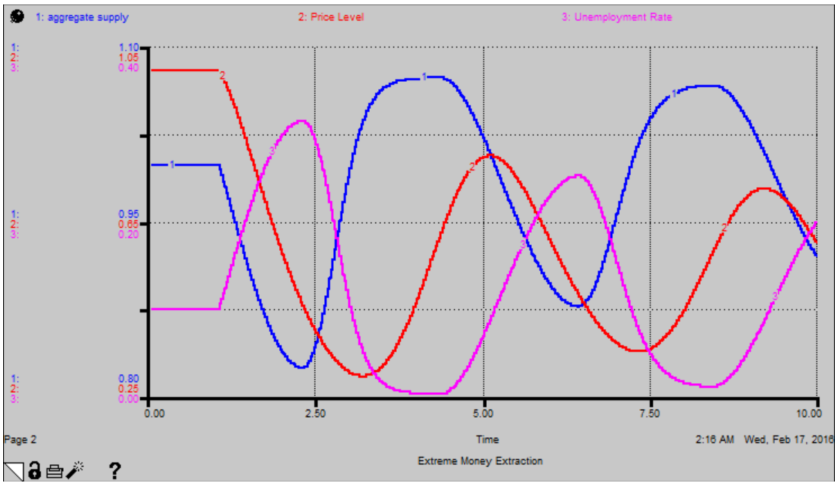

Figure 7.5 : *Aggregate Supply*, *Price Level* and *Unemployment Rate* after 50% money extraction at $t = 1$.

According to the simulation result, *Aggregate Supply* and *Price Level* begins to increase and *Unemployment Rate* begins to decrease. In the first half of the third year, *Aggregate Supply* has its lowest value. *Unemployment Rate* rises up to 31%. *Price Level*, on the other hand, continues to fall until $t = 3.2$. The extreme money injection shock creates a recession at first and then a boom. The first recession is so severe that economic activity falls approximately 18%. The following recessions are relatively moderate. The cycle continues with a diminishing amplitude.

It is very unlikely to observe such a case in real life. However, in this extreme case, a severe recession is expected immediately after the money extraction. *Aggregate Supply* falls and *Unemployment Rate* rises in this period. *Price Level* also falls in this period, in a way to recover the economy by rising *Aggregate Demand* again. When it has fallen enough, *Aggregate Supply* rises again.

7.2.5.3 Extremely strict labor market scenario

In this scenario, suppose that there are too much governmental regulations on the labor market, and hiring or firing new labor is almost impossible. In order to simulate this scenario, *Labor Adjustment Time* is assumed to be extremely high, and *Hiring* and *Firing* is set to be equal to zero, no matter what *Target Labor* is. At the beginning, 5% money shock is applied. Simulation result is shown in Figure 7.6.

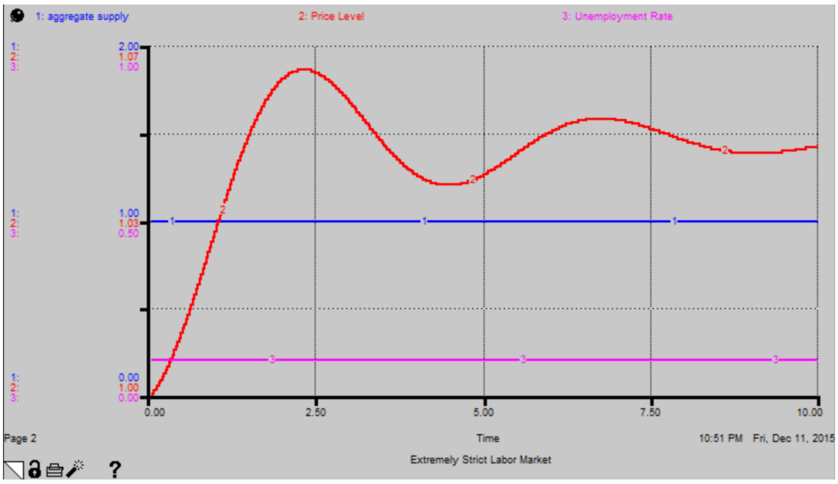

Figure 7.6 : *Aggregate Supply*, *Price Level* and *Unemployment Rate* after 5% money shock when labor market is extremely strict.

Accordingly, *Unemployment Rate* and *Aggregate Supply* do not change during the simulation period. This result is obvious since the change in labor market is artificially restricted. *Price Level*, on the other hand, begins to rise for 2.5 years, and then makes a damping oscillation.

When hiring a new worker or firing an existing one is too difficult because of strict regulations, monetary growth does not affect real economic activity. The additional money directly affects *Price Level* but that takes time. The simulation result is similar to what would be expected in such a scenario.

7.2.5.4 Extremely flexible labor market scenario

In the previous scenario, labor market is assumed to be extremely strict that hiring and firing is impossible due to governmental regulations. In this scenario, the opposite case is concerned. In other words, labor market is assumed to be extremely flexible, so that hiring and firing is too easy.

In order to simulate this scenario, *Labor Adjustment Time* is set to be 0.01 years. At the beginning, 5% money shock is applied. The model is simulated for 10 years. Figure 7.7 shows the simulation results of *Aggregate Supply*, *Price Level* and *Unemployment Rate*.

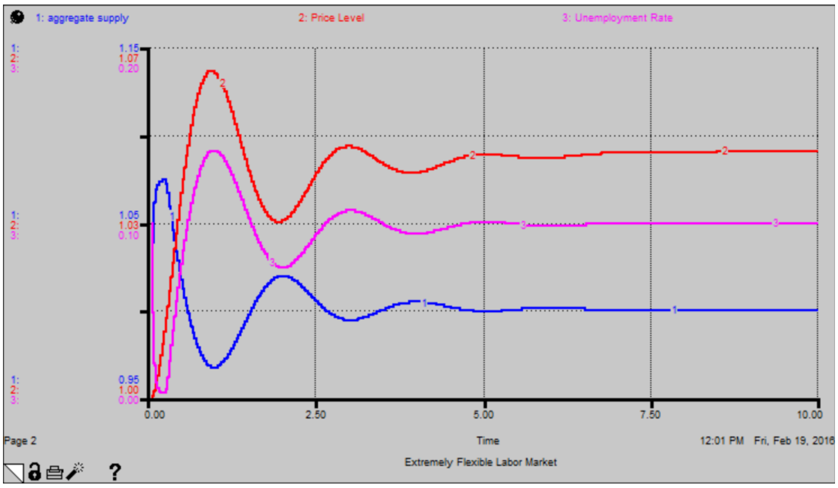

Figure 7.7 : *Aggregate Supply*, *Price Level* and *Unemployment Rate* after 5% money shock when labor market is extremely flexible.

As seen in the simulation result, money injection at $t = 0$ creates an economic growth in a very short amount of time. After only 0.2 years, *Unemployment Rate* falls almost to zero and *Aggregate Supply* rises approximately 7%. At this point, only 1% of the monetary expansion is reflected to nominal prices since *Price Level* is 1.01.

After this rapid expansion, *Aggregate Supply* begins to fall until it is approximately 3% below its equilibrium value at $t = 1$. The first recession following the expansion is smaller in magnitude compared to the expansion. The following expansions and recessions get smaller each time and the oscillations die out within 10 year period.

As a result, initial real effects of the monetary shock are observed very rapidly when labor market is extremely flexible. However, this monetary shock generates a damping oscillation. After the second recession period, the effect on *Aggregate Supply* become less than 1%. Model eventually stabilizes in 10 years. These results are not at odds with extreme case expectations.

7.2.5.5 Extreme minimum wage scenario

In this scenario, it is assumed that governmental authority sets an extreme minimum wage level. For illustration, suppose that *Wage Level* is set to 1.4 in the model artificially, which is twice the equilibrium value. Change in the wage level is ignored based on the assumption that minimum wage is already too high and every worker is already paid the minimum. Model is simulated with this setting for 20 years, without any monetary shock. Simulation result for *Aggregate Supply*, *Unemployment Rate* and *Price Level* are given in Figure 7.8.

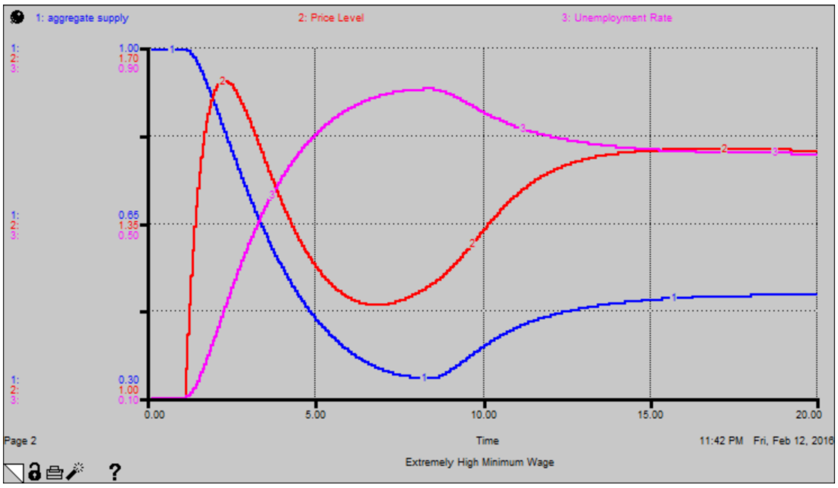

Figure 7.8 : *Aggregate Supply*, *Price Level* and *Unemployment Rate* in the presence of extremely high minimum wage.

Minimum wage policy is applied at $t = 1$. *Price Level* begins to rise immediately while *Aggregate Supply* begins to fall. The moving of *Price Level* and *Aggregate Supply* in the opposite directions is a different mode of behavior then the reference simulations for monetary shocks. This is because extreme condition test for a very high minimum wage is a supply side shock to the system, unlike the monetary shocks being demand side.

After the extreme minimum wage shock, *Unemployment Rate* begins to fall as well. This behavior is what we expect to happen in the presence of very high minimum wage. The forced rise in the *Wage Level* leads to an increase in unit costs, and *Price Level* increases as a result. Since no new money is added to the system, this new higher value of *Price Level* leads to a lower *Aggregate Demand* than before, and a portion of the initial *Employed Labor* becomes unnecessary. As a result, some of the

Employed Labor is fired and economic system converges to a new equilibrium with an *Unemployment Rate* of 66%, and a *Price Level* of 1.5. In other words, increasing minimum wage without injecting new money into the system creates a new equilibrium of lower economic activity.

7.2.6 Parameter sensitivity test

This test aims to determine the parameters which the behavior of the model is sensitive to. It is expected that model behavior does not dramatically change for very small changes in the parameter values. If different behavioral patterns emerge during this test, it can be discussed that if these different behaviors are observed in real system.

In Chapter 6, the model is tested for two different shocks; money shock and inflation shock. The behaviors of *Aggregate Supply*, *Inflation*, *Unemployment Rate*, *Wage Inflation* and *Real Wage* are mainly analyzed. It is shown that the model is capable of explaining original Phillips Curve (the relation between unemployment rate and wage inflation), Phillips Curve and Wage Curve as well as the relation between inflation and growth rate. The model may or may not generate a cycle, depending on the parameters.

For behavior sensitivity test, the parameters which can be changed alone without breaking the ground rules of the model are chosen. The model is simulated for three different values of each parameter. Other than the reference values which are assumed in the model behavior phase, 10% above and 10% below values are also considered. The graph of the key variables are presented in order to compare the results of three different values.

Figure 7.9 shows the sensitivity of original Phillips Curve to *Labor Adjustment Time*. Blue, red and pink dots represent the simulation results for the parameter value of 1.8, 2.0 and 2.2 respectively. Accordingly, the properties of the scatter diagram do not change. In all cases, the relation is negative, there is a slight non-linearity, and the direction of data is counter-clockwise.

However, for higher values of *Labor Adjustment Time*, the generated data are less scattered. This is because, high values lead to small cycles. At one critical point, the cyclic behavior vanishes and the model settles down in the long run. After a number of experiments, it is found that this critical point is 2.4 years. The higher

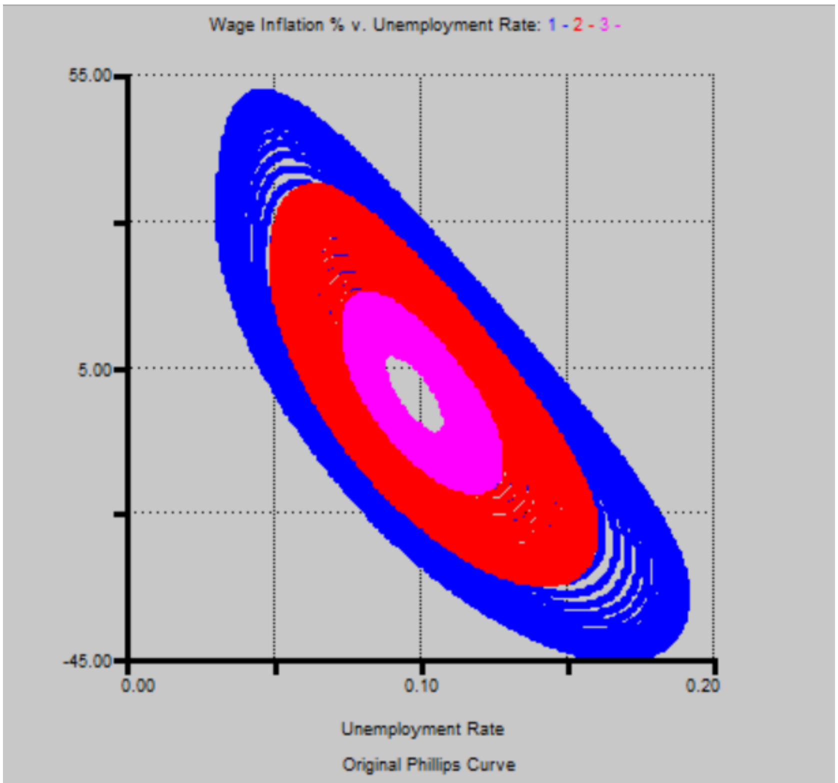

Figure 7.9 : Sensitivity of original Phillips Curve to *Labor Adjustment Time*.

the parameter value is, the earlier the cycle vanishes. Similarly, below 2.4 years, the lower the parameter value is, the greater the amplitude of the cycle becomes.

Figure 7.10 shows the sensitivity of Phillips Curve to *Labor Adjustment Time*. Blue, red and pink dots represent the simulation results for the parameter value of 1.8, 2.0 and 2.2 respectively. Accordingly, the shape and properties of the scatter diagram do not significantly change. The only change is that, for higher values of the concerned parameter, the curved line is a little bit more vertical.

This difference can be interpreted as, when labor market works better, hiring and firing becomes easier, the cycles in the demand will easily be reflected to supply, and the effect on prices will be low. Consequently, when labor market does not work perfectly, or too many regulations to prevent hiring or firing easily, the changes in the demand will be reflected to prices with a higher degree. Although this interpretation makes sense, more tests would be necessary to highlight this conclusion.

There is another difference in the simulation results. For higher values of *Labor Adjustment Time*, the length of the observed curve is smaller, or in other words, data is less scattered. The reason behind is the amplitude of cycles as explained before.

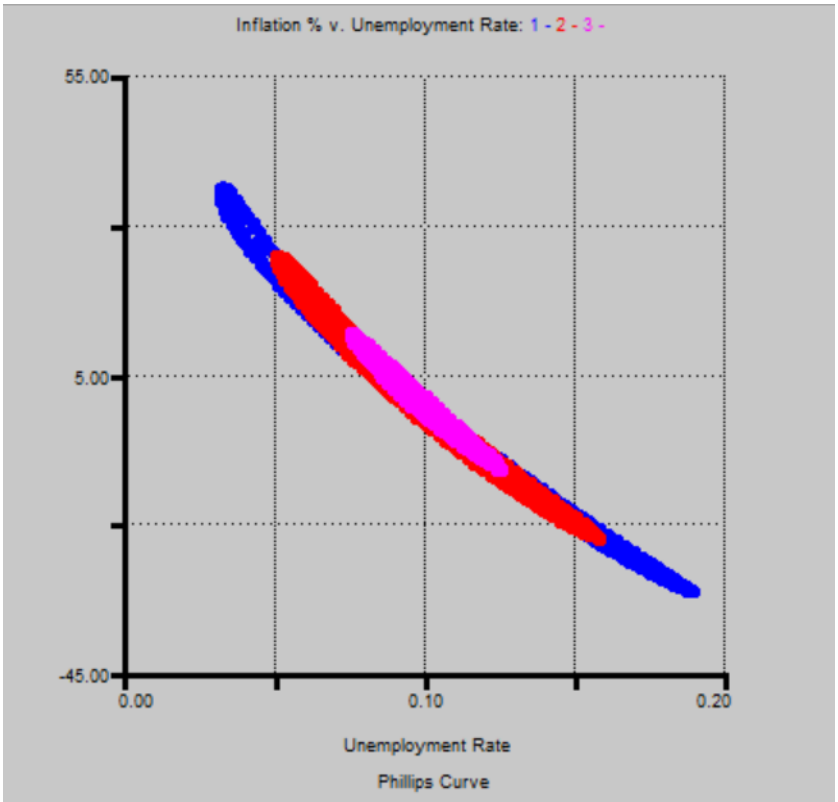

Figure 7.10 : Sensitivity of Phillips Curve to *Labor Adjustment Time*.

Figure 7.11 shows the sensitivity of *Aggregate Supply* to *Labor Adjustment Time*. Blue, red and pink dots represent the simulation results for the parameter value of 1.8, 2.0 and 2.2 respectively. Two differences in the simulation results can be noted. The first is the amplitude of the cycle, and the second is the duration.

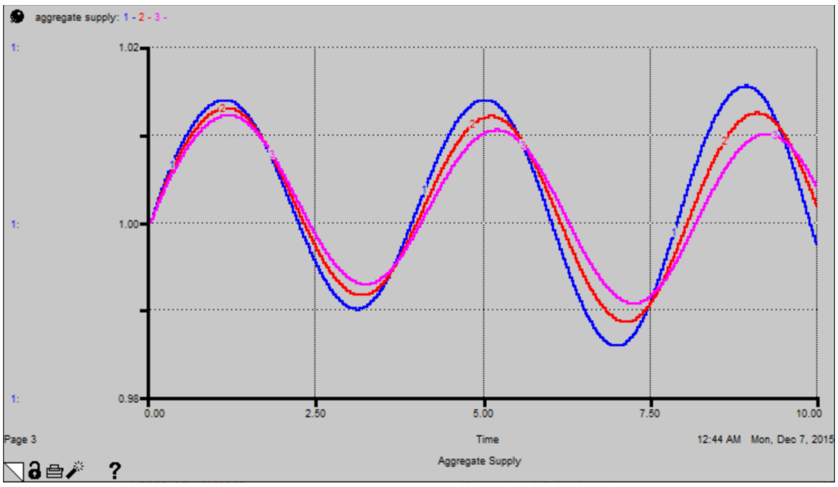

Figure 7.11 : Sensitivity of *Aggregate Supply* to *Labor Adjustment Time*.

Accordingly, for higher values of *Labor Adjustment Time*, the amplitude of cycle is smaller. This means that, when it is not 'too easy' to hire or fire, the economy would be more stable. From a different point of view, if job-security is higher and workers are employed for long periods, the amplitudes of business cycles would be smaller. This result is surprising, and there is not a short-cut way to compare it with the realities. Additional work is necessary to check if this result is apparent in the data.

The other observed difference is about duration. Accordingly, for higher values of *Labor Adjustment Time*, the duration of cycle increases. In other words, when hiring or firing is not 'too easy', business cycles are not only small, but also rare. When these two simulation results are combined, it can be argued that labor market regulations for long-term employments lead to economic stability.

It is apparent that *Labor Adjustmet Time* is an important parameter affecting the behavior of economic variables. The other possible candidate is *Price Level Adjustment Time*. Figure 7.12 shows the sensitivity of original Phillips Curve to this parameter. Blue, red and pink dots represent the simulation results for the parameter value of 1.1, 1.0 and 0.9 respectively.

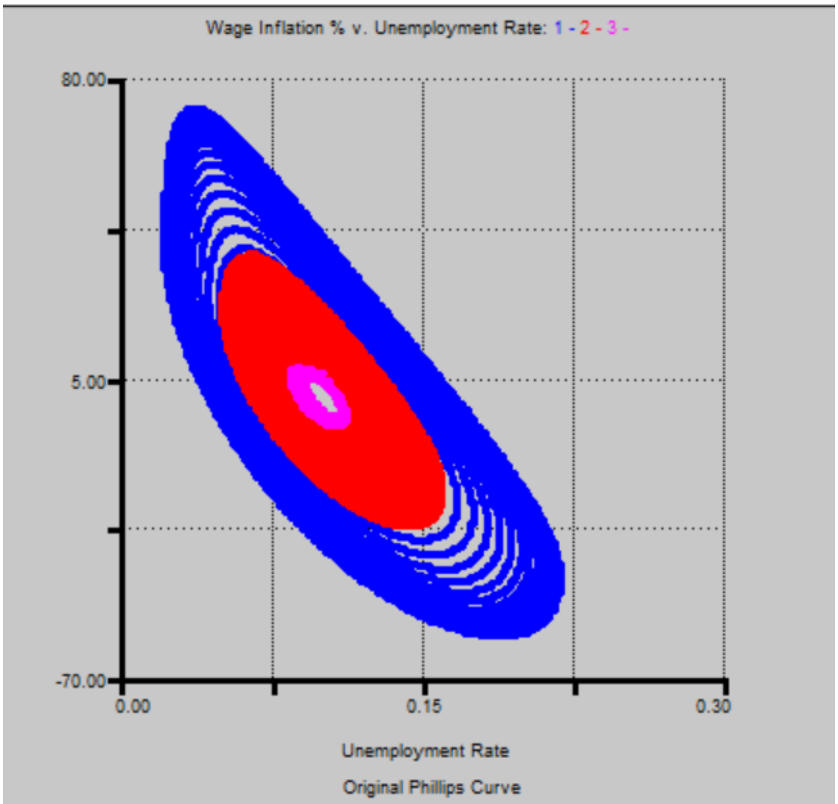

Figure 7.12 : Sensitivity of original Phillips Curve to *Price Level Adjustment Time*.

Accordingly, the same inverse and non-linear relation between *Wage Inflation* and *Unemployment Rate* is observed for different values of *Price Level Adjustment Time*. However, as the parameter gets smaller, the length of the curve declines. This is because, for small values of this parameter, the cycle gets smaller. In other words, for small values of the parameter, economic system becomes more stable. The critical value for *Price Level Adjustment Time* is somewhere between 0.9 and 1.0. Below this critical value, the cycle vanishes eventually. The smaller the value, the faster cycle vanishes. Other than that, the shape of the relation do not change.

Figure 7.13 shows the sensitivity of Phillips Curve to *Price Level Adjustment Time*. Blue, red and pink dots represent the simulation results for the parameter value of 1.1, 1.0 and 0.9 respectively. Accordingly, the length of the observed curve declines for small values of *Price Level Adjustment Time* as expected. The shape of the curve is not affected by the parameter.

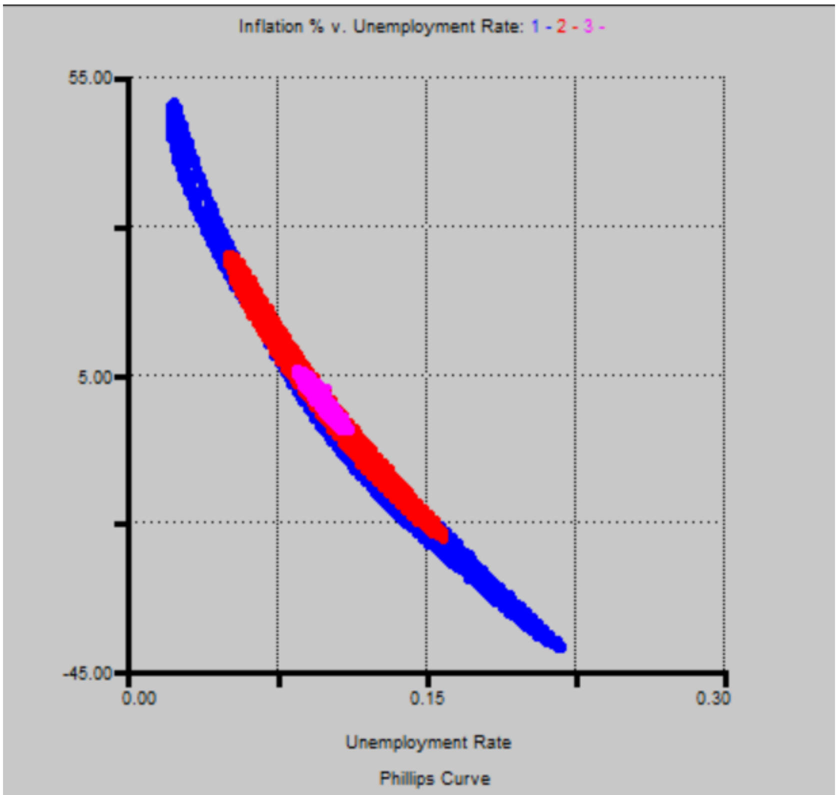

Figure 7.13 : Sensitivity of Phillips Curve to *Price Level Adjustment Time*.

Finally, the behavior of *Aggregate Supply* should be analyzed. Figure 7.14 shows the sensitivity of *Aggregate Supply* to *Price Level Adjustment Time*. Blue, red and pink dots represent the same parameter combination as before. Accordingly, the behavior of *Aggregate Supply* is slightly sensitive to *Price Level Adjustment Time*.

The initial response of *Aggregate Supply* do not change for different parameter values. However, the amplitude of cycle becomes smaller for smaller values of the parameter. This result is consistent with the sensitivity results of other variables. However, the

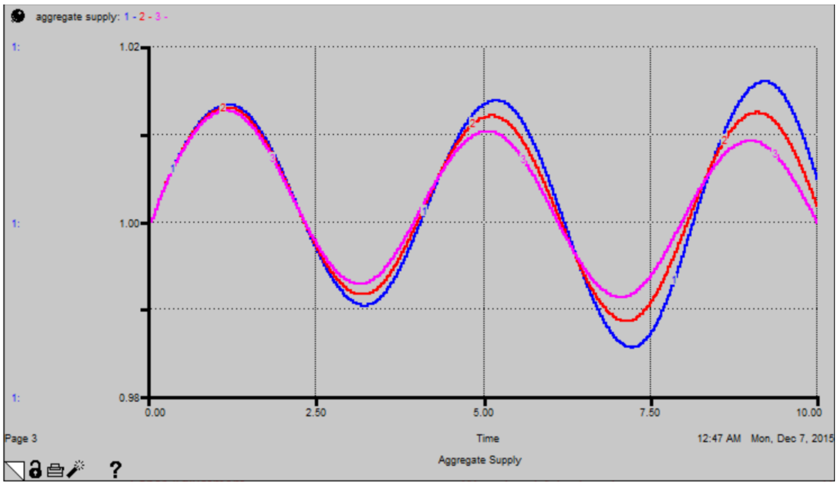

Figure 7.14 : Sensitivity of *Aggregate Supply* to *Price Level Adjustment Time*.

duration of the cycle declines as well, when the parameter value is decreased. In other words, when *Price Level Adjustment Time* is lower, the economy faces with smaller business cycles, but more frequently.

If these results are interpreted together, lower values of *Price Level Adjustment Time* is favorable because it helps the economy to omit business cycles. However, this also leads to cycles with low frequencies. Additional work with the observed data is required to justify these findings. On the other hand, the relation between *Unemployment Rate* and *Inflation* or *Wage Inflation* is not affected by the parameter value.

Another important parameter in the proposed model is *Wage Level Adjustment Time*. Figure 7.15 shows the sensitivity of original Phillips Curve to different values of this parameter. Blue, red and pink dots represent the simulation results for the parameter value of 0.9, 1.0 and 1.1 respectively.

Accordingly, original Phillips Curve is sensitive to *Wage Level Adjustment Time*. The shape of the curve is similar, but slightly less vertical for higher values of the parameter. This effect is opposite of the effect of *Labor Adjustment Time*. In other words, when wages respond harder or labor adjustment is easier, the original Phillips Curve becomes more flat. This result makes sense, since the change in demand would cause change in the labor and volatility in the horizontal axis will be greater compared to the volatility in the vertical axis, and the curve would be more flat.

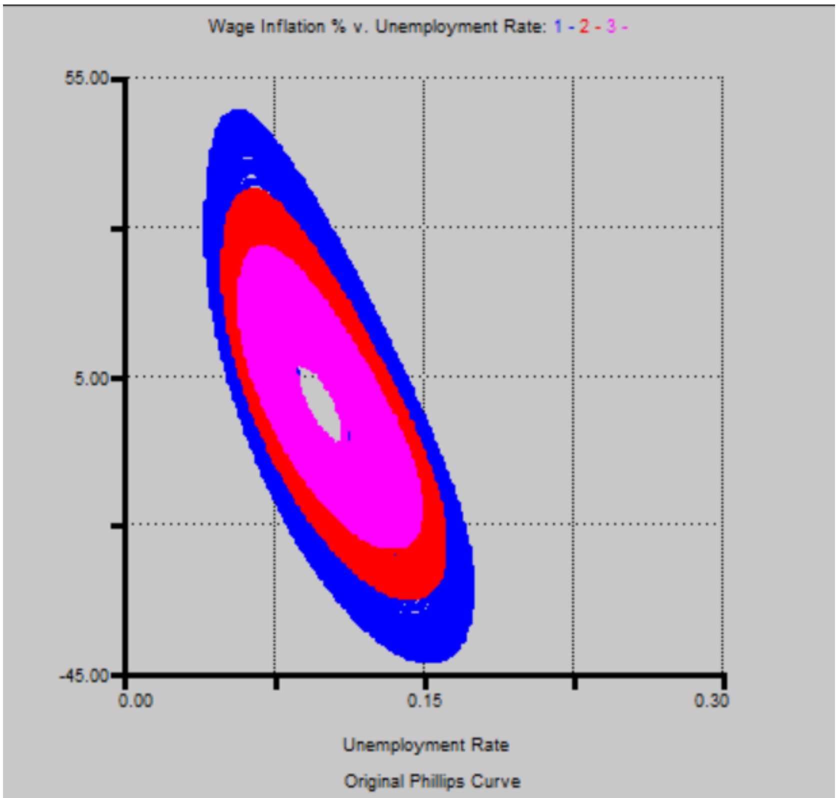

Figure 7.15 : Sensitivity of original Phillips Curve to *Wage Level Adjustment Time*.

The other observation is that, for higher values of *Wage Level Adjustment Time*, the graph is less scattered. This is because higher values generate cycles with smaller amplitudes. In that sense, when wage contracts are signed for longer time periods, the economy becomes more stable. This results supports the Post-Keynesian proposal of governmental control of wages for stabilization purposes.

There is a critical value of *Wage Level Adjustment Time* which is somewhere around 1.6 years. For the values above this critical value, cycles vanish eventually. The larger the value is above this critical value, the faster the cycle vanishes.

Figure 7.16 shows the sensitivity of Phillips Curve to *Wage Level Adjustment Time*. Blue, red and pink dots represent the simulation results for the parameter value of 0.9, 1.0 and 1.1 respectively as before. Accordingly, Phillips Curve is also affected by *Wage Level Adjustment Time*. As the value of *Wage Level Adjustment Time* increases, the Phillips Curve becomes more horizontal. This effect is similar to original Phillips Curve and reasonable, since wage inflation is assumed to be transferred to price inflation through the markup-pricing behavior of the firms.

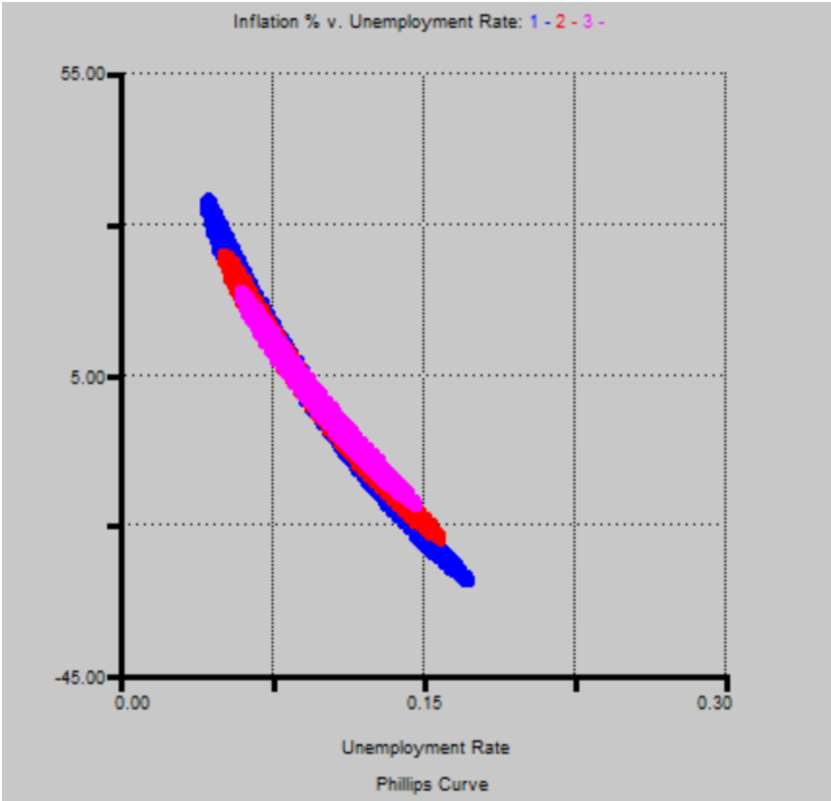

Figure 7.16 : Sensitivity of Phillips Curve to *Wage Level Adjustment Time*.

Figure 7.17 shows the sensitivity of *Aggregate Supply* to *Wage Level Adjustment Time*. Blue, red and pink dots represent the same parameter set as before. Accordingly, the initial response of *Aggregate Supply* after the money shock is not affected by the considered parameter. However, the duration of the cycles increases as the adjustment time increases. Although it is not apparent in the 10-year graph, the amplitude also declines in the long run.

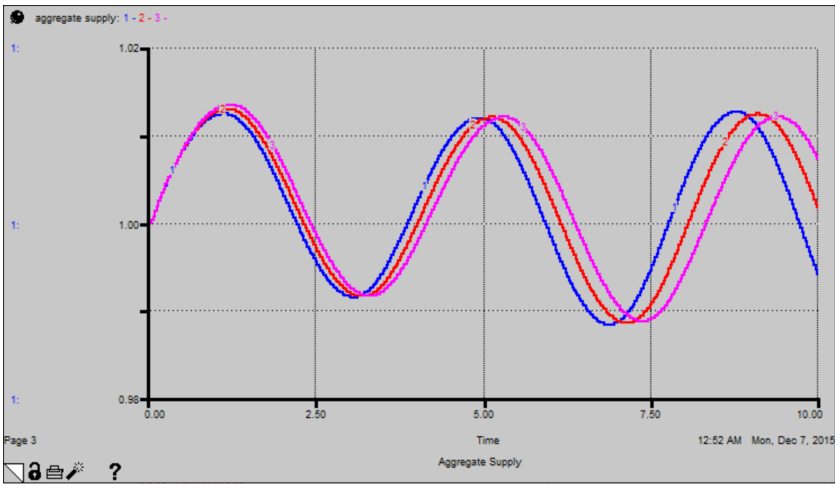

Figure 7.17 : Sensitivity of *Aggregate Supply* to *Wage Level Adjustment Time*.

When the critical behaviors are considered together, *Wage Level Adjustment Time* do not affect the behavior pattern of key variables significantly. In other words, the inverse relation, non-linearity and counter-clockwise behavior is apparent for different parameter values. In terms of the slope of the curves, the effect of *Wage Level Adjustment Time* is opposite of the effect of *Labor Adjustment Time*. On the other hand, higher values of the parameter creates cycles with lower amplitudes and higher durations. In other words, higher values of *Wage Level Adjustment Time* lead to more stable economies.

It is worth to note that, *Wage Level Adjustment Time* and *Labor Adjustment Time* have similar effects on the business cycles. For higher values of both parameters, generated cycles have lower amplitudes and higher durations. In other words, when labor and wages are rigid, business cycles become less severe and rare. This result is at odds with the mainstream assumption that labor market flexibility leads to economic stability. The model simulations show that, when there are more regulations in labor market and wage contracts, economic system become more stable.

Reference Inventory Coverage shows the desired level of *Inventory* in terms of average sales. Figure 7.18 shows the sensitivity of original Phillips Curve to *Reference Inventory Coverage*. Blue, red and pink lines represent the simulation results for the parameter value of 0.9, 1.0 and 1.1 respectively.

Accordingly, the shape of the original Phillips Curve is not sensitive to *Reference Inventory Coverage*. However, the graph is less scattered for higher values of the parameter because they lead to larger cycles in the economy. The critical value for *Reference Inventory Coverage* is somewhere around 1.6. The larger the value is above this critical value, the faster the cycle vanishes.

Figure 7.19 shows the sensitivity of Phillips Curve to *Reference Inventory Coverage*. Blue, red and pink dots represent the same parameter set. Accordingly, the shape of Phillips Curve is also not sensitive to *Reference Inventory Coverage*. Because of the large cycles created by higher values of *Reference Inventory Coverage*, the length of the curve becomes larger.

Figure 7.20 shows the sensitivity of *Aggregate Supply* to the same parameter. The parameter set is again 0.9, 1.0 and 1.1 respectively. Accordingly, the initial response

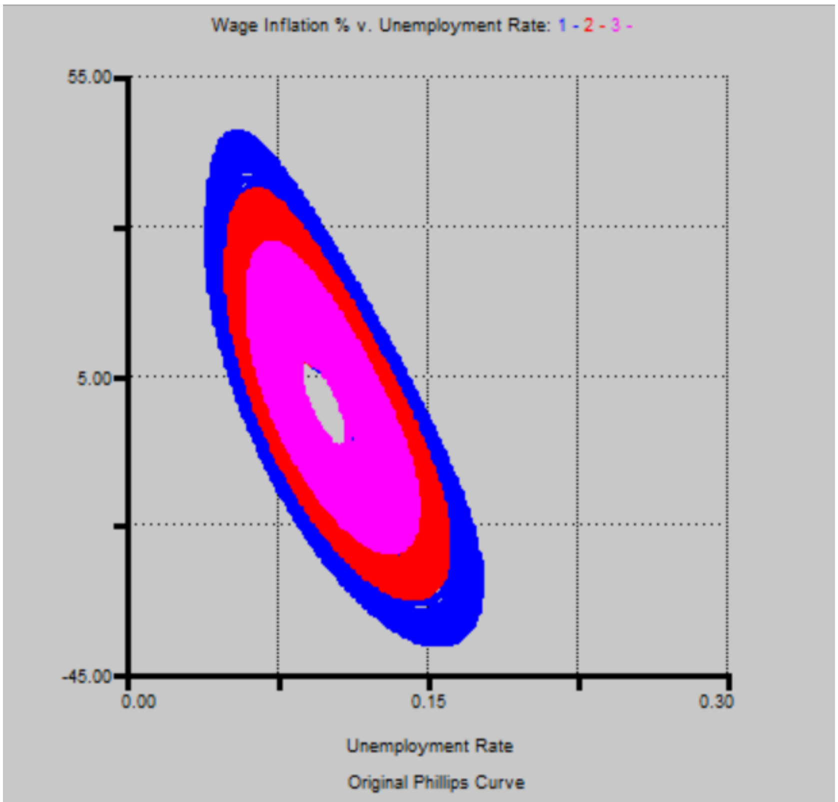

Figure 7.18 : Sensitivity of original Phillips Curve to *Reference Inventory Coverage*.

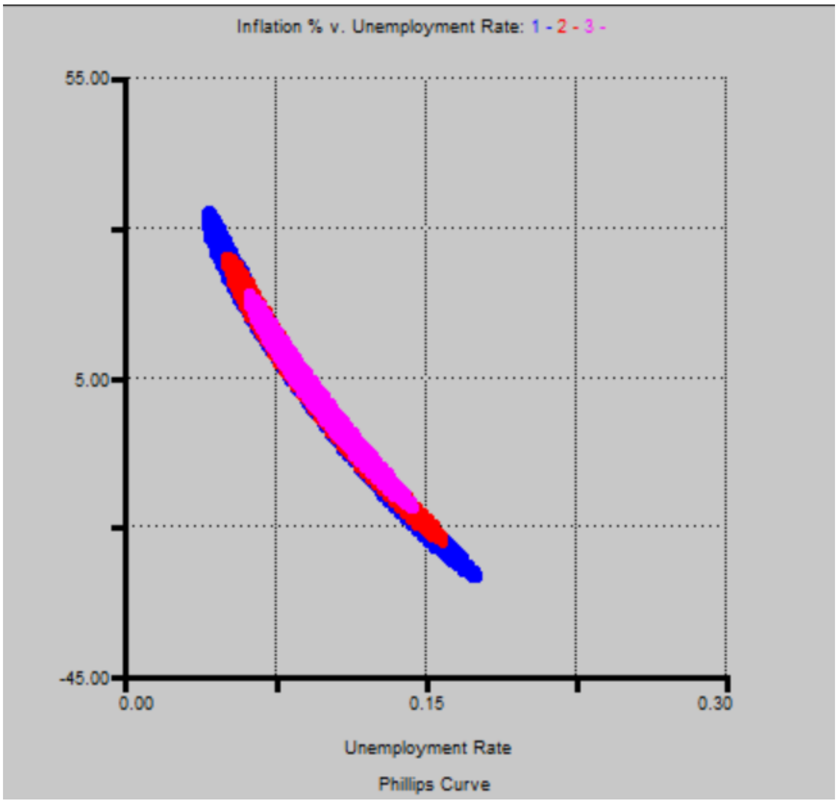

Figure 7.19 : Sensitivity of Phillips Curve to *Reference Inventory Coverage*.

of *Aggregate Supply* is not significantly affected by *Reference Inventory Coverage*.

However, the both the amplitude and the duration of cycles decrease for higher values of the parameter.

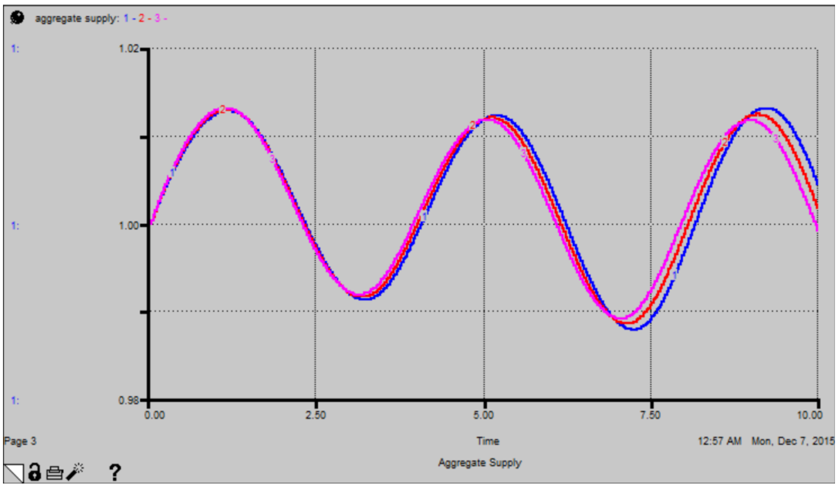

Figure 7.20 : Sensitivity of *Aggregate Supply* to *Reference Inventory Coverage*.

The sensitivity of Wage Curve is analyzed for the parameters mentioned above. The change in Wage Curve is similar to the two versions of Phillips Curve. In other words, when those curves become more vertical after a parameter is changed, then Wage Curve become more vertical too. Accordingly, *Wage Level Adjustment Time* affects the slope of Wage Curve positively while *Labor Adjustment Time* affects it negatively. *Price Level Adjustment Time* and *Reference Inventory Coverage* has no effect on the slope of any curve.

The effect of *Natural Rate of Unemployment* is also analyzed. For small changes in this variable (10%), the observed behavior in the simulations do not change significantly. The shape of the different versions of Phillips Curve do not change but only shifts as expected. The effect of small changes in this parameter on *Aggregate Supply* is also negligible. Only larger shifts of *Natural Rate of Unemployment* generate an observable difference in the simulation result.

Figure 7.21 shows the behavior of *Aggregate Supply* when the parameter is 5%, 10% and 15% respectively. Accordingly, when *Natural Rate of Unemployment* is higher, both the amplitudes and the durations of cycles increase. In other words, lower natural rates are preferable for a relatively stable economy.

These tests are applied for Wage Curve and Expectations-Augmented Phillips Curve as well. The results for Expectations-Augmented Phillips Curve is similar to Phillips Curve. In other words, whenever the slope of Phillips Curve changes, the slope of

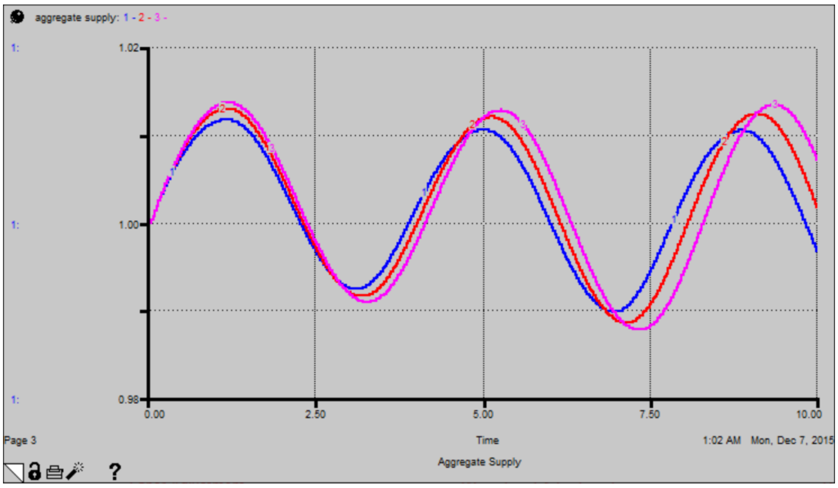

Figure 7.21 : Simulation result of *Aggregate Supply* when U^* is equal to 5% (blue), 10% (red) and 15% (pink) respectively.

Expectations-Augmented Phillips Curve changes as well in the same direction. For higher values of *Labor Adjustment Time*, Wage Curve becomes more vertical, and for higher values of *Wage Level Adjustment Time*, it becomes more horizontal.

Moreover, sensitivity of model behavior for *Household Balances Turnover*, *Business Balances Turnover* and *Aggregate Demand Forecast Adjustment Time* are also concerned. It turns out that the model behavior is not sensitive to these variables. The differences are too small and can be negligible. The amount of money shock is also tested for sensitivity and the effect observed to be insignificant. Finally, the effect of *Reference Loanable Funds Ratio* is analyzed. For small changes in this parameter, simulation results do not significantly change. However, it appears that higher values for this parameter leads to a slightly higher amplitude in the generated business cycles.

The same tests are applied for the case of inflation shock rather than money shock. The results for these tests are not reported because they are almost completely the same with the money shock case. Other parameters which are not mentioned here are skipped in this sensitivity test because the values for them are strictly tied with each other and cannot be analyzed alone.

To sum up, the results show that, the same key behavioral patterns emerge with small changes in the parameters. Business cycles, original Phillips Curve, Phillips Curve, and Wage Curve emerges in the simulation results. The relation of variables during the business cycles are similar to the empirical observations. This result supports the validity of the model structure.

7.3 Behavioral Validation

In Section 7.2, several structural validation tests are applied. Structural validation is about the inner structure of the model. In other words, variables within the model, equations, parameters, their units and values are of concern. Once enough confidence is built about the model structure, validation of the model behavior can be concerned.

In behavioral validation, the behavior of the model is analyzed. It is expected that the simulation of the model generates the observed behavioral pattern of the real system. The purpose of the proposed system dynamics model is to explain how money affects output. For this reason, the behavior patterns to be tested are chosen to be related with the scope of the model.

In the real system, it is observed that money has an effect on output, at least in the short-run. In other words, monetary variables and real variables are not behaving independently. This effect can be shown by the empirical relation between unemployment rate and wage inflation [13]. Figure 7.22 shows the original Phillips Curve fitted to 1861-1913 data and a cycle between 1861-1868 [13].

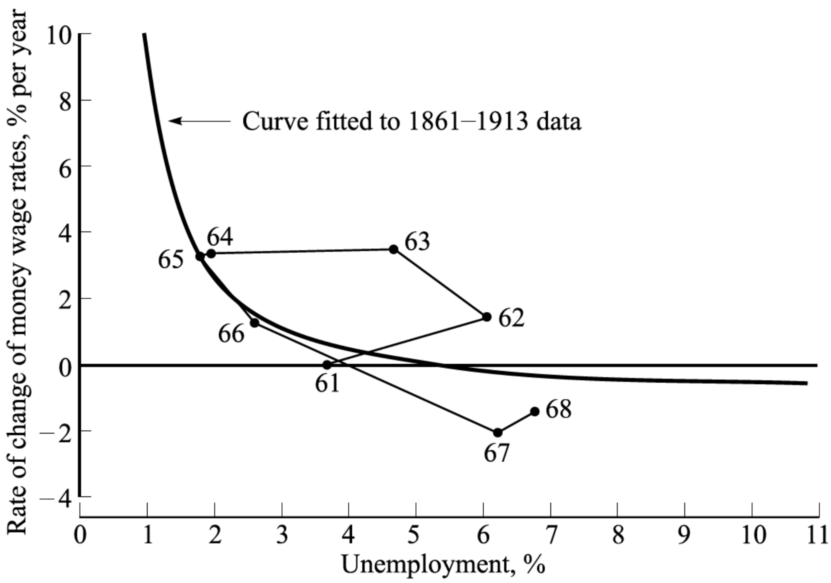

Figure 7.22 : Original Phillips Curve and a counter-clockwise cycle between 1861-1868, adopted from [13].

In the empirical study of Phillips [13], there are several similar counter-clockwise cycles, around the bending curve. This bending curve, which is referred as the original Phillips Curve in this study, represents the average of the observations in the concerned time period. The move of the data around this curve can be interpreted as business cycles, or trade cycles in the terminology of Phillips [13]. The cycles being counter-clockwise can be interpreted as wage inflation being higher for a given unemployment rate when economic activity is rising, and being lower for the same unemployment rate when economic activity is falling.

The proposed system dynamics model generates a behavior similar to the empirical curve. As seen in Figure 7.23, there is a clear inverse relation between unemployment rate and wage inflation. Wage inflation is given as the percentage value in the graph. The relation is also non-linear, as seen in the red line which lies between the scattered data points.

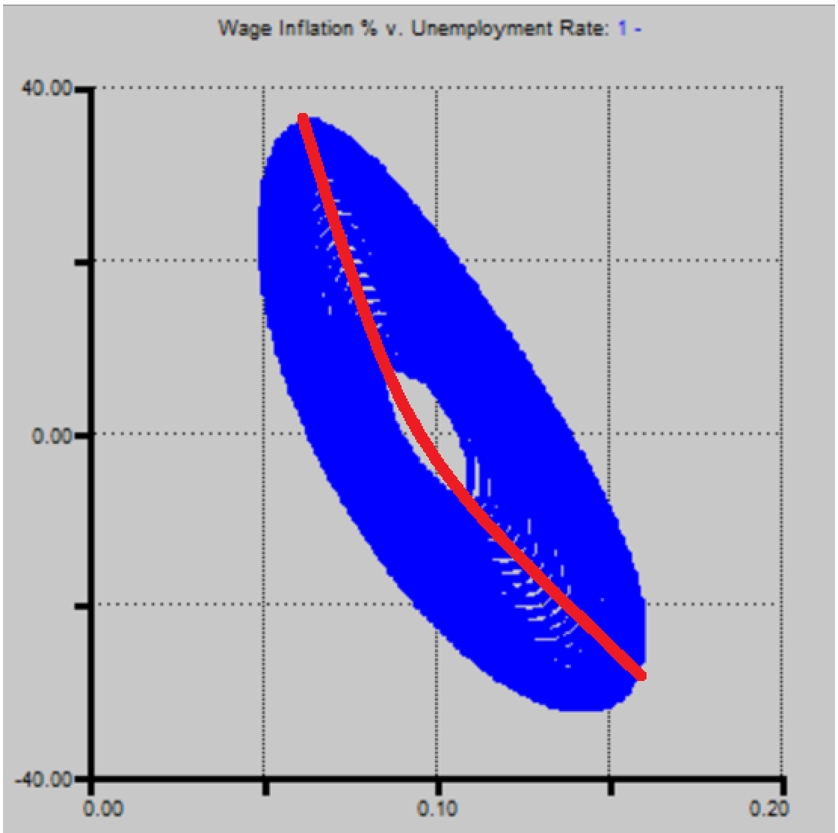

Figure 7.23 : Original Phillips Curve generated by SDMI model after 5% money shock.

Simulation results for wage inflation and unemployment rate show counter-clockwise cycles around the average curve passing through the data points. Figure 7.24 shows the simulation results for the first 6 years. Simulation result for $t = 0$ and $t = 6$ are marked on the graph to show the initial and final results of the simulation. Accordingly, wage inflation not only depends on unemployment rate, but also the direction of change of unemployment rate.

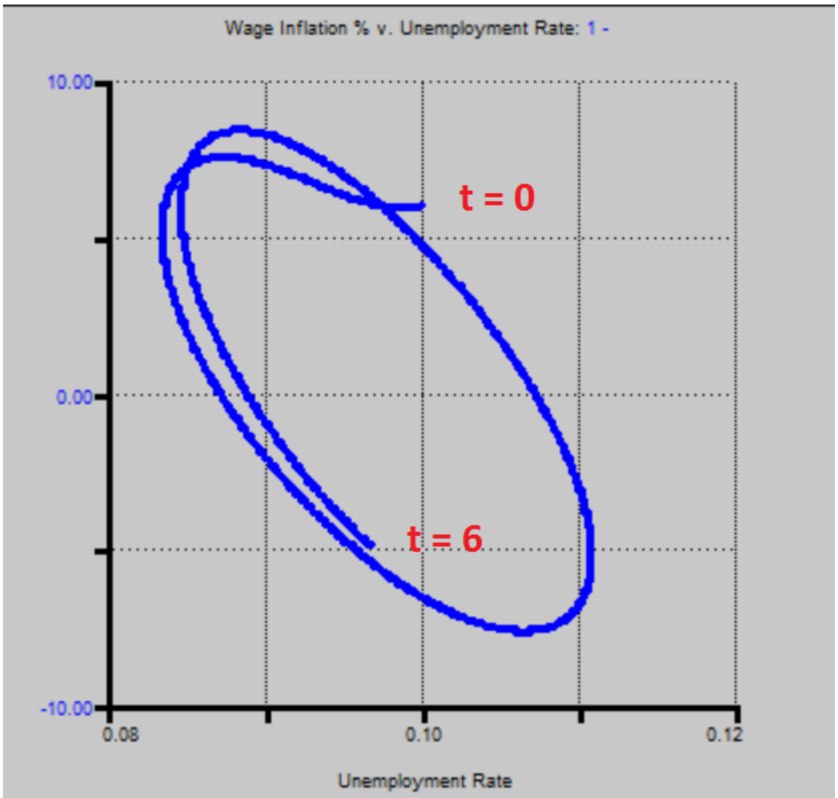

Figure 7.24 : Scatter diagram of unemployment rate and wage inflation for the first 6 years, after money shock.

Figure 7.25 shows the percentage unemployment rate [143] and yearly change of hourly earnings of production and nonsupervisory employees in the manufacturing sector [144] of United States, between 1950 and 1966. The original monthly data is converted into yearly averages. After that, percent change of hourly earnings is calculated in order to get annual wage inflation.

The negative relation between wage inflation and unemployment rate can be seen in this graph. Accordingly, during the years in which unemployment rate is substantially rising, wage inflation tends to fall. Conversely, during the years in which unemployment rate is substantially falling, wage inflation tends to rise.

Figure 7.26 shows the comparison of the data for the years 1951, 1953, 1959 and 1960. Values of unemployment rate and wage inflation for these years are presented on the graph. Unemployment rate in 1951 and 1953 are very close, 3.3% and 2.9%

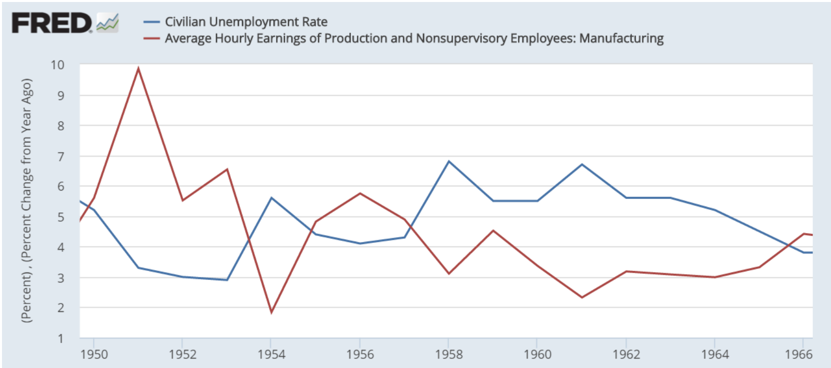

Figure 7.25 : Unemployment rate and wage inflation in the United States between 1950 and 1966, adopted from [145].

respectively. However, wage inflation in 1951 is substantially higher than in 1953, even though unemployment rate is slightly higher in 1951. This result may be due to the fact that, unemployment rate is decreasing in 1951 while it is increasing in 1953. In other words, business activity is rising in 1951 while it is falling in 1953.

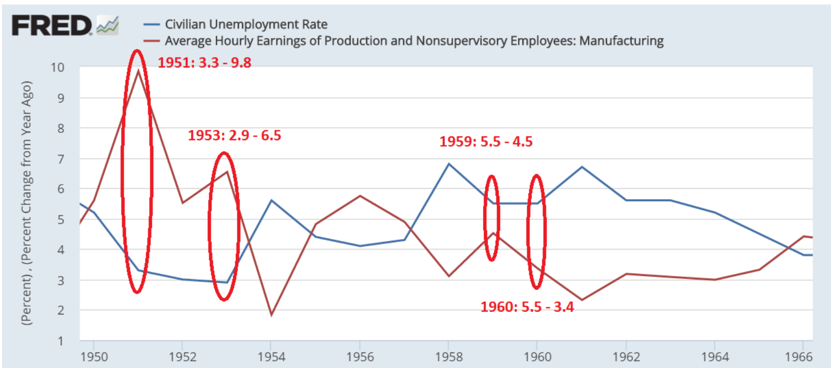

Figure 7.26 : Comparison of unemployment rate and wage inflation in the United States for the years 1951, 1953, 1959 and 1960, adopted from [145].

Similarly, the data points for 1959 and 1960 can be compared. Unemployment rate in 1959 and 1960 are the same; 5.5%. However, there is a significant decrease in the wage inflation from 1959 to 1960. The reason for this may be due to the direction of change in the unemployment rate. Unemployment rate is falling from 6.8% in 1958 to 5.5% in 1959, and is rising from 5.5% in 1960 to 6.7% in 1961. In other words, unemployment rate is falling between 1958 and 1959, is relatively stable between 1959 and 1960, and rising again between 1959 and 1960. As a result, the direction of change in unemployment rate may have an effect on wage inflation.

This result is consistent with the counter-clockwise cycles in the model behavior. In the two-dimensional space, when the data is moving from right to left, meaning that unemployment rate is falling, wage inflation is higher than it would be otherwise.

Moreover, when the data is moving from left to right, meaning that unemployment rate is rising, wage inflation is lower than it would be otherwise.

In his empirical study, Phillips [13] makes a similar interpretation. In other words, wage inflation is not only determined by the rate of unemployment, but also the change in the rate of unemployment. This shows that the firms desire to hire more labor may contribute to the change in the wage level, even though the additional labor is not hired yet.

The rise in nominal wages due to labor market conditions should be reflected to nominal prices, so that employers continue to make the profit they used to. As a result, the dynamics which leads to an increase in wages are expected to rise price level as well. Empirically, there is a similar inverse relation between inflation and unemployment rate, and is called Phillips Curve. As an example, Japan's Phillips Curve for the years between 1980 and 2005 is given in Figure 7.27.

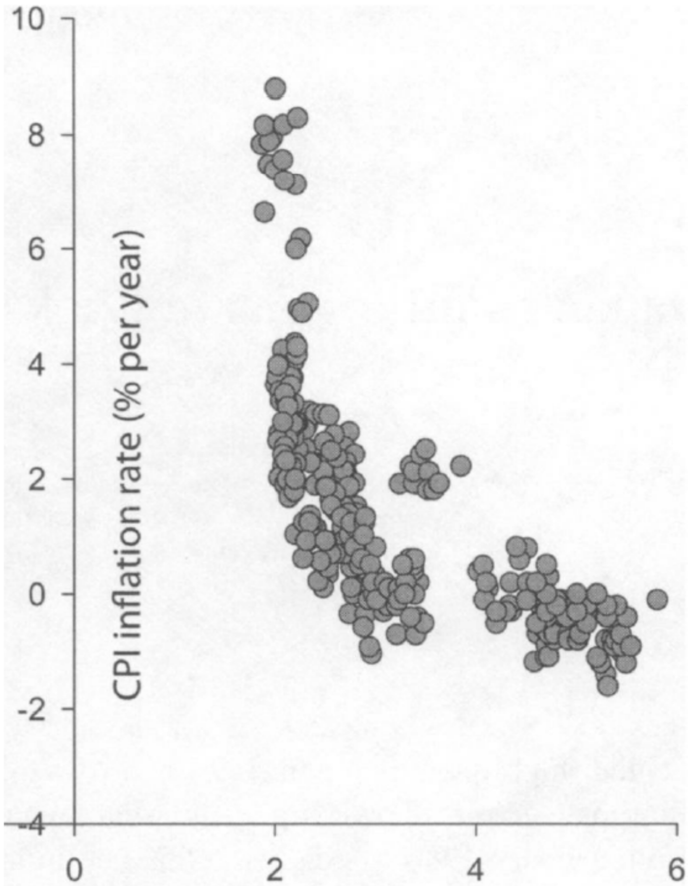

Figure 7.27 : Phillips Curve for Japan for the years between 1980 and 2005, adopted from [146].

The proposed system dynamics model generates a similar curve as well. For this purpose, total amount of money is increased 1% by money injection and the model is simulated for 100 years. Figure 7.28 shows the scatter diagram of the simulation result. The red line, average of the data points, represents the simulated Phillips Curve.

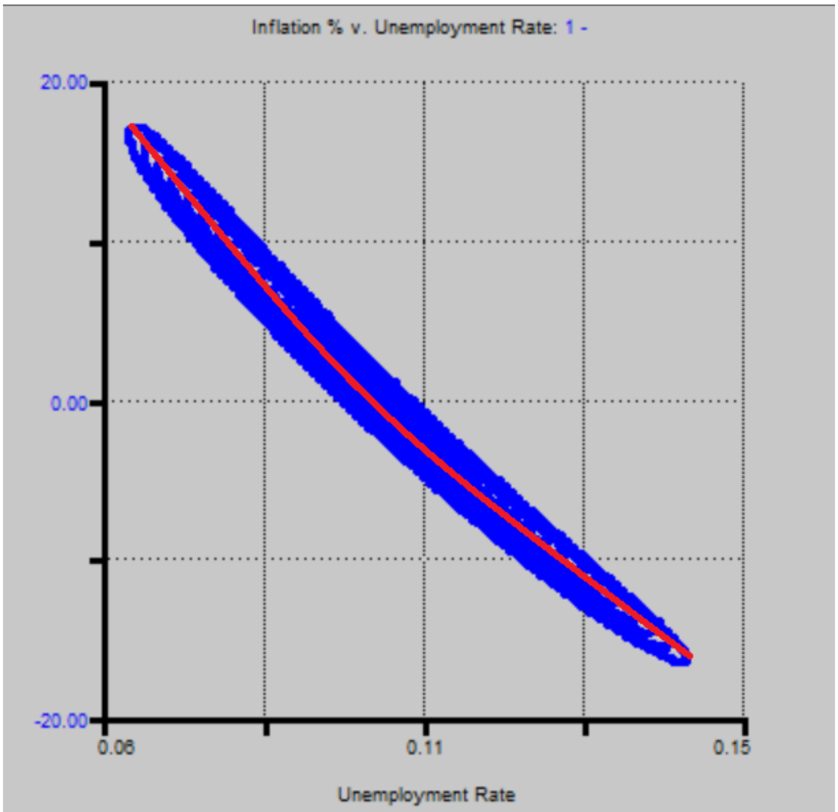

Figure 7.28 : Phillips Curve generated by SDMI model after 1% money shock.

After 1960's, Phillips Curve is interpreted as a trade-off between inflation and unemployment rate. In other words, it has been believed that unemployment rate can be decreased permanently by inflationary policies. However, it turned out that the inverse relation between inflation and unemployment rate is not permanent, and may shift. Figure 7.29 represents such a case in the United States during 1970's and early 1980's, based on data from U.S. Bureau of Labor Statistics.

The inverse relation between *Inflation* and *Unemployment Rate* is a disequilibrium phenomenon and cannot be interpreted as a permanent trade-off in equilibrium. In other words, based on the inverse relation between them, a policy of increasing money supply at a higher rate would fail to permanently keep unemployment at low levels.

This disequilibrium nature can be expressed from another perspective, by changing the amount of inflation shock. Figure 7.30 shows the comparison of two curves after

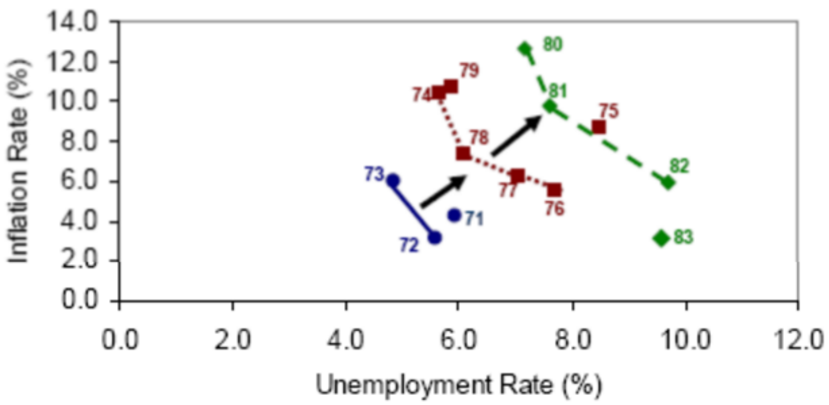

Figure 7.29 : Phillips Curve shifts during 1970's and early 1980's, adopted from [147].

5% and 15% inflation shocks respectively. Accordingly, when the rate of change of money is increased, the appeared curve in scatter diagram shifts, while maintaining the basic properties. The shift of the simulated Phillips Curve is similar to the empirical observations given in Figure 7.29.

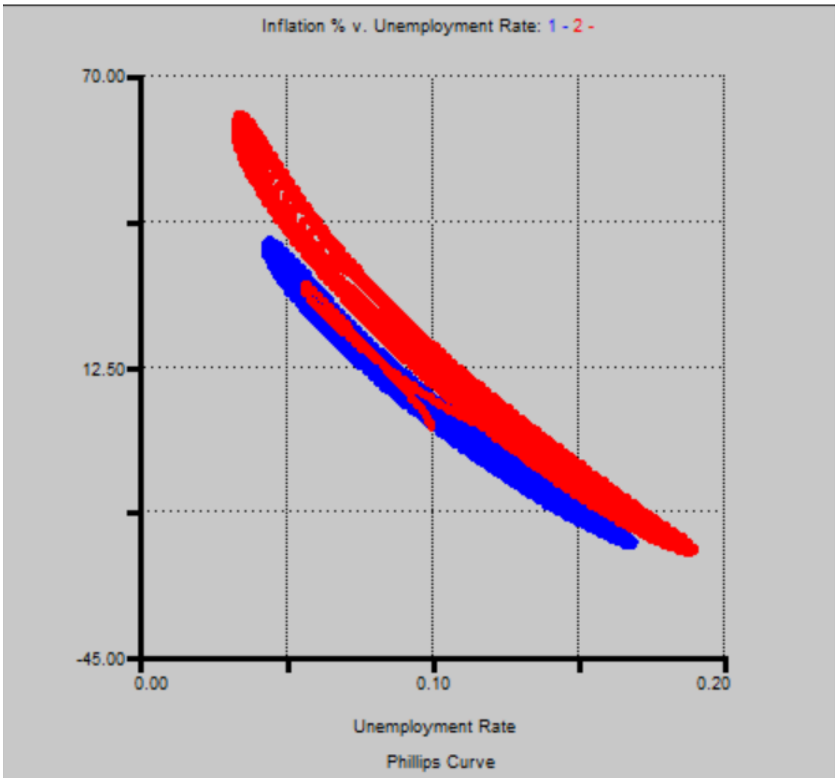

Figure 7.30 : Simulated Phillips Curve after inflation shock of 5% (blue) and 15% (red).

Phillips Curve is later criticized of not taking expectations into account, and the inflation-unemployment relation is updated. This version of Phillips Curve is referred as 'Expectations-Augmented Phillips Curve' and is actually similar in shape to the previous one. Proposed model can generate this curve as well.

For simulation purposes, 1% of money is injected into the system and the model is simulated for 50 years. The simulation result is given in Figure 7.31. The behavior shown in the scatter diagram of the simulation result shows an inverse relation between *Unexpected Inflation* and *Unemployment Rate*, where *Unexpected Inflation* is defined as the difference between *Inflation* and *Expected Inflation*, and the expectation is defined to be backward-looking.

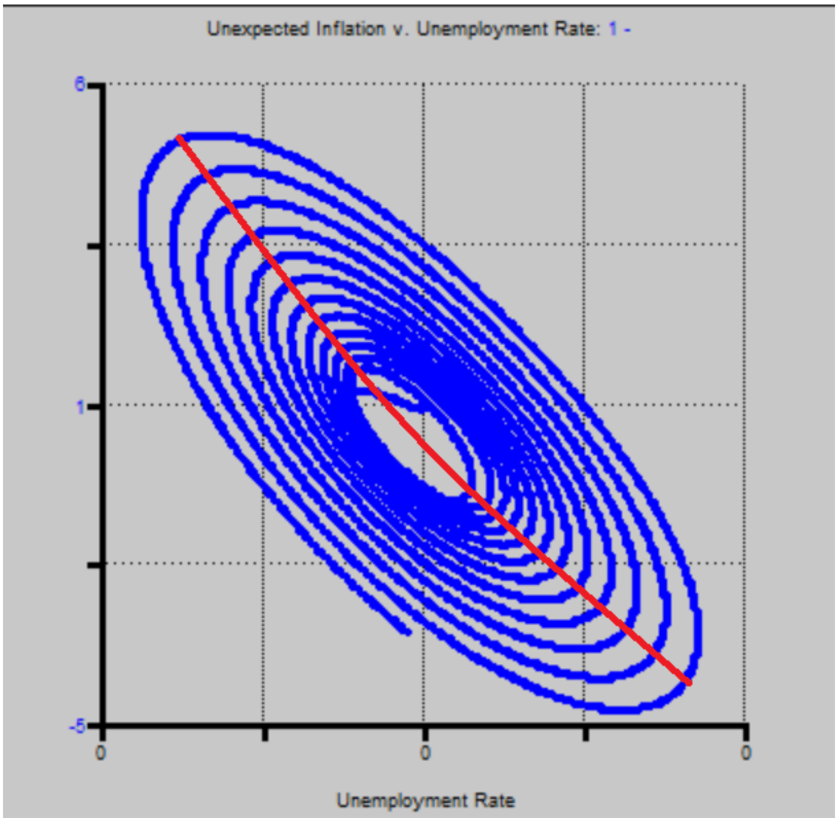

Figure 7.31 : Expectations-Augmented Phillips Curve appear in 50 years of simulation after 1% money shock.

Hoover [148] gives a similar result for the inflation and unemployment rate data of US between 1976 and 2002, given in Figure 7.32. Accordingly, there is an inverse relation between unemployment rate and change in the inflation rate. Change in the inflation rate corresponds to the unexpected inflation in this study, with the assumption that expected inflation is equal to the inflation for the previous year.

In Chapter 6, the model is shown to produce business cycles, with the assumed parameter set. The duration of the cycles is approximately 4 years. Business cycles include recessions and expansions following each other. The cycle duration is usually

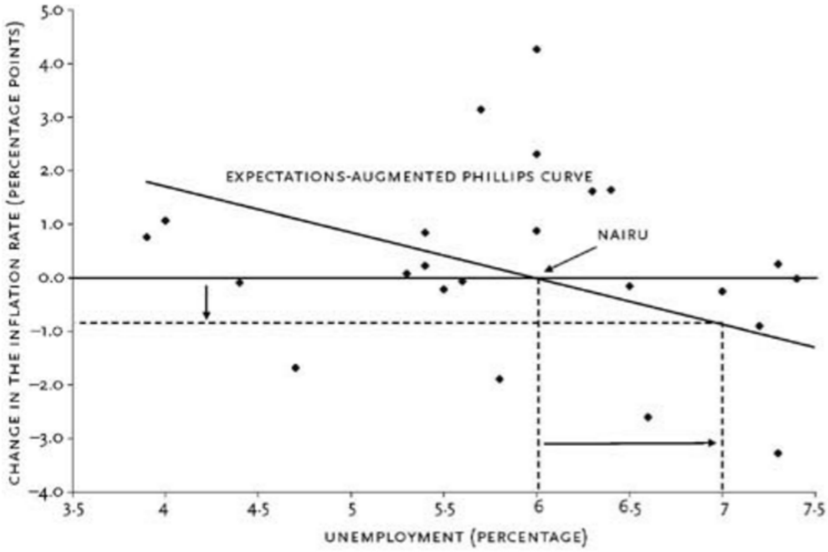

Figure 7.32 : The Expectations-Augmented Phillips Curve in US for the period 1976-2002, adopted from [148].

lie between 1.5 years and 8 years [149]. Thus, it may be argued that the average duration of business cycles is around 4 to 5 years. As a result, 4-year business cycles generated by the model is consistent with the empirical facts.

In a business cycle, economic aggregates usually follow a common pattern. In recessions, unemployment rate rises and economic output falls. In expansions, growth rate rises and unemployment rate falls. Figure 7.33 shows Unemployment Rate in US between 1948 and 2005. The data are from the Bureau of Labor Statistics. The shaded areas indicate recessions.

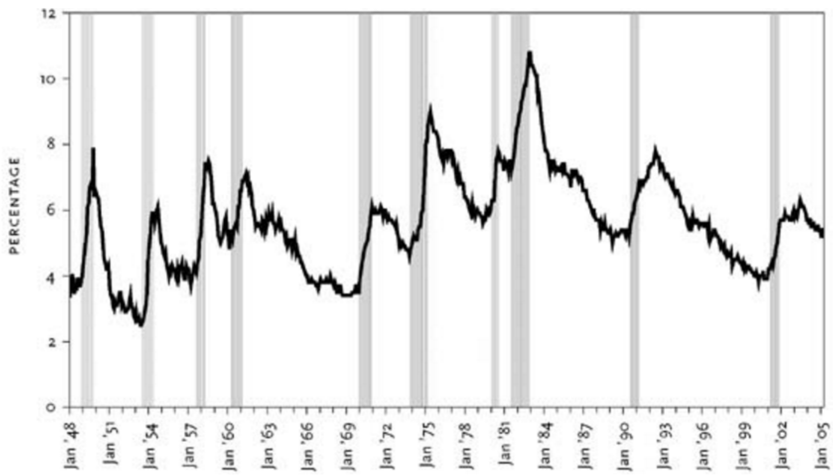

Figure 7.33 : Unemployment Rate and Recessions in US between 1948 and 2005, adopted from [150].

In business cycles, inflation move towards the same direction with growth rate, usually with a lag. Figure 7.34 shows the growth rate and inflation rate in US for the years between 1968 and 1982. Growth rate is calculated as the percent change of the annual GDP [151] and inflation is calculated as the percent change of the annual CPI [152]. The shaded areas indicate recessions.

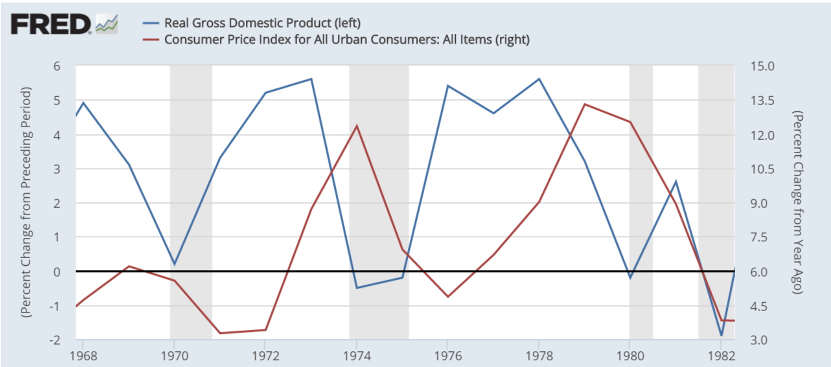

Figure 7.34 : Growth rate and inflation in US between 1968 and 1982, adopted from [145].

According to Figure 7.34, periods of low growth rates are soon followed by periods of low inflation rates. Similarly, periods of high growth rates are followed by periods of high inflation rates. Between the peak and trough points of growth rate and inflation, there is approximately a year time lag. For example, growth rate is trough in 1970 and increases again the following year. However, the trough point for inflation occurs in 1971. Similarly, a peak of growth rate is seen in 1973 while a peak of inflation is seen the next year. In all the shaded areas indicating recession periods, growth rate is increasing but inflation is decreasing.

The time lag between growth rate and inflation can be interpreted as inflation being sticky and responding the economic activity with a delay. The proposed system dynamics model generates a similar delay in the limit cycle. Figure 7.35 shows simulation results for growth rate and inflation after money shock, for the years between 100 and 110. Accordingly, there is approximately a year lag between the peak and trough points of growth rate and inflation.

The delayed response of inflation is also observed after a monetary policy is applied. This late response of inflation to monetary shocks is defined as a 'mystery' by Mankiw [14]. He gives two propositions about the problem and argues that there is a wide agreement on them in economics discipline. Firstly, monetary shocks have negative effects on unemployment rate. Secondly, the response of inflation to these monetary shocks are delayed and gradual. For a 2% disinflation policy, he presents some

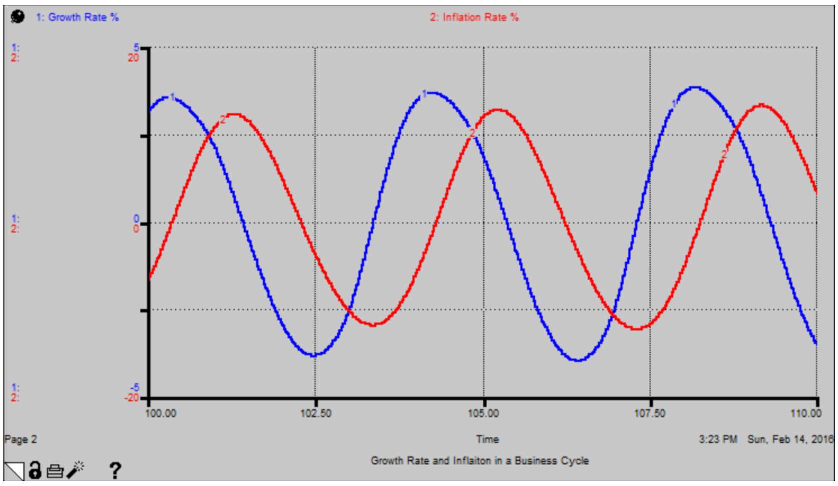

Figure 7.35 : Growth rate and inflation in the limit cycle of the model after money shock.

numbers to capture the consensus view for the purpose of illustration. These numbers are given in Table 7.1.

The second column in Table 7.1 represents the consensus view about the response of inflation after a disinflation policy to reduce inflation 2%. The other columns represent unemployment rate estimated by traditional backward-looking formula, backward-looking formula with hysteresis assumption, New-Keynesian model and Fuhrer-Moore model respectively. The numbers are given as the percentage change from the their initial values. Mankiw [14] argues that, the first two estimations of unemployment rate approximately represents the observed behavior but these two formulations do not have theoretical backgrounds. The other two estimations have theoretical backgrounds, but do not fit the behavioral pattern of the data.

Table 7.1 : Illustrative numbers given by Mankiw [14].

Quarter	Inflation (%)	U_1 (%)	U_2 (%)	U_3 (%)	U_4 (%)
0	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	-0.8	-0.4
2	-0.1	+0.8	+0.8	-1.6	-0.4
3	-0.3	+1.6	+1.7	-2.4	-0.4
4	-0.6	+2.4	+2.6	-3.2	-0.4
5	-1.0	+3.2	+3.7	-3.2	0.0
6	-1.4	+3.2	+4.0	-2.4	+0.4
7	-1.7	+2.4	+3.5	-1.6	+0.4
8	-1.9	+1.6	+3.0	-0.8	+0.4
9	-2.0	+0.8	+2.3	0.0	+0.4
10	-2.0	0.0	+1.6	0.0	0.0

According to the data given in Table 7.1, effect of a disinflation policy, which can be represented by constant money extraction in the proposed system dynamics model, affects the observed inflation with a delay. Inflation gradually falls 2% below its initial level in 10 quarters. The behavior of unemployment can be described by either third or forth column of Table 7.1, according to Mankiw [14]. Accordingly, unemployment falls due to disinflation policy, the highest affect is observed before the adjustment of inflation finishes, and the affect on unemployment gradually disappears.

The behavior of *Unemployment Rate* and *Inflation* in the proposed model can be compared with the behavior described by Mankiw [14]. For this reason, *Money Injection* is formulated to extract 2% of the money each year. The measured rate of inflation is represented by the variable *Inflation Rate*, which is formulated by the TREND function of *Price Level*, instead of *Inflation* which shows the momentary value. Since 10 quarters is equal to 2.5 years, 5 year of simulation would be enough for comparison. Figure 7.36 shows the simulation results.

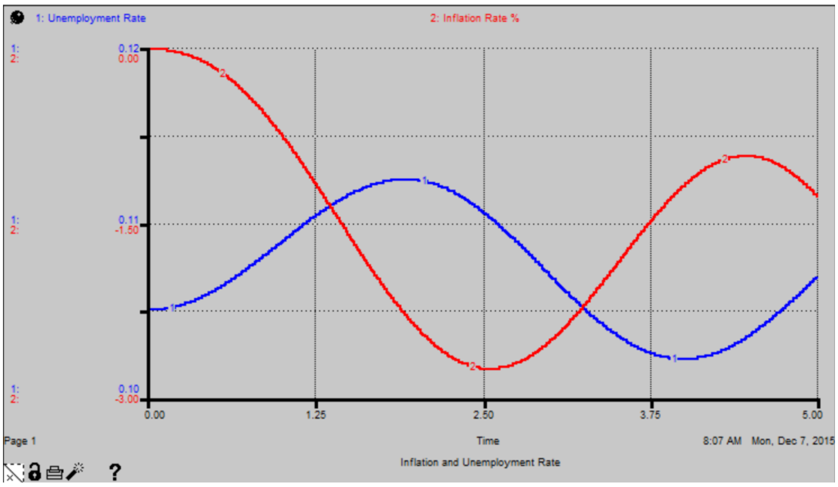

Figure 7.36 : *Inflation Rate* and *Unemployment Rate* after 2% disinflation shock.

According to the simulation results, *Inflation Rate* gradually responds to the disinflation shock, reaches to its lowest value approximately at $t = 2.5$ years, then continues to cycle. *Unemployment Rate* begins to rise with a delay, but responds faster than *Inflation Rate*. It reaches its maximum value before $t = 2$ years, and continues to cycle.

Direct comparison of the behavior in simulation results and behavior described by Mankiw [14] is difficult since the model creates a cycle after an inflation shock but the numbers given by Mankiw [14] represents the average values after cycles and noises are filtered by impulse-response analysis. In the simulation results, the initial response is interfered by the generated cycle. However, since the aim is not point-by-point matching, a sketch can be drawn over the graphs to approximately explain the initial response.

Figure 7.37 shows the simulation result of *Inflation Rate* alone, with a sketch drawn to filter the effects of cycle. The sketch is not a perfect drawing but is enough to give the main idea. *Inflation Rate* shows a delayed and gradual response to the disinflation shock, and settles around the targeted value in 5 years.

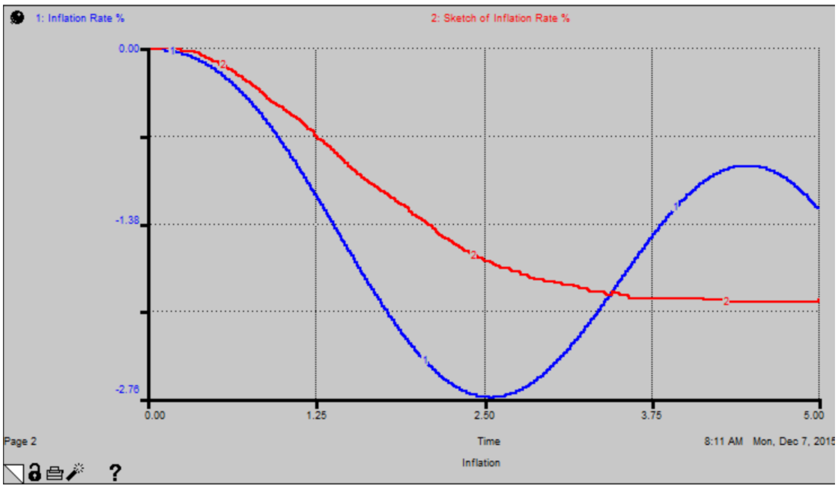

Figure 7.37 : *Inflation Rate* after 2% disinflation shock.

Figure 7.38 shows the simulation result of *Unemployment Rate*, again with a similar sketch graph to exclude the effect of cycle. *Unemployment Rate* rises as a result of disinflation shock, reaches its peak value approximately at $t = 1.5$ years, and affect gradually vanishes in 5 years. The exact numbers and even the exact timing is not concerned with this comparison, since these number may differ with different parameters, and even the numbers given by Mankiw [14] are only illustrative approximates. However, the simulation results are consistent with the observed behavior in terms of the direction and shape the of effects after disinflation shock.

In other words, backward-looking formulations are good estimators of unemployment rate after a disinflation shock, given the delayed and gradual response of inflation. However, these formulations are not the results of a theoretical model. According to Mankiw [14], New-Keynesian theoretical framework not only fails to generate the observed results about unemployment rate and inflation, but also predicts the opposite of what the data says. The proposed system dynamics model is built on the

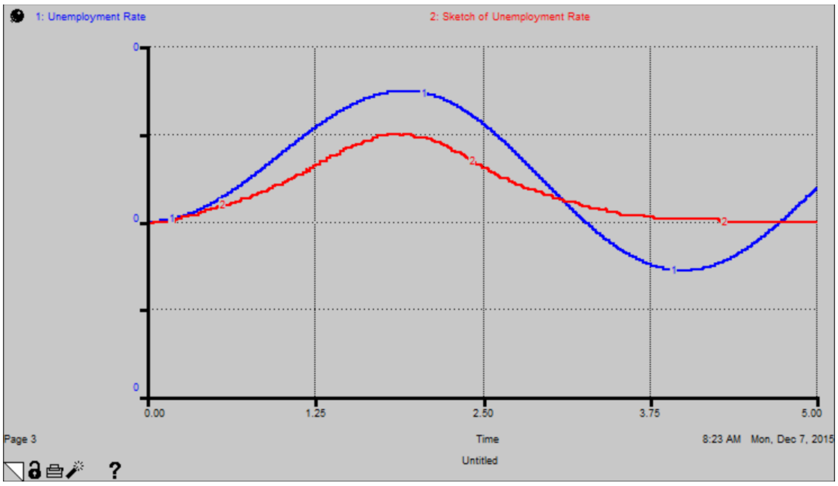

Figure 7.38 : *Unemployment* after 2% disinflation shock.

disequilibrium theories in Keynesian and Post-Keynesian spectrum. It is capable of approximately generating the observed behavior of unemployment rate and inflation, after a disinflation shock, without directly using any empirical relation in the model formulations.

In this section, validation of the model behavior is concerned. The proposed model generates behavior patterns such as Phillips Curve, business cycles and inflation persistence. These behavior patterns are already recognized empirically. Some examples about the similarities of the empirical observations and model behaviors are shown in this study. These results add confidence to the proposed system dynamics model.

8. MODEL ANALYSIS

In Chapter 6, the behavior of the proposed system dynamics model is given. With the assumed values of the parameters and the initial values of the stock variables, the model is in equilibrium without any given shock. In order to illustrate how the model behaves out of the equilibrium, two different shocks are applied. In the first case, an additional money is injected into the system only once at the beginning of the simulation. In the second case, a constant proportional money is injected into the system continuously. Both shocks seems to generate disequilibrium in the model and reveals how the variables dynamically behave outside the equilibrium.

The simulations show that monetary shocks affect real economic variables in the short run. In other words, money injection boosts real demand and generate temporary economic growth. Similarly, money extraction suppresses real demand and generates a recession. The real affects of monetary shocks are due to the fact that supply decisions are formed based on the realized demand. When the nominal prices respond to this demand side changes, the real affects of monetary shocks diminish.

During the disequilibrium state created by monetary shocks, the model shows some behavior patterns consistent to empirical and theoretical knowledge. As an example, there is an inverse relation between wage inflation and unemployment rate as stated in the original Phillips Curve. Similarly, inflation, unexpected inflation and real wage level are also negatively correlated with unemployment rate.

The proposed model proposes a theoretical explanation for these behaviors. Accordingly, monetary shocks initially increase real demand because nominal prices do not change at that time. Supply decisions of the firms are formed based on the realized demand. If there is a gap between supply and demand at any time, firms try to fill this gap by adjusting the amount of labor used for production. The adjustment of labor breaks the former equilibrium in the labor market and nominal wages change. As a result, unit cost of producers change and firms reflect this change to prices based on markup pricing rule. When nominal price level changes, the initial effect of monetary shock on real demand disappears.

The behavior of real wage level confirms this causation. Accordingly, when unemployment rate is low, not only nominal wages, but also real wages rise. In other words, when economic activity grows due to monetary reasons, the first affect is observed on wages, not prices. This is not because prices are more sticky than wages, and there is no apparent reason to expect price adjustment to be more costly than wage adjustment. Instead, the chain of causation is from labor market to prices because of the pricing behavior of firms. In other words, firms are not price takers and quantity setters, they are quantity takers and price setters. This causal structure, which is consistent with empirical observations, is an important theoretical implication of this study.

In Chapter 7, several tests are applied for validation purposes, parameter sensitivity test being one of them. This test shows that the same key behavior patterns are observed for different parameter values. For example, there is an inverse relation between wage inflation and unemployment rate no matter what the parameter values are, and this relation is non-linear and cyclical. However, there can be minor differences in the model behavior, like the slope of the Phillips Curve, when parameter set is changed.

Initial shocks on the model generate oscillation. For the assumed parameter set, this oscillation converges to a limit cycle. For different parameter values, this oscillation may fade out. It is reasonable to assume that the parameter values may change in time due to various reasons. In that case, it would be reasonable to expect that economic systems may sometimes be oscillatory and sometimes be relatively stable.

For the assumed parameter set, the duration of the limit cycle is approximately 4 years. The estimates of durations for this type of business cycles varies. It is argued to be 3 years on average for EU by Altavilla [153], 4 years on average for US and EU by Croux et al. [154], and between 3 to 8 years by Levy and Dezhbakhsh [155]. As a result, 4 years of business cycle duration appears to be consistent with the real life observations.

In the parameter sensitivity test, an interesting result is observed about the limit cycles. For higher values of *Wage Level Adjustment Time*, the amplitude of the limit cycle for *Aggregate Supply* becomes smaller. The model is simulated for broad values of this parameter, from extremely small to extremely large, and the result is found to be the same. Figure 8.1 shows the last 10 years of *Aggregate Supply* in a 200-year simulation. Blue, red and pink lines represent *Wage Level Adjustment Time* being 0.5, 1.0 and 1.5 years respectively.

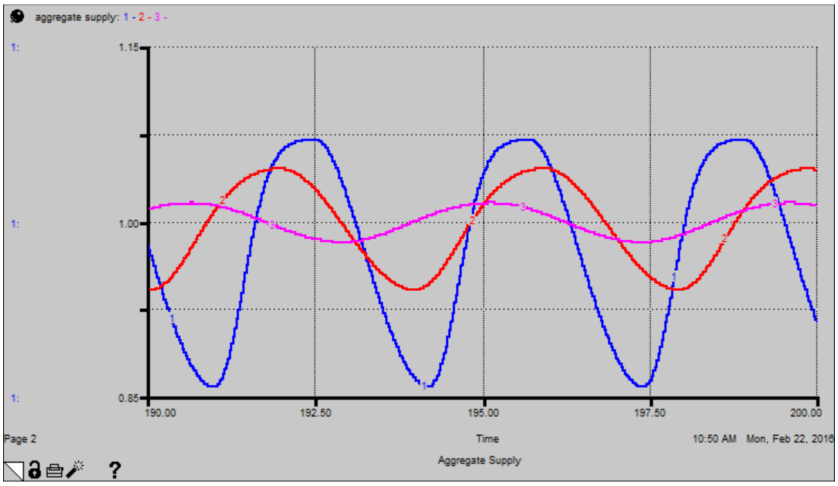

Figure 8.1 : *Aggregate Supply* when *Wage Level Adjustment Time* is 0.5 (blue), 1.0 (red) and 1.5 (pink).

Accordingly, for higher values of *Wage Level Adjustment Time*, the amplitude of the cycle becomes smaller, and the duration becomes larger. In other words, when wages more flexible, economic system faces more severe and frequent cycles. As a result, factors that makes nominal wages sticky, like governmental regulations and labor unions, actually lead to more stable macroeconomic behavior. This result is the opposite of the mainstream belief, and is an important real life implication of this study.

Another interesting result of the parameter sensitivity test is about the effect of *Labor Adjustment Time*. For the values slightly above and below the assumed value of 2 years, higher values of *Labor Adjustment Time* lead to smaller and less frequent business cycles. However, the extreme condition test in section 7.2.5.4 shows that this result cannot be generalized. Accordingly, for extremely small values of *Labor Adjustment Time*, limit cycle vanishes. After broader values of this parameter are analyzed, it is found that the amplitude of the cycle increases at first, then decreases, as the value of the parameter is increased from extremely small values to very higher values.

Figure 8.2 shows *Aggregate Supply* for three different values of *Labor Adjustment Time* as an example. Blue, red and pink lines represent the parameter being 0.2, 0.8 and 1.4 respectively. The graph shows that amplitude of the cycle increases at first, then decreases, as the parameter value is increased. As a result, the model cannot refer to a definite conclusion about the effect of *Labor Adjustment Time* to the stability of the economy.

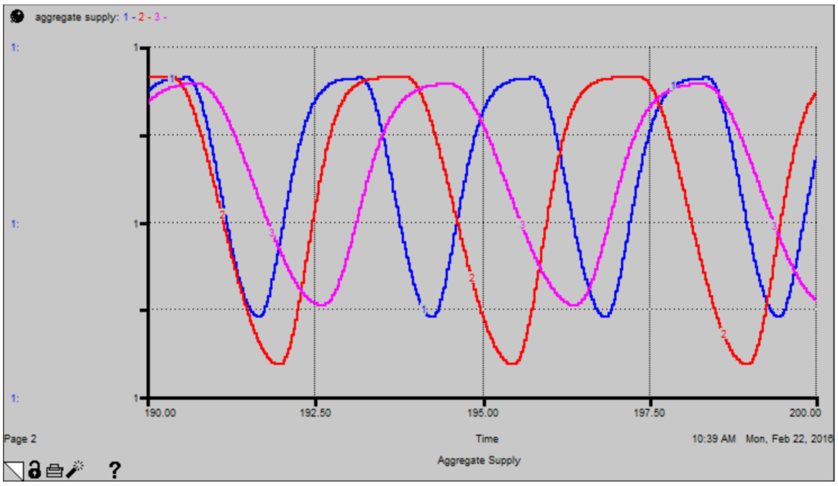

Figure 8.2 : *Aggregate Supply* when *Labor Adjustment Time* is 0.2 (blue), 0.8 (red) and 1.4 (pink).

It is shown that money shock affects real output, at least in the short run. In the long run, money shock can generate limit cycles, depending on the parameter values. Interestingly, the strength of the money shock is irrelevant to this limit cycle. In other words, whether it is 1 dollar or a thousand dollars, the properties of the limit cycle is the same. It can be argued that this type of shock is inevitable in real life, thus the cyclic behavior is the built-in property of the economic system.

Figure 8.3 shows *Aggregate Supply* in 10 years after money shock. Blue line represents the 1% money shock case, and red line represents the 5% money shock case. Accordingly, a higher amount of money shock has more real effect. The amount of time between peak and trough points are similar in both cases.

Although different amount of money shocks have different initial effects on *Aggregate Supply*, they both converge to the same limit cycle. Figure 8.4 shows the behavior of *Aggregate Supply* for the last 10 years in a 200-year simulation. Blue line represents 1% money shock case and red line represents 10% money shock case. Accordingly, both cycles have the same amplitude and duration. As a result, the amount of money shock is irrelevant to the properties of the limit cycle.

However, it is also interesting to note that, the strength of the inflation shock affects the limit cycle. When the amount of shock is increased, the duration of the limit cycle

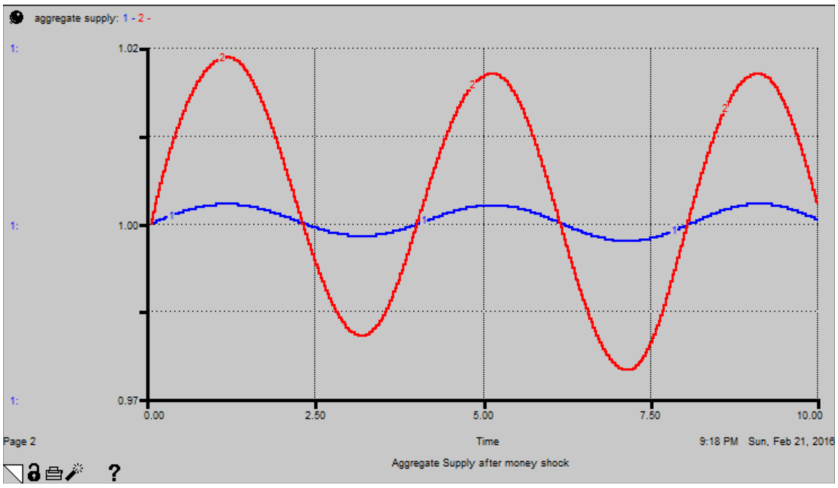

Figure 8.3 : *Aggregate Supply* after 1% money shock (blue) and 10% money shock (red).

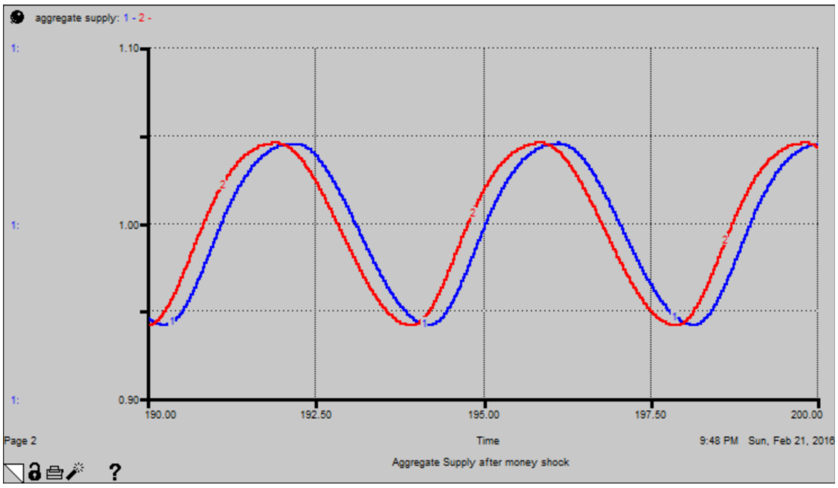

Figure 8.4 : *Aggregate Supply* between the years 190 and 200, after 1% money shock (blue) and 10% money shock (red).

decreases while the amplitude of the cycle increases. In other words, in an economy with a high average inflation, up's and down's are not only more severe, but also more frequent.

For illustration, the model is simulated for 200 years, with a simulation step of $1/128$, in order to make sure that the results fully converge to a limit cycle. Table 8.1 summarizes the properties of generated limit cycles, for different values of inflation shock. The first column shows the rate of growth of money in circulation. It can be represented as the average inflation in the long run, because there is no potential growth in the model. The second and the third column represent the highest and lowest values of unemployment rate observed in the limit cycle. Forth column is the average of all the unemployment rate data within a cycle duration. Finally, the last column represents the

Table 8.1 : Sensitivity of the limit cycle to inflation shock.

Shock	U max.	U min.	U avr.	Duration
0%	17.45%	4.01%	10.20%	3.98 years
5%	18.56%	3.40%	10.28%	3.88 years
10%	19.48%	2.95%	10.38%	3.79 years
15%	20.23%	2.62%	10.48%	3.70 years
20%	20.83%	2.38%	10.58%	3.63 years
25%	21.27%	2.21%	10.69%	3.55 years
30%	21.59%	2.10%	10.78%	3.48 years

duration of a cycle. The duration is calculated by taking the time difference between the last two observations that unemployment rate is equal to the natural rate.

There are three important considerations in the sensitivity result of limit cycle to inflation shock. First, as the rate of money injection increases, the duration of business cycle shortens. Secondly, the increase in unemployment rate during contractions is greater than the decrease during expansions. Finally, on average, a higher average unemployment rate is occurred, meaning an output loss for the economy. As a result, high levels of inflation lead to greater and more frequent instability, and harmful for the economy. Moreover, recessions are stronger than booms for high levels of average inflation. These results are also consistent with the wide agreement that high levels of inflation should be avoided.

9. CONCLUSIONS AND RECOMMENDATIONS

This study was set out to develop and introduce System Dynamics Model of Inflation. The purpose of the model is to explain how money affects output in an economic system. Empirically, this effect is apparent in the dynamic relation between monetary and real economic variables. System dynamics is a methodology for analyzing dynamic behavior in complex systems, and is suitable for the research question.

Inflation is defined as the sustained rise in the overall price level. Theoretically, it has been considered to be a purely monetary phenomenon. This view is changed in late 50's, after an empirical inverse relation is shown between inflation (and wage inflation) and unemployment rate, which is known as Phillips Curve. For a while, this curve is used as a policy guide to choose from a set of 'inflation-unemployment' pairs, as if there is a permanent trade-off between them. After long years of 'high inflation-low unemployment' policy, it is found that the empirical Phillips Curve shifts, and high inflation become permanent while unemployment rate rises again.

As a result, the definition of Phillips Curve is changed to be about an inverse relation between unexpected inflation and unemployment rate. However, a theoretical debate then began in economics, about how the expectations are formed. In this debate, the assumption of rational expectations gained wide acceptance among economists, which states that economic actors perfectly foresee future states of the economic system. Then, the era of equilibrium-oriented rational expectations theory began in economics, namely new-consensus macroeconomics.

Although it is theoretically appealing, new-consensus model is criticized to be unsuccessful in producing the analytical results which are consistent with empirical findings. What the data says can be summarized in a few statements. First, monetary policy affects economic activity, at least in the short run. Secondly, inflation is persistent to monetary policy. And finally, there is still a negative relation between inflation and unemployment rate. Analytical results are not similar enough to these empirical results, and in some cases depicts the opposite.

This study aims to build a system dynamics model, which can explain the dynamic behavior seen in the data. At the beginning of the model building process, it is realized that there are very fundamental conflicts between the reasoning of mainstream economic theory and system dynamics methodology. The very basic, fundamental and indispensable property of system dynamics is that, it formulates change. A system dynamics model can be many things but a model without change. Formulating change endogenously means that, there must be an endogenous process within the model which leads to a change. However, in the equilibrium-oriented theory, conceptually, a part of the model cannot change independent of the whole model. In other words, equilibrium-theory makes a strong abstraction that, the state of the whole system, with all its units strongly tied to each other, can only 'jump' from one an equilibrium state, to another.

In the process of searching for some accumulated knowledge within economics discipline, which can help to build the intended model, an interesting work is found, namely Phillips Machine. It is also important to note that, he was the same Phillips who the name in the empirical curve refers to. This machine is actually a system dynamics model, a very simple but useful one, which took wide attention within the field. The machine, with plastic water tanks and pipes linking them, dynamically simulates how economic aggregates such as income, consumption, saving and investment are related to each other. It is the first system dynamics economic model, perhaps the first system dynamics model in history, even introduced before the methodology was first defined. Due to its intellectual value and relation to both the research question and the adopted methodology, a significant portion of this study is dedicated to this work, and explained in detail at the very beginning.

As it turns out, the very fundamental conflict between the necessities of system dynamics methodology and the abstractions of equilibrium-oriented economic thinking is strongly related to a historical controversy within economics. Accordingly, during the theoretical shift in economic thinking after 70's, the misconceptualization of time had been strongly debated. These debates are later continued, and still continues to some degree, within Post-Keynesian school. These discussions are sometimes centered around the concept of equilibrium or rational expectations assumption, but they are almost always linked to the conceptualization of time somehow. For this reason, before introducing the system dynamics model, it is considered to be necessary to employ a discussion chapter which summarizes this controversy and defines it for the first time as 'time controversy'.

Phillips Machine and Phillips Curve are strongly related with each other, with other academic works of Phillips, with the controversy of time and equilibrium and finally with the purpose of this study. There is a line of continuity in the studies of Phillips. In his studies, Phillips utilizes an economic thinking in which economic concepts are dynamically linked to each other outside of equilibrium, with feedback loops endogenously working in order to reach a dynamic equilibrium in real time. When the first Phillips Curve article is read together with his preceding and succeeding studies, it is apparent that he implies a theory behind this empirical relation which is totally different than it is interpreted. He explains the relation between wage inflation and unemployment as the dynamic interaction of internal forces which cyclically moves the state of the economic system outside of equilibrium. The static interpretation of Phillips Curve was an unfortunate misunderstanding of the data and the trade-off interpretation of the policy was completely at odds with what he theoretically implied.

Following the studies of Phillips about dynamic modeling of an economic system and the theory behind the empirical Phillips Curve, the theoretical discussions about time and equilibrium, and Keynesian and Post-Keynesian theories of how the economic system works, the proposed system dynamics model is developed. During the model development phase, a great number of alternative models have been built and tested both structurally and behaviorally. The simplest version which is complex enough to address key issues is reported in this study as the final model. However, other models, some of which are modifications or extensions, can be used for future studies in order to extend the scope of this model towards being a more generic economic model.

The proposed model consists of six sub-models, or sectors. Monetary sector is, to a high degree, a remake of Phillips Machine, with only a few modifications necessary to link it with other sectors of the model. It shows how the income circularly flows within economic system in the form of money. It dynamically simulates the behavior of income, consumption, saving and investment. When it is allowed to rest, expenditure becomes equal to income, saving becomes equal to investment and interest rate becomes equal to the equilibrium value.

In goods sector of the model, an aggregate inventory is defined as a buffer between aggregate supply and aggregate demand so that they do not have to be equal at all times. Aggregate demand is defined as the outflow from inventory which can be interpreted as sales. Aggregate supply is, on the other hand, defined as the inflow to inventory which can be interpreted as production. Firms are assumed to be quantity takers and price setters in this model.

In the price sector of the model, price level is gradually adjusted to a desired value. This value is determined by a markup rule, which is the Post-Keynesian interpretation of price setting theory. However, this definition of price is consistent with the marginal cost interpretation, because increasing quantities of supply due to increased labor leads to a decrease in labor productivity and consequently an increase in the unit costs. As a result, marginal cost based pricing and markup based pricing are consistent with each other.

In the labor sector of the model, employed labor and unemployed labor are defined as two stock variables. There are also two flows between them representing the hiring and firing of labor. The decision of hiring or firing labor is determined by the supply decision of the firms, which is in turn determined by aggregate demand and the inventory coverage. In other words, aggregate demand is formed based on the price level and firms try to match this demand by adjusting the labor hired.

However, this adjustment of labor affects wage level. The adjustment of wage level is introduced in the wage sector of the model. Based on the interpretations of Phillips about the empirical relation between wage inflation and unemployment rate, wage level is assumed to increase due to the desired amount of hired labor and the actual unemployment rate at that time. Accordingly, wage level increases not only when unemployment rate is below the natural rate, but also when it is decreasing. Similarly, wage level decreases not only when unemployment rate is above the natural rate, but also when it is increasing.

In the investment sector of the model, investment is assumed to be affected by the demand forecast and output. Together with the interest rate mechanism in the monetary sector, the value of investment is determined. This formulation of investment is consistent with most macroeconomic textbooks. Nominal value of investment is later translated to real value, and used to determine aggregate demand in the goods sector.

When allowed to rest, the values of the economic variables are consistent with the theoretical equilibrium conditions. In equilibrium, demand, supply, income and total expenditure, which are separately defined in the model become equal to each other. Unemployment rate is equal to natural rate, and the wage level do not change. Real wage is consistent with the labor share implied by the production function. Price level is stable and consistent with supply.

Only in equilibrium, equalities between economic variables, which are directly implied by the very definition of equilibrium in system dynamics, can be interpreted similar to equilibrium-oriented theory. In other words, the equilibrium state of the model is exactly the same as the equilibrium-oriented theory would predict. For instance, aggregate supply can be interpreted as the quantity implied by the supply curve when price is given, although the formulation is the other way around in the model. Similarly, price level can be interpreted as being equal to marginal cost, given the values of wage level, labor and production function. When disturbed by an exogenous shock, however, the model will behave different than the equilibrium-oriented theory would predict. Until another equilibrium is maintained (if it occurs), the system is always in a disequilibrium state, and the equalities of the equilibrium condition do not hold. This is the main difference between a system dynamics model and an equilibrium model.

In order to explain model behavior, two different shocks are experimented. First, additional money is injected into the system for once, at the beginning of the simulation. Secondly, additional money is injected with a constant rate into the system, starting from the beginning of the simulation. For both experiments, some key variables are observed and their behaviors are reported. The responses of the model to these shocks are similar.

When simulated after a monetary shock, the proposed model behaves similar to what data says. For example, a simulated original Phillips Curve, the scatter diagram of wage inflation and unemployment rate, can be generated by the model with the same properties of the empirical one. Accordingly, the relation is negative, non-linear, and data moves in the counter-clockwise direction. These properties are apparent in the first empirical observation. Other than that, a simulated Phillips Curve, the scatter diagram of inflation and unemployment rate, can also be generated by the model. The relation is also negative and slightly non-linear, similar to the empirical curve. The other version of Phillips Curve, the relation between unemployment rate and unexpected inflation, can be generated by the model as well, when unexpected inflation is defined as the difference between inflation and expected inflation, and expected inflation defined with a backward looking formulation. Another empirical curve, called Wage Curve, which indicates a negative relation between real wage level and unemployment rate can be virtually generated as well.

The similarity of the model behavior and the empirical data can be seen in time series graphs as well. The comparison of aggregate supply (represents GDP in the empirical data) to price level, and growth rate to inflation rate indicate that there is a phase difference between monetary and real variables, similar to what the data says. This lag between the cycles is close to a year, which is similar to empirical observations. The initial response of inflation to monetary policy shocks is also delayed in the simulation results, which is also empirically observed and called inflation persistence.

Proposed model generates significant business cycles after a monetary shock. This cycle may converge to be a limit cycle or may fade out, depending on the parameter setting. The amplitude of this cycle is observed to be sensitive to parameter setting as well, however, for plausible estimates, its effect on GDP is around 5%. Duration is approximately 4 years for reasonable parameters. These results are also similar to the empirically observed business cycles.

In order to build confidence for the proposed model, some validation tests are applied on the model structure and behavior. Model structure reflects the disequilibrium theories for the components of the system, either directly or with necessary modifications from the system dynamics perspective. Model parameters are shown to be empirically observable or theoretically reasonable.

As a part of the validation tests, sensitivity of the model behavior to key parameters is analyzed. It is found that, wage level adjustment time and inventory coverage are inversely related with the amplitude of the generated cycle, while price adjustment time is positively related. In other words, small values of price adjustment time and high values of wage adjustment time and inventory coverage lead to more smooth macroeconomic behavior.

The negative effect of unemployment rate on wage inflation, price inflation and real wage level are apparent for different values of parameters. However, labor adjustment time is found to be negatively related with the slop of these curves, while wage adjustment time is positively related. In other words, high levels of wage adjustment time and low levels of labor adjustment time are preferred for more flat Phillips Curve and Wage Curve. Price adjustment time and inventory coverage turn out to be irrelevant to the slope of these curves.

System Dynamics Model of Inflation, is able to explain the main mechanisms relating monetary and real variables in an economic system. It can generate similar behavior patterns to the empirical relations between these variables. It also provides a disequilibrium economic theory to explain the observed economic phenomena.

The introduced model can be extended in a number of ways. First, the turnover parameters in the monetary sector can be defined to reflect the risk awareness behavior for very high levels of inflation or very high levels of volatility in economic variables. This may give further insights about the macroeconomic behavior in the economies facing hyperinflation.

Another extension may be about including the tools used by monetary authority to control the money supply and inflation. With directly introducing policy interest rates, targeted rate of inflation and reserve ratios, alternative monetary policy rules can be modeled and analyzed. With this extension, the model can be used as a monetary policy test environment.

Finally, potential growth rate can be included, in order to provide a generic long-run economic model. For this purpose, technology level and capital stock dynamics can be defined. Moreover, workforce changes and hysteresis effect can be included in the labor sector. These extensions has the potential to analyze the long-run effects of economic policies.

The most important finding of the study is that, the instability of an economic system, sometimes observed as deviations of economic growth and sometimes as the persistent behavior of inflation, is strongly related to the labor market. When the relative bargaining powers of workers and capital owners change due to the change in the state of labor market, wage level changes proportionally. In other words, it is the rate of change in wage level, not the amount of change itself, which the labor market conditions determine. For this reason, sustained cycles and stationary behavior in the rates of changes are observed in the economic system. Policy makers are recommended to consider this issue, and closely monitor the labor market conditions, not only the unemployment rate, but also other economic indicators which may effect wage changes.

Researchers of macroeconomic theory are recommended to consider relaxing the strong equilibrium assumptions in their models. Economic agents may not capture the macroeconomic results of individual rational decisions, not because they are irrational, but because the aggregate results can be counter-intuitive. Dynamic adjustment of rational economic behavior at the micro level with constantly monitoring the outcomes at the macro level, can give rise to theoretical models consistent with empirical regularities.

Finally, the researchers from the system dynamics field with a motivation of building economic models, are recommended to investigate Keynesian and Post-Keynesian theories. The current mainstream economic theories are not suitable for directly adopting in system dynamics models. Keynesian and Post-Keynesian theories, however, offer the disequilibrium interpretations of economic concepts and mechanisms.

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APPENDICES

APPENDIX Model Equations

APPENDIX

MONETARY SECTOR

Business_Balances(t) = Business_Balances(t - dt) + (consumption + investment - income) * dt

INIT Business_Balances = Initial_Business_Balances

INFLOWS:

consumption = Household_Balances * Household_Balances_Turnover*(1-Saving_Rate)

investment = Desired_Nominal_Investment / Relative_Interets_Rate

OUTFLOWS:

income = Business_Balances * Business_Balances_Turnover

Household_Balances(t) = Household_Balances(t - dt) + (income - consumption - saving) * dt

INIT Household_Balances = Initial_Household_Balances

INFLOWS:

income = Business_Balances * Business_Balances_Turnover

OUTFLOWS:

consumption = Household_Balances * Household_Balances_Turnover * (1 - Saving_Rate)

saving = Household_Balances * Household_Balances_Turnover * Saving_Rate

Loanable_Funds(t) = Loanable_Funds(t - dt) + (saving + money_injection - investment) * dt

INIT Loanable_Funds = Initial_Loanable_Funds + 0.75 * Additional_Money * (1 - Inflation_Switcher)

INFLOWS:

saving = Household_Balances * Household_Balances_Turnover * Saving_Rate

money_injection = (Loanable_Funds + Total_Balances) * Money_Growth_Rate * Inflation_Switcher

OUTFLOWS:

investment = Desired_Nominal_Investment / Relative_Interets_Rate

Additional_Money = 0.05

Inflation_Switcher = 0

Loanable_Funds_Ratio = Loanable_Funds / Total_Balances

Money_Growth_Rate = 0.05

Relative_Interets_Rate = Reference_Loanable_Funds_Ratio / Loanable_Funds_Ratio

Total_Balances = Household_Balances + Business_Balances

GOODS SECTOR

Inventory(t) = Inventory(t - dt) + (aggregate_supply - aggregate_demand) * dt

INIT Inventory = Reference_Inventory_Coverage

INFLOWS:

aggregate_supply = Reference_Aggregate_Supply * Effect_of_Employed_Labor_on_Aggregate_Supply

OUTFLOWS:

aggregate_demand = Nominal_Aggregate_Demand / Price_Level

Demand_Pressure = Desired_Supply / aggregate_supply

Desired_Supply = aggregate_demand * Effect_of_Inventory_Coverage_on_Desired_Supply

Effect_of_Employed_Labor_on_Aggregate_Supply = (Employed_Labor / Reference_Employed_Labor)^0.7

Effect_of_Inventory_Coverage_on_Desired_Supply = 2/(1 + EXP(Inventory_Coverage - Reference_Inventory_Coverage))

Inventory_Coverage = Inventory / aggregate_demand

Nominal_Aggregate_Demand = consumption + investment

PRICE SECTOR

Price_Level(t) = Price_Level(t - dt) + (price_level_adjustment) * dt

INIT Price_Level = 1

INFLOWS:

price_level_adjustment = (Target_Price_Level - Price_Level) / Price_Level_Adjustment_Time + TREND(Target_Price_Level,2,0) * Price_Level

Inflation_% = price_level_adjustment / Price_Level * 100

Markup = Normal_Markup * Demand_Pressure

Output_per_Labor = aggregate_supply / Employed_Labor

Target_Price_Level = Unit_Cost * (1 + Markup)

Unit_Cost = Wage_Level / Output_per_Labor

LABOR SECTOR

Employed_Labor(t) = Employed_Labor(t - dt) + (hiring - firing) * dt

INIT Employed_Labor = 1

INFLOWS:

hiring = (Target_Labor - Employed_Labor) / Labor_Adjustment_Time*Effect_of_Unemployment_Rate_on_Hiring

OUTFLOWS:

firing = (Employed_Labor-Target_Labor) / Labor_Adjustment_Time

Unempoloyed_Labor(t) = Unempoloyed_Labor(t - dt) + (firing - hiring) * dt

INIT Unempoloyed_Labor = Initial_Unemployed_Labor

INFLOWS:

firing = (Employed_Labor - Target_Labor) / Labor_Adjustment_Time

OUTFLOWS:

hiring = (Target_Labor - Employed_Labor) / Labor_Adjustment_Time * Effect_of_Unemployment_Rate_on_Hiring

Effect_of_Demand_Pressure_on_Desired_Labor = Demand_Pressure

Effect_of_Unemployment_Rate_on_Hiring = Unemployment_Rate / Natural_Rate_of_Unemployment

Target_Labor = Employed_Labor * Effect_of_Demand_Pressure_on_Desired_Labor

Total_Labor = Employed_Labor + Unempoloyed_Labor

Unemployment_Rate = Unempoloyed_Labor / (Employed_Labor + Unempoloyed_Labor)

WAGE SECTOR

Wage_Level(t) = Wage_Level(t - dt) + (wage_level_adjustment) * dt

INIT Wage_Level = 0.7

INFLOWS:

wage_level_adjustment = (Target_Wage_Level - Wage_Level) / Wage_Level_Adjustment_Time + TREND(Target_Wage_Level,2,0) * Wage_Level

Effect_of_Target_Labor_Rate_on_Wage_Level = Target_Labor_Rate - Reference_Target_Labor_Rate

Effect_of_Unemployment_Rate_on_Wage_Level = Natural_Rate_of_Unemployment - Unemployment_Rate

Real_Wage_Level = Wage_Level / Price_Level

Target_Labor_Rate = Target_Labor / Total_Labor

Target_Wage_Level = Wage_Level * (1 + Effect_of_Unemployment_Rate_on_Wage_Level + Effect_of_Target_Labor_Rate_on_Wage_Level)

Wage_Inflation_% = wage_level_adjustment / Wage_Level * 100

INVESTMENT SECTOR

Aggregate_Demand_Forecast(t) = Aggregate_Demand_Forecast(t - dt) + (aggregate_demand_forecast_adjustment) * dt

INIT Aggregate_Demand_Forecast = 1

INFLOWS:

aggregate_demand_forecast_adjustment = (aggregate_demand - Aggregate_Demand_Forecast) / Aggregate_Demand_Forecast_Adjustment_Time + TREND(aggregate_demand,2,0) * Aggregate_Demand_Forecast

Desired_Investment = Reference_Desired_Investment * Effect_of_Aggregate_Demand_Forecast_on_Desired_Investment * Effect_of_Output_on_Desired_Nominal_Investment

Desired_Nominal_Investment = Desired_Investment * Price_Level

Effect_of_Aggregate_Demand_Forecast_on_Desired_Investment = Aggregate_Demand_Forecast / Reference_Aggregate_Demand_Forecast

Effect_of_Output_on_Desired_Nominal_Investment = aggregate_supply / Reference_Output

OTHERS

Expected_Inflation(t) = Expected_Inflation(t - dt) + (expected_inflation_adjustment) * dt

INIT Expected_Inflation = 0

INFLOWS:

expected_inflation_adjustment = (Inflation_% - Expected_Inflation) / Expected_Inflation_Adjustment_Time

Expected_Inflation_Adjustment_Time = 1

Growth_Rate_% = TREND(aggregate_supply,1,0) * 100

Inflation_Rate_% = TREND(Price_Level,1,0) * 100

Unexpected_Inflation = Inflation_% - Expected_Inflation

PARAMETERS

Aggregate_Demand_Forecast_Adjustment_Time = 1

Business_Balances_Turnover = 4

Household_Balances_Turnover = 4

Initial_Business_Balances = 1 / Business_Balances_Turnover

Initial_Household_Balances = 1 / Household_Balances_Turnover

Initial_Loanable_Funds = (Initial_Household_Balances + Initial_Business_Balances) * Reference_Loanable_Funds_Ratio

Initial_Unemployed_Labor = Natural_Rate_of_Unemployment / (1 - Natural_Rate_of_Unemployment)

Labor_Adjustment_Time = 2

Natural_Rate_of_Unemployment = 0.1

Normal_Labor_Productivity = 1

Normal_Markup = 0.3 / 0.7

Price_Level_Adjustment_Time = 1

Reference_Aggregate_Demand_Forecast = 1

Reference_Aggregate_Supply = 1

Reference_Desired_Investment = 0.3

Reference_Employed_Labor = 1

Reference_Inventory_Coverage = 1

Reference_Loanable_Funds_Ratio = 0.5

Reference_Output = 1

Reference_Target_Labor_Rate = 1 - Natural_Rate_of_Unemployment

Saving_Rate = 0.3

Wage_Level_Adjustment_Time = 1

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