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# **Essays on Inflation Volatility**

**Shesadri Banerjee**

**Doctoral Thesis**

Department of Economics, Finance and Business

Durham Business School, University of Durham

23/26 Old Elvet, Durham DH1 3HY, UK

Email: [shesadri.banerjee@durham.ac.uk](mailto:shesadri.banerjee@durham.ac.uk)

Thesis submitted for the Degree of Doctor of Philosophy in Economics

June, 2013

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## Acknowledgement

I would like to express my gratitude to all who have supported me over the last three and half years of my doctoral research.

I am grateful to my supervisor Professor Parantap Basu for his excellent supervision, advices and insightful criticisms which contributed to my thesis in innumerable ways. I am thankful to Professor Guido Cozzi for his helpful suggestions, advices and comments, especially in the early days of my research.

I am indebted to Dr. Leslie Reinhorn and Dr. Hugo Kruiniger for their valuable comments on the empirical chapter of my thesis. I sincerely acknowledge the funding support provided by the Durham University Business School, the administrative support of Doctoral Office, trainings provided by the Graduate School and the technical supports of Business School IT Department to continue my research. My work has greatly benefitted from the thought provoking discussions with my colleagues Manzoor Ahmed, Yoseph Gatechew, Eddy Gunawan, Brett Manning, E. Y. Oh, Nan Shi and Sigit Wibowo.

I am thankful to the participants of the European Economics and Finance Society Conference (June, 2012) and the Economic Growth and Development Conference of Indian Statistical Institute, Delhi (December, 2012) for their valuable comments.

My parents, brothers and sisters deserve my deepest gratitude and regard for their immense support and faith in me that has urged to continue my research. Finally, my heartiest thanks to my wife, Anindita, for her constant persuasions, encouragements and efforts to keep me motivated in completing the thesis.

# Dedication

*To my father*

## Abstract

Inflation volatility is one of the key constituents of inflation dynamics and has not received much attention in the literature. The study of inflation volatility is important because it has adverse economic consequences. This thesis aims to study the determinants of inflation volatility for advanced and developing countries. At the outset, I explore the empirical regularities of inflation volatility based on monthly and quarterly CPI inflation data (1968 to 2011) using time and frequency domain analysis. I establish a stylised fact that inflation is significantly more volatile in developing countries than advanced countries. This raises a research question why it is so. Using a New Keynesian paradigm, an answer to this research question is sought from two angles. First, a policy rule for interest rate (known as Taylor rule) is estimated over a balanced panel of advanced and developing countries to examine the difference in policy activism between these two groups of countries. This follows from the New Keynesian argument that an active monetary policy is a necessary condition for stable dynamics of inflation. Using the Generalized Method of Moments and the Arellano and Bover (1995) method of dynamic panel estimation, I find that monetary policy is active in advanced countries but passive in developing economies. This striking difference in the policy regimes between these two groups can be one of the reasons for the difference in inflation volatility. Second, motivated by the asymmetry in consumption basket of CPI between advanced and developing economies, a two-sector New Keynesian model with food and non-food is developed. The model features: i) composite consumption and labour index, ii) differential Calvo-type price adjustment of firms across sectors, and iii) Taylor type

monetary policy rule. Characterising the distinct structures of advanced and developing economies by two different parameterizations, the model calibration shows that demand disturbance generated by the preference shock is one of the fundamental forces for inflation volatility. In addition, my simulation analysis demonstrates that other structural parameters such as the frequency of price adjustment, distribution of labour and the elasticity of labour substitution, and the policy parameter of inflation in the Taylor rule are also critical factors explaining the greater volatility of inflation in developing economies.



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# Chapter One

## Introduction

### 1.1 Introduction

Three key properties of inflation dynamics are of interest in macroeconomics, namely i) mean or level of inflation, ii) persistence of inflation and iii) inflation variability<sup>1</sup>. While there is an abundant literature on the features of the first two attributes, the literature on variability or volatility of inflation is thin. Although the extant literature provides strong evidence on the adverse effects on economic welfare<sup>2</sup>, it says little about the empirical features of inflation volatility across the economies. The current literature also lacks a theoretical analysis of the fundamental determinants of inflation volatility. Furthermore, in the sparse research on inflation volatility, there are more studies based on advanced countries<sup>3</sup> and less for developing countries<sup>4</sup>. Given this gap in the literature, my thesis aims to examine the empirical regularities of inflation volatility and explain it by using the theoretical foundation of New Keynesian economics for advanced and developing countries together. In this regard, this introductory chapter will provide an overview of the thesis.

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<sup>1</sup> See Capistran & Ramos-Francia, (2009).

<sup>2</sup> See Friedman (1977) and Katz and Rosenberg (1983).

<sup>3</sup> See Caporale and McKiernan (1997), Grier and Perry (1998), Kontonikas (2004).

<sup>4</sup> See Grier and Grier (1998), Rizvi and Nakvi (2009).



## 1.2 Motivation

Inflation volatility describes the unforeseen components in the time series process of inflation that emerges from the recurrence of shocks. It can be considered as one of the major aspects of macroeconomic volatility that an economy encounters in the course of its evolution. Any interaction of inflation with other macroeconomic variables remains subject to the behaviour of its volatility component, and this can lead to non-trivial outcomes. In fact, a volatile inflation impairs economic stability. It distorts relative prices, leads to misallocation of resources, erodes savings, deteriorates investment and impedes economic growth. Furthermore, countries differing in inflation volatility could experience different welfare losses and economic growth, in the short run and in the long run. An economy with a more volatile inflation faces greater uncertainty in forming expectations for future price levels. Long term nominal contracts are then subject to an inflation premium due to higher costs for hedging against inflation risks. Differences in the volatility of inflation between two different economies can impose different economic burdens through the channels of investment and consumption. The uncertainty of real income expectations rises with greater volatility of inflation and induces greater precautionary savings that depresses investment in physical assets<sup>5</sup>. Moreover, in an unindexed tax system, interaction between volatile inflation and the tax structure causes higher effective tax on capital, and can be detrimental for investment<sup>6</sup>. Similar to investment, consumption may be adversely affected due to unforeseen rise in inflation tax. The differences in inflation volatility across economies can also contribute to

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<sup>5</sup> See Wachtel (1977).

<sup>6</sup> See Feldstein (1982).

differences in wealth distribution when a higher inflation affects fixed and un-indexed income groups. It is thus important, both from an academic point of view and for the purposes of policy design, to gain a better understanding of the volatile behaviour of inflation regarding its empirical features and the key determinants across different groups of economies.

### **1.3 Research Question**

The central research question of this thesis is: why do countries experience different inflation volatility? To answer this question systematically, I first document the volatility of inflation for advanced and developing economies using time domain and frequency domain approaches. This is conducted on a sample of thirty advanced and developing countries over the period of 1968 to 2011. From the short run to the long run, I find that in all phases of cyclical variations, inflation remains highly volatile in developing economies than their advanced neighbours. Specifically, the higher inflation volatility of developing countries appears glaring in contrast to developed economies during the period of Great Moderation in the post-1980s. Researchers have spent considerable efforts in attempting to explain the declining nature of inflation volatility for advanced countries<sup>7</sup> but have overlooked the situation of developing countries. Addressing this research gap, my thesis aims to explain the distinguishing feature of inflation volatility between advanced and developing economies.

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<sup>7</sup> See Clarida et al., (2000); Kahn et al., (2002), Stock and Watson, (2002); Lubik and Schorfheide, (2004), Sims and Zha, (2006).

## **1.4 Research Methodology**

In the thesis, the research question is posed through an intensive empirical exercise. I analyse the volatility of inflation in developed and developing countries using time series models of conditional volatility, such as the ARCH effect test, the GARCH model and estimation of a first order autoregressive model in a panel of inflation variance series. After analysing the time domain properties of inflation, I explore the volatility of inflation at various frequencies by frequency domain techniques. Using the Christiano-Fitzgerald (2003) band pass filter over different periodicities, the volatility of inflation is computed at various frequencies. Results of frequency domain analysis are consistent with the time domain properties of inflation volatility, and they comprehensively substantiate the difference of inflation volatility between advanced and developing economies. Throughout this empirical exercise, the thesis uses monthly and quarterly inflation data of Consumer Price Index from the database of International Financial Statistics over the period 1968 to 2011. The period of study is chosen according to the availability of data. This is the maximum length of data (1968 to 2011) which are available for the inflation in advanced and developing countries together.

On the theoretical front, using a New Keynesian approach, the thesis aims to answer the research question from two angles. First, I examine whether there is any significant difference in the policy response to inflation between monetary authorities of advanced and developing countries. This is accomplished by estimating Taylor rules for different groups of countries. I find that the interest rate response to inflation is remarkably higher for advanced countries compared to developing countries. This differential policy

response has important consequences for inflation volatility. Using a simple three equation new Keynesian model, I show that greater policy response to inflation unambiguously lowers steady state volatility of inflation. Second, in addition to policy issues, the structural differences between advanced and developing economies could also contribute to cross-country difference in inflation volatility. I demonstrate this using a fully specified structural model involving two sectors food and non-food. Motivation for such two sector model has come from empirical observations of the asymmetry of food and non-food composition in CPI consumption basket of advanced and developing economies. A log-linearized version of the model characterising the equilibrium dynamics is derived. Given two different parametric configurations for advanced and developing economies, the model simulated results are compared with quarterly macroeconomic data (1978 – 2011) at second order theoretical moments.

### **1.5 Contribution of this Thesis**

Broadly speaking, this thesis makes two major contributions to the existing literature. First, it empirically documents the inflation volatility in advanced and developing countries using time and frequency domain approaches. Second, it attempts to explain these stylised facts of inflation volatilities of advanced and developing economies using a New Keynesian approach. In these contributions, there are three novelties which distinguish the present thesis from the extant literature. These are as follows.

- i) The first novelty comes from the methodologies used in empirical investigation of this thesis. It includes the approach to measure the long run volatility, and the

method of frequency domain analysis. Both of these methodologies are simple to implement but useful to assess the inflation volatility.

- ii) Secondly, using a simple three equation New Keynesian model, the inverse relation between inflation volatility and the inflation coefficient of the Taylor rule is shown and exploited to explain the difference in volatility, which is new to the literature. The empirical finding that monetary policy is substantially passive in the developing economies is also new to the literature to the best of my knowledge. This empirical finding emphasises the need for aggressive anti-inflationary policy in the developing economies to lower the volatility of inflation.
- iii) Finally, the thesis contributes to the literature by providing a Two Sector New Keynesian Model of food and non-food to explain inflation volatility. It identifies the asymmetry in the consumption basket of the consumer price index between advanced and developing economies with respect to composition of food and non-food expenditure. Then, it models aggregate inflation as a composition of food and non-food inflation. The two sector structural model developed in this thesis includes inelastic nature of labour reallocation between the sectors due to physical constraint. This gives rise to structural idiosyncrasies that can critically control the propagation of exogenous shocks to aggregate inflation and has the potential to explain the volatile behaviour of inflation in developing economies. To the best of my knowledge, modelling of inflation volatility in the New Keynesian domain by food and non-food sector with inelastic labour adjustment is novel in the DSGE literature.

## **1.6 Organisation of Chapters**

The rest of this thesis is organised into three major chapters followed by concluding remarks. In Chapter 2, the research problem is posed in context with support from the literature, empirical evidence and welfare implications. In Chapter 3, investigation on the nature of monetary policy for advanced and developing countries is placed with theoretical foundation and subsequently, the empirical findings are documented. Chapter 4 provides a fully specified two sector New Keynesian Model with calibration to study the structural differences between advanced and developing economies. Chapter 5 concludes with a summary of results, a discussion on the limitations of the thesis and future directions for research.

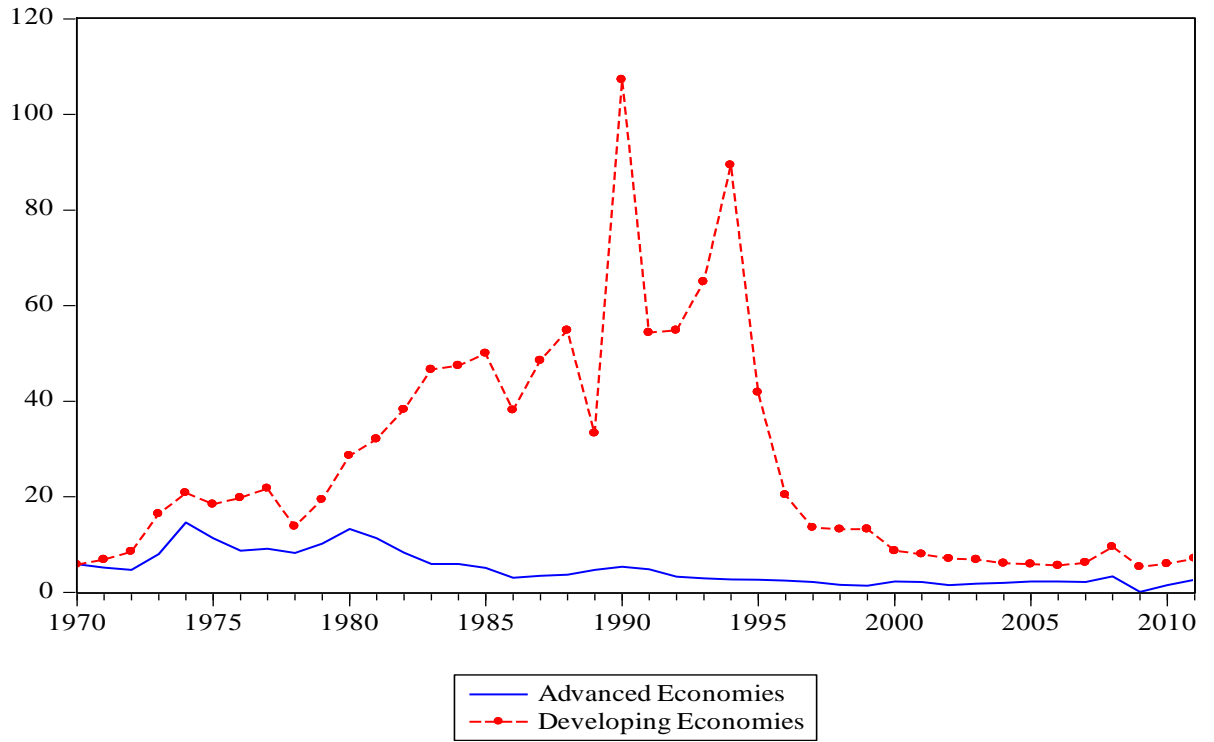
## **Chapter Two**

# **Empirical Regularities of Inflation Volatility: Evidence from Advanced and Developing Economies**

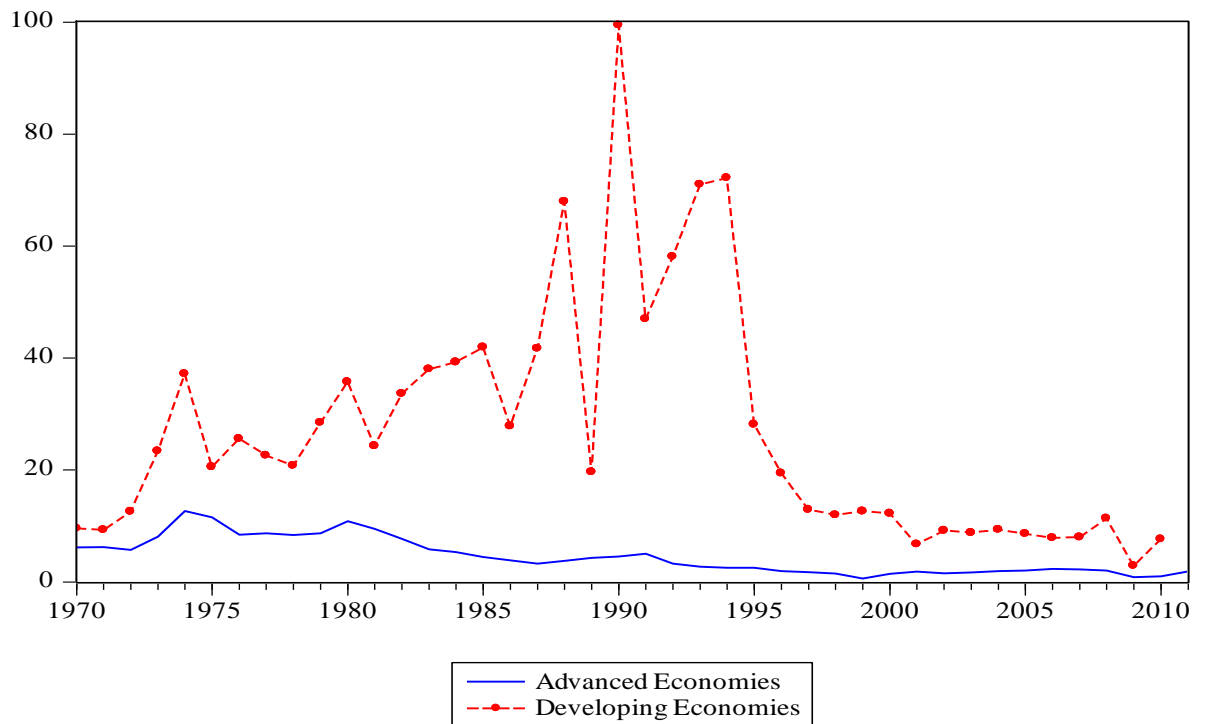
### **2.1 Introduction**

Inflation volatility entangles the behaviour of unanticipated components of inflation emerging from exogenous shocks. It is evident from the literature that the second order characteristic of inflation dynamics, whether interpreted as uncertainty or variability, can affect economic well-being adversely. It does so by various ways and through different channels. Even though evidence of negative welfare consequences is in place, researchers have paid little attention to measuring the intensity of inflation volatility across economies. Difference in the intensity of inflation volatility can give rise to different patterns in the inflationary process and be crucial in terms of economic costs for different groups of economies. This necessitates a critical assessment of inflation volatility for different sets of economies. Classifying the economies broadly into two categories as ‘Advanced Economies’ and ‘Emerging & Developing Economies’ following the definition of the International Monetary Fund (IMF), this chapter aims to unearth the empirical regularities of inflation volatility and presents a comparison between them. Comparing advanced and developing economies in terms of inflation volatility provides an understanding of the fundamental difference in inflationary processes between these two groups and the difference in subsequent welfare cost borne

**Figure 2.1A: Annual CPI Inflation in Advanced & Developing Economies**



**Figure 2.1B: Annual Inflation from GDP Deflator in Advanced & Developing Economies**





by them. This chapter shows that, irrespective of methodologies used, inflation is substantially volatile in nature for developing countries than that of developed countries. Such empirical finding opens up two dimensions for existing research. Firstly, it invokes policy discussions, especially on the role of monetary authorities in developing countries vis-à-vis advanced countries. Secondly, it motivates structural analyses, which can pin down the structural differences between advanced and developing economies and identify the main sources of volatility. For a preview of the main observation of this chapter, the plots of inflation data of advanced and developing countries are presented. In Figures 2.1A and 2.1B, the analytical group data<sup>8</sup> of annual inflation (in percentage) from Consumer Price Index (CPI) and Gross Domestic Product (GDP) deflator for advanced (33 countries) and developing economies (149 countries) are produced respectively.

It is evident that the trajectory of inflation is quite different between developed and developing countries. Almost for the entire sample period, i.e. over the period of last four decades (1970 – 2011)<sup>9</sup>, inflation remains higher for the developing and emerging countries than for the advanced group. It is important to note that the incidence of high spikes of shocks, the amplitude of momentous fluctuations, the large swings, and their persistent behaviour confers the distinguishing feature for the inflationary process of developing economies compared to developed countries. It can also be seen that such variability intensifies particularly during the period of the 1980's to 2005. This

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<sup>8</sup> The term “Analytical Group” is used by IMF to classify the economies in groups as ‘advanced’ and ‘developing’.

<sup>9</sup> Data Source: Database of International Financial Statistics.

observation reveals that inflation variability is substantially greater for developing economies than for that of advanced economies. Overall, it is apparent that shocks have a considerable impact on inflation path. This visual inspection gains support from the results of summary statistics of CPI inflation data produced in Table 2.1.

**Table 2.1: Summary Statistics of Annual CPI Inflation**

	1970 – 79		1980 – 89	
	Advanced	Developing	Advanced	Developing
Mean	8.595	15.121	6.477	41.736
Median	8.480	17.385	5.522	42.389
Maximum	14.601	21.700	13.276	54.785
Minimum	4.711	5.784	3.067	28.575
Std. Dev.	3.003	6.043	3.444	8.846
Skewness	0.524	-0.534	0.960	-0.088
Kurtosis	2.713	1.675	2.613	1.645
Jarque-Bera	0.493	1.206	1.598	0.778
Probability	0.782	0.547	0.450	0.678
Sum	85.954	151.208	64.766	417.359
Sum Sq. Dev.	81.146	328.626	106.764	704.301
Observations	10	10	10	10

	1990 – 99		2000 - 09	
	Advanced	Developing	Advanced	Developing
Mean	2.928	47.270	1.986	6.882
Median	2.657	48.067	2.166	6.488
Maximum	5.344	107.241	3.352	9.491
Minimum	1.397	13.127	0.072	5.272
Std. Dev.	1.281	33.340	0.826	1.394
Skewness	0.801	0.503	-0.937	0.690
Kurtosis	2.589	2.068	4.515	2.229
Jarque-Bera	1.141	0.783	2.420	1.041
Probability	0.565	0.676	0.298	0.594
Sum	29.276	472.703	19.856	68.824
Sum Sq. Dev.	14.778	10003.910	6.136	17.483
Observations	10	10	10	10

From Table 2.1, it can be noted that, across different sub-periods, both mean and standard deviation of inflation are greater for developing countries. The range of fluctuations in inflation is also higher for developing countries. It is noteworthy that while the variability of inflation has declined gradually for the advanced group over time, it has gone up sharply for the developing economies. For all sub-periods, the variability of inflation has outsized remarkably in developing countries compared to the developed group due to the incidence of shocks. Moreover, the time-varying nature of inflation variability is also perceptible, since inflation variability changes across the sub-samples under study<sup>10</sup>. As mentioned earlier from the plots, and from the results of standard deviation of inflation, the period of the 1980's to 2000 has witnessed the most significant difference in inflation volatility between advanced and developing countries. This time span is widely known as the period of Great Moderation. It is striking that, during this era, inflation has moderated for advanced countries but not for developing countries. While researchers have recognised the low and stable inflation for advanced economies and investigated its sources, the contrasting scenario of developing and under-developed economies has remained unexplored.

This chapter aims to provide an empirical assessment of inflation volatility for advanced and developing countries from time as well as frequency domain perspectives. During the course of empirical analysis, a clear quantitative distinction has been detected between two sets of economies. The time domain analysis is conducted using the standard econometric techniques of ARCH-LM test and GARCH model on monthly CPI inflation data and balanced panel GMM estimation on the conditional variance of

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<sup>10</sup> One can obtain similar observation from the annual inflation data computed over GDP deflator.

monthly CPI inflation. It is observed that developing economies are far more affected by volatile inflation than advanced economies. The frequency domain analysis is conducted using the Symmetric type Christiano – Fitzgerald (2003) band pass filter on quarterly CPI inflation data. It is found that over the cyclical components across different frequency bands, inflation is more volatile for emerging economies. All results, in sum, elucidate one single stylised fact explicitly from different angles that inflation volatility is inherently higher for developing economies than their developed counterparts. Finally, the welfare loss is evaluated using a Loss Function of Central Bank to identify the cost of inflation volatility. It is found that more than twice greater welfare cost is imposed on developing countries due to higher inflation volatility compared to advanced nations. The rest of this chapter is organised into different sections and sub-sections. In Section 2.2, the motivation behind this study is discussed. Section 2.3 explains the dataset and methodology chosen for this empirical investigation. Section 2.4 presents the results of the empirical analysis of inflation volatility. In Section 2.5, an evaluation of the welfare cost of inflation volatility is provided using the Central Bank’s Loss Function based on a New Keynesian framework. Section 2.6 concludes this chapter by raising the key research question of the thesis based on observed regularities of inflation volatility.

## **2.2 Motivation**

This section intends to explain the motivation for this study that has come from understanding the ill effects of volatile inflation and an awareness of the relevant research gap in the literature on the empirical regularities of inflation volatility.

### **2.2.1 Cost of Inflation Volatility: A Review of Literature**

Scholars, economists and policymakers have unanimously recognised the adverse economic consequences of inflation and documented in detail how inflation can tax an economy by eroding purchasing power, deteriorating economic growth and depreciating societal welfare. Alongside inflationary consequences, the upshot of inflation variability has received considerable attention from researchers. Ample evidence are available in the literature that emphasises the effects of volatile inflation.

#### **Evidence from Theoretical Works**

Since the 1970s, attention has been given to the relation between inflation and its temporal variance. Phelps (1972) pointed out that variable inflation is costly and needs to be accounted for. Friedman (1977) argued that inflation volatility hurts economic prosperity. According to him, the potential cost of volatile inflation can come out through two channels. These are as follows:

Firstly, volatile inflation shortens the optimum length of un-indexed commitments and makes indexation beneficial for the economic agents. However, such indexation comes into effect after sluggish adjustment. This entails rigidity of prior arrangements, reduces the effectiveness of market forces, and infuses an element of uncertainty to every market transaction. Due to sluggish adjustment, the benefits of indexation accrue to economic agents with lags. Such slow adjustment in commitment and imperfections of indexation can cause high unemployment and depreciate economic efficiency.

Secondly, volatile inflation leaves market prices in a less efficient state by adding frictions. According to Hayek (Friedman, 1977), the key function of a price system is to convey the correct information efficiently to economic agents to facilitate decisions about production, and allocation of resources across the economy. While observing the absolute prices, agents make their decisions based on the relative prices of goods and factors of production as well as intertemporal relative prices. The relative price provides the signal to the economic agents regarding the relative scarcity or abundance of the resources and enables optimal decision making within the economy. When inflation is stable, it is comparatively easy for the economic agents to extract the signal about relative prices. However, if inflation is volatile, extracting signal<sup>11</sup> from the relative prices becomes difficult<sup>12</sup>. In an environment of volatile inflation, information content of prices lacks worth and planning for investment decision making becomes difficult. Further, if nominal rigidities are in place, volatile inflation can generate greater uncertainty about the relative price of final goods and input costs. This can lead to higher level of unemployment, misallocation of resources, and impair economic growth. In sum, inflation volatility results in distorting effects of uncertainty via rigidity of contracts and sluggish indexation, and it taints the fundamental behaviour of the price system.

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<sup>11</sup> Note that, the implication of signal extraction in this context is not the same as it is interpreted in the literature of Econometrics. In Econometrics, problem of signal extraction connotes finding of the optimal estimate of an unobserved component at a particular time point in the sample. See Harvey (1993) for further details.

<sup>12</sup> Barro (1976), in his signal extraction model, derived a positive link between the variance of surprise inflation and the relative price dispersion. Empirical evidence on such positive link can be found in the work of Grier and Perry (1996).

In addition to the arguments of Friedman, there are two approaches existing in the literature that can be followed to explain the cost of inflation variability. The first approach considers the cost incurred directly from the definition of inflation variability, and the second views inflation variability as the ‘uncertainty’ of inflation and accordingly it measures the cost.

For the first strand of literature, one can start with the work of Lucas (1973). Lucas argued that increased volatility of inflation accentuates firm’s real responses to observed price variation and worsens the trade-off between output and inflation. From time series and cross-sectional observations, Okun (1971) concluded that inflation tends to be more variable as it increases. Following this observation, Wachtel (1977) argued that the uncertainty of real income expectations rises with inflation. This induces greater savings propensity via the precautionary responses of the people to increasing uncertainty of inflation. Such phenomena finally cause a depressing effect on net investment in physical assets. The key point to note is that the uncertainty revolving around inflation injects and spreads out ‘economic pessimism’ across the economy and gets manifested from the precautionary savings behaviour of the economic agents.

In line with his contemporaries, Taylor (1981) identified the high economic costs of inflation volatility. According to him, inflation volatility induces risk as well as uncertainty regarding the changes of average prices and therefore, it undermines the information contained in relative prices. This results in a sub-optimal allocation of

resources and societal cost. All these works emphasises that ‘volatility’ or ‘variability’ of inflation creates uncertainty which is costly for the economy.

It is also argued in the literature that variability of inflation gives rise to production inefficiency which causes reduction in the output level that otherwise could be attained under price stability. This point has been illustrated by Katz and Rosenberg (1983). According to them, inflation variability leads to variability of real wage which produces an inferior equilibrium in relation to employment and output compared to that under stable price. Irrespective of the rise or fall of output, such inefficiency in production will emerge due to inflation variability and is prone to involve welfare cost.

Another problematic issue of inflation variability is the variability of effective tax rates. Since taxes are not indexed, inflation variability can cause the uneven distribution of the real burden of tax. Feldstein (1982) has argued that interaction between inflation and tax structure, typically distortionary taxes on capital income, needs to be addressed. Volatile behaviour of inflation can lead to expectation error in the inflation forecast. Even if neutralised by adjusting the nominal interest rate, this may have non-neutral consequence for non-indexed tax structure. Given the fact that individual tax rate differs considerably across the economy, an inflationary shock will put increasing burdens on investors who are sensitive to the real net of tax return. According to Feldstein (1982), variable inflation will raise capital intensity if the rate at which savers are taxed is less than the tax rate on borrowers. Hence, high variability of inflation will alter the capital-



labour substitutability, factor intensity and push the economy towards distorted macroeconomic equilibrium.

Considering the second approach of the literature, it has often been found that inflation volatility is treated synonymously with inflation uncertainty. Ragan (1994) argues that inflation uncertainty exerts its real effect on the economy. He compares the long-run behaviour of the real economy in stable and unstable inflation environments, and examined the same in a micro-founded dynamic stochastic general equilibrium model. Under the assumption of incomplete credit market due to absence of indexed loan-contracts, his analysis revealed that unstable inflation raises the nominal riskiness of all borrowers' distribution, leads to greater possibility of bankruptcy and augments the cost of financial intermediation. This increases the spread between lending rate and deposit rate and results to a reduction of financial intermediation. Therefore, the aggregate economic activity shrinks.

Further, inflation volatility can alter the nominal returns from assets and induce portfolio adjustment for optimising individuals. Dibooglu & Kenc (2009) have argued that such portfolio adjustment can be costly in terms of economic growth and social welfare. Using a stochastic general equilibrium balanced growth model with micro-foundation, Dibooglu & Kenc (2009) studied the growth and welfare effects of inflation variance emerging from monetary policy uncertainty. They observed that a substantial welfare gain in the magnitude of 21.16% of initial capital is possible if inflation is stabilised at the socially optimum level.

Landskroner & Ruthenberg (1985) and Miller (1992) also find that total credit is negatively affected by inflation uncertainty due to increased bank costs<sup>13</sup>. There is evidence that inflation uncertainty increases the risks associated with the portfolios of firms and banks, causes these agents to act risk averse, and creates disequilibrium in the credit market. The literature on credit rationing (Stiglitz & Weiss, 1981; Williamson, 1987) claims that increased uncertainty in the economy causes banks to ration credit and can lead to disequilibrium in credit markets. Tests on both developed and developing countries show that inflation uncertainty has a significant bearing on credit markets either directly or indirectly, regardless of the depth of financial markets (Yigit, 2002). Therefore, curbing uncertainty of inflation would reduce the risk of contracts and foster the growth of investment.

### **Economic Growth Effect of Inflation Volatility: Evidence from Empirical Studies**<sup>14</sup>

In connection to the relationship between inflation and growth, researchers have noticed that volatile inflation, associated with high inflation, impairs economic growth. High inflation is associated with high variability will lower output (Levi & Makin, 1980). Empirical support for this observation is provided by Evans (1980) and Mullineaux (1980) for US economy. Froyen and Waud (1987) observed the negative impact of inflation uncertainty on growth for Canada and the UK. Holland (1993) summarises eighteen studies on the empirical link between inflation uncertainty and real activity. Among these, fourteen studies show a significant negative relation. Al-Marhubi (1998)

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<sup>13</sup> On the other hand, Huizinga (1993) and George & Morriset (1995) claim that uncertainty of inflation will sometimes lead to higher profit fluctuations and may result in increased investment.

<sup>14</sup> It is important to note that there exists a standard problem to split up the cost of inflation and cost due to inflation variability. Empirical research has identified this difficulty.

found negative growth effects of conditional and unconditional inflation volatility for a panel of 78 countries. Using regressions, Judson and Orphanides (1999) estimated the contemporaneous relationship between income growth and the level and volatility of inflation in a panel of 119 countries, over the period 1959 to 1992. They found evidence that inflation volatility, measured by standard deviation of intra-year inflation rates, has contributed significantly to lower economic growth in a wide panel of countries. Blanchard and Simon (2001) obtain a strong positive link between inflation volatility and output volatility for large industrialised countries. Elder (2004), Fatás and Mihov (2005), and Grier and Grier (2006) found that higher inflation volatility can depress economic growth.

Literature provides evidence on the adverse effect of inflation volatility on investment which can be detrimental to economic growth. In his empirical work, Fischer (2011) has shown that the period of high inflation volatility is associated with reduced fixed asset investment. One percentage point increase in inflation uncertainty (approximately 1.15 standard deviations), is associated with a reduction in intended fixed asset investment between 15% and 37% relative to the mean. While inflation uncertainty may serve as a proxy for other forms of systemic risk or macroeconomic factors, the negative relationship between uncertainty and firm-level investment is robust even after controlling for inflation levels, exchange rates, and aggregate economic activity. This evidence indicates that inflation volatility can adversely affect the aggregate output in the economy through the investment channel.

## **Inflation Volatility and Corruption**

Braun and Tella (2004) present evidence on the link between corruption and inflation variability in a sample of 75 countries over 14 years. Controlling for the country-specific effects and variables, used as proxy for other theoretically plausible influences on corruption, they found that higher inflation variability is associated with higher level of corruption. Moreover, the effects are economically significant. Their panel estimates implied that a one standard deviation increase in inflation variability from the median is associated with an increase in corruption of 12% of a standard deviation. According to Braun and Tella (2004), agents can inflate the price that owners pay for goods, which is desirable to start an investment project. High and variable inflation is assumed to increase uncertainty about prices and therefore to increase the cost of auditing the agent's behaviour. This can lead to higher corruption and lower investment in equilibrium. This finding underlines the social consequences of inflation volatility.

### **2.2.2 Relation between Level and Volatility of Inflation: A Brief Review**

A large body of literature has evolved on inflation volatility, premised over the relation between inflation and its variability. The general conjecture is that the average level of inflation is positively related to its second order moment. It is evident from the literature that, if average inflation is higher, the aggregate inflation will be more variable in nature. This, in turn, leads to inflation uncertainty. Okun (1971) reported a positive association between standard deviation and average value of inflation calculated from GDP deflator. He used the data for seventeen OECD countries during the period 1951 to 1968. Similar results were obtained by Logue and Willett (1976) with a more

comprehensive dataset covering the inflation rate of forty-one countries over the period 1948 to 1970. Results provided by Foster (1978) were also in line with these studies. Froyen and Waud (1987) found that high inflation led to high inflation volatility and uncertainty in the USA, Germany, Canada and the UK.

In cases of industrialised economies, Ball (1992) found a significant link between the level of inflation and its conditional variance. At the international level, there is strong evidence that countries with high inflation have significantly higher levels of inflation volatility on average (Baillie *et al.*, 1996; Davis and Kanago, 1998). Aggregate price data for the USA, Israel and the UK indicate that periods of high inflation are also periods of high conditional variance in inflation (Brunner and Hess, 1993; Ungar and Zilberfarb, 1993; Kontonikas, 2004). Arguably, the link between the level of inflation and inflation volatility may arise due to asymmetric stabilization policy (Demetriades, 1989), idiosyncrasies of the economy, and the stage of the economic development. Nevertheless, inflation volatility may respond to other characteristics of states due to relative levels of economic development or as a consequence of public policy.

Apart from the works on the relation between mean and variance of inflation, there are several seminal works in the literature which provide volatility models to study the time-varying dynamics of inflation. Pioneering work by Robert Engle (1983) first modelled inflation volatility as autoregressive or time-varying conditional Heteroskedasticity (ARCH). Later, Bollerslev (1986) and Taylor (1986) individually introduced Generalised ARCH or GARCH model to characterise the conditional variability of

inflation. There are several instances where volatility of inflation has been modelled by ARCH or GARCH formulation. Most of these works have been conducted for major developed countries, such as Brunner and Hess (1993) for US CPI data; Joyce (1995) for UK retail prices; Corporal and McKiernan (1997) for annualised US inflation rate; Kontonikas (2004) for the UK; Grier and Perry (1998) for G7 countries and Fountas et. al (2000) for G7 countries. Studies which have focussed on developing countries include Della Mea and Pena (1996) for Uruguay; Grier and Grier (1998) for Mexican inflation; Magendzo (1997) for Inflation in Chile. Furthermore, using an autoregressive conditional heteroskedasticity (ARCH) model, Neyapti (2000) showed that inflation variability significantly raised the uncertainty of wholesale price in Turkey during 1982 - 1999. Evidence from Nas and Perry (2000) also supports this finding. Capistrán and Ramos Francia (2006) showed that inflation variance is subject to the idiosyncratic factors in the context of Latin American countries. Rizvi and Nakvi (2009) have examined inflation volatility for ten Asian economies (1987-2008) and found significant evidence for volatility in response to different shocks.

### **2.3 Dataset and Methodologies for Empirical Analysis on Inflation Volatility**

This section explains the rationale behind the choice of different dataset and methodologies for empirical analysis of inflation volatility. In the first sub-section, the dataset under scrutiny is described with respect to different methodologies of analysis. Depending on the perspective of analysis, the choice of data and sample varies. There is also an issue of data availability for the chosen sample and these are all clarified in the description of data. After describing the data, in the second sub-section, methodologies adopted for empirical analysis are explained. This is coupled with the reviews of

existing techniques in the literature. The empirical investigation on inflation volatility is done from two perspectives. One is the *Time Domain Analysis* and other is the *Frequency Domain Analysis*. The second sub-section, therefore, illustrates the battery of techniques and aspects relevant for time and frequency domain study.

### **2.3.1 Description of Data**

All data have been collected from the database of International Financial Statistics (IFS). Depending on the analytical purpose, two types of dataset on Consumer Price Index (CPI) are exploited. The first is the monthly data for Time domain analysis and the second is the quarterly data for Frequency Domain Analysis. The time domain analysis aims to model the volatile nature of inflation which requires high frequency data. Given the record of inflation, monthly frequency of data is the best alternative. The frequency domain analysis examines inflation volatility from the cyclical components and at different frequencies of fluctuations. The literature (e.g. Baxter & King, 1999) suggests that quarterly data is more suitable for the extraction of cyclical components and frequency decomposition as it mitigates noise from the data but retains the basic pattern in the movement of the concerned variable.

In addition to categorising the use of data according to methodological purpose, data on CPI are assembled into two layers. The first is for group level data and the second is for individual country level data following the classification of IFS. The motivation behind considering the data for the group as well as for individual countries is to check the robustness of the findings obtained from the empirical analysis. The group of advanced

economies comprises thirty three countries, including Euro area, G7 countries, new industrialised Asian countries and advanced countries other than G7 & Euro area. The group of emerging and developing economies consists of one hundred forty nine countries, including Central and Eastern Europe, Commonwealth of independent states, Developing Asia, Sub-Saharan Africa, Middle East and North Africa and Latin America and the Caribbean countries<sup>15</sup>. Such group level data are particularly useful for obtaining an initial overview of the scenario at aggregate level. It is possible to identify the distinguishing feature of significant volatility in inflation for developing countries than for the advanced group. Nevertheless, analysis has been extended to get conformity of the key stylised fact of inflation from individual country level data. For this purpose, two samples of advanced and developing countries have been constructed. The sample countries, whether they belong to advanced or developing group, are chosen in a way that the homogeneity of each group can be maintained. Besides, it is considered whether these sample countries can be well representative for their respective groups.

In case of advanced group, countries like US and UK are well known developed countries in the world. Along with them, the several EU countries are chosen which are homogenous in terms of country specific traits. Further, given the fact that these countries are under similar type of monetary policy rule, it would be convenient to control for the heterogeneity of policy specific shocks. In case of developing economies group, first, the countries are classified into four broad categories geographically, viz., Latin America, Sub-Saharan Africa, Middle-East and North Africa and East, South-East

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<sup>15</sup> See IFS website for further details.



and South Asia. Latin American countries have a history of hyperinflation. Since the aspect of hyperinflation is not addressed in this thesis, this group of countries is not considered. Sub-Saharan Africa and Middle East and North African countries are subject to political instability and social unrest which make their economic structure quite different (and sometime treated as the ‘outlier’) in the entire group of developing nations. By contrast, East, South-East and South Asia reflect some similarity in their pattern of economic development with respect to growth, market structure, liberalization and public policies. At the same time, these countries are well representative in terms of inflation volatility for the group. The range of coefficient of variation of inflation is 0.42 to 0.56 for these four categories of developing countries and South East Asian region lies in the range with 0.48. Finally, in comparison with other regions, very little work has been done on inflation volatility for South East Asian nations. In sum, all these factors provide motivation to choose the sample of countries from East, South-East and South Asian region.

**Table 2.2A: Sample of Countries for Time Domain Analysis**

<i>Country ID</i>	<i>Advanced</i>	<i>Developing</i>
1	Austria	Bangladesh
2	Belgium	Cambodia
3	Canada	China
4	Denmark	India
5	Finland	Indonesia
6	France	Malaysia
7	Germany	Myanmar
8	Italy	Nepal
9	Japan	Pakistan
10	Norway	Philippines
11	Switzerland	Srilanka
12	UK	Thailand
13	US	Vietnam

**Table 2.2B: Sample of Countries for Frequency Domain Analysis**

<i>Country ID</i>	<i>Advanced</i>	<i>Developing</i>
1	Austria	Bangladesh
2	Australia	Cambodia
3	Belgium	China
4	Canada	Fiji
5	Denmark	India
6	Finland	Indonesia
7	France	Malaysia
8	Germany	Myanmar
9	Italy	Nepal
10	Japan	Pakistan
11	Norway	Philippines
12	New Zealand	Papua New Guinea
13	Switzerland	Srilanka
14	UK	Thailand
15	US	Vietnam

The empirical analysis considers the sample period of 1968 to 2011 as this is the maximum time span for which the inflation series are available for both the advanced and developing countries. For the time domain analysis, monthly data on CPI are collected for the sample period of 1968M01 to 2011M09. From the dataset of CPI, inflation series are calculated as the logarithmic difference of price indices between two consecutive time periods. The group level data is used to implement the first method of ARCH Effect test while the country-wise data for individual sample countries are utilised for GARCH estimation and estimation of long run volatility. Following the country classification of IFS, sample of advanced and developing countries are chosen. In Table: 2.2A, the sample countries are listed. Each group of economies contains thirteen countries in the sample. For the frequency domain analysis, quarterly data on CPI are gathered for the sample period of 1968 Q1 to 2011 Q2. In Table 2.2B, the

countries selected in the sample are listed<sup>16</sup>. Once again, inflation has been computed as the logarithmic difference of price indices between two consecutive time periods. Considering the inflation series for analytical group and individual country, the method of frequency filter is applied to dissect the innate volatility at different frequencies of the underlying process. For the country level study, the sample is almost same as it is for time domain analysis, but with a little difference.

### **2.3.2 Description of Methodologies**

As mentioned earlier, the empirical analysis stands on the two pillars of time domain and frequency domain analysis. Time domain analysis is implemented following the traditional outlook for economic time series data, where data is considered to be generated by a repetitive process over time. Therefore, the time domain analysis reveals the time series properties and characterisation of time-varying variability of inflation for advanced and developing economies. However, the serious limitation of this traditional approach is its failure to recognise the regularities that surface from the cycles of various frequencies in the series under consideration (Brandes, et al., 1968). The evaluation and analysis of the time series taking place in the time domain is unable to depict the frequency characteristics across the different frequencies of time series. Inspecting from the frequency domain one can obtain a deeper insight into the structure, cyclical behaviour and amplitude of fluctuations of inflation in different time scales, as well as the development of time series decomposition in terms of periodic contribution

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<sup>16</sup> It can be noted that due to unavailability of monthly CPI data for few countries, the sample size is smaller for time domain analysis than that of frequency domain analysis.

(Poměnkova & Maršalek, 2011). Moreover, frequency domain analysis enables us to circumvent the standard problems of structural break and seasonality which are of serious concern in the time domain analysis (Harvey, 1993). Even after having all of these advantages, surprisingly, little effort has been made in the existing empirical literature to explore the inflation volatility at different frequencies. Hence, in this chapter, a comprehensive synthesis of analysis is conducted between the time and frequency domain approach in order to assess the dynamic behaviour of inflation. Both approaches not only complement each other but also ensure the robustness of one single fact that inflation in developing countries is affected by greater volatility<sup>17</sup>.

### **Methodology for Time Domain Analysis**

In the time domain approach, volatility of inflation has been assessed for advanced and developing countries by three different methods which elucidate the stylised fact that inflation volatility is significantly higher for developing countries than for developed countries. Using the first method, standard Autoregressive Moving Average (ARMA) models are specified and followed by the ARCH-LM test of residuals for these two groups to examine the presence and size of ARCH effect in the inflation series. In the second method, the GARCH (1, 1) model of volatility is used on a sample of twenty six countries and the statistical significance of the difference in sample proportion between advanced and developing economies affected by volatile inflation is examined. Finally, in the third method, an autoregressive model is estimated by using the GMM technique

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<sup>17</sup> All the empirical analysis is done using E-Views routine.

on the balanced panel of conditional variance series of inflation obtained from the second method of GARCH (1, 1) model estimation.

### **Method One: Testing of ARCH Effect in Inflation**

The group level inflation data on advanced and developing countries are taken into consideration initially. Then the tests for stationarity are conducted to examine whether the data series are free of long memory process. Confirming the stationarity condition, presence of seasonality is checked. Seasonal variation has a pronounced influence on the aggregate variance of a time series process and is a common trait of the economic data, especially in the case of monthly data. To ensure correct diagnosis of the time-varying variability of inflation, seasonal components are extracted from the data by seasonal differencing. Using twelve month differencing for the monthly dataset, the deterministic annual seasonality is removed<sup>18</sup>. Thereafter, Autoregressive Moving Average (ARMA) models have been specified for both groups of economies to characterise the time series process of inflation.

The ARMA model is expressed in terms of past values of the variable itself (i.e. the autoregressive component), in addition to the current and lagged values of a ‘white noise’ error term (i.e. the moving average component). ARMA models can be viewed as a special class of linear stochastic difference equations. By definition, an ARMA model is covariance stationary and it has a finite and time-invariant mean and covariance. In equation (1), a general representation of ARMA model has been stated.

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<sup>18</sup> See Enders (2010) on seasonal differencing.

$$\pi_t = \mu + \sum_{i=1}^p \alpha_i \pi_{t-i} + \sum_{j=1}^q \beta_j \varepsilon_{t-j} \dots\dots (1);$$

Where,  $\pi_t$  = inflation at period ‘t’ ; and  $\varepsilon_t$  = inflationary shocks (or forecast errors).

ARMA models have been criticised on the basis of their simplistic, subjective, agnostic and *a-theoretic* nature. However, these critical issues are the factors which give the necessary flexibility for these models to study the dynamic properties of time series data under consideration (Saz, 2011). In order to construct an appropriate ARMA model of inflation data series, the standard practice of identification, estimation and diagnostic checking is done as suggested by the methodology of Box-Jenkins (1976). The appropriate model will be the best description of the temporal dependence in the inflation series. After eliminating the non-stationary components of the data by differencing and de-seasonalising, the plots of Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) reveal the pattern of the autoregressive and moving average terms. Following the identification of this pattern, the potential ARMA model is proposed and estimated by the Ordinary Least Square (OLS) method.

Once the two specific ARMA models are set up, the formal ARCH effect test is carried over the squared residuals or the inflationary shocks obtained after estimation. For this purpose, the ARCH-LM test proposed by Engel (1982) is followed. In this test, the square of residuals is regressed on a constant and its lagged values are shown in Equation (2).

$$\varepsilon_t^2 = \gamma_0 + \gamma_1 \varepsilon_{t-1}^2 + u_t \dots\dots\dots (2);$$

Where,  $\varepsilon_t^2$  = square of residuals;  $u_t$  = white noise

In this test,  $H_0: \gamma_1 = 0$  vs.  $H_1: \gamma_1 \neq 0$

Rejection of the null hypothesis indicates the presence of ARCH effect in the estimated residuals obtained from the ARMA model specification. In econometric terms, if the null hypothesis is rejected then it can be concluded that variance of forecasting errors are conditional to the lagged values of errors. Such a test of the ARCH effect is intuitive and informative in order to assess the time-varying volatility of inflation.

### **Method Two: Estimation of GARCH (1, 1) Model for Inflation Volatility**

It is possible to identify the distinguishing feature of volatility in inflation for developing versus advanced countries from the ARCH Effect test on the analytical group CPI inflation data. Nevertheless, it is also essential to examine if such feature of inflation variability is true for the individual country level data, or if it is spurious and surfacing due to the problem of data aggregation. In fact, if the result obtained from the ARCH effect test provides evidence for time-varying variability of inflation, a comprehensive model of volatility would be worth investigating. In order to study the time-varying variability of inflation, one can use the ARCH model by choosing appropriate number of lags. However, empirical research shows that the ARCH model often requires a long lag process of the squared residuals to explain volatility. To circumvent this problem, researchers subsequently suggested variations and extensions of the basic ARCH model. Bollerslev (1986) and Taylor (1986) independently developed the Generalised ARCH (GARCH) model in which the conditional variance is considered as a function of the lagged values of shocks and conditional variance itself. Major advantages of the GARCH (1, 1) are the model is parsimonious; it avoids the

over-fitting problem; and it is less likely for breaching the non-negativity constraints on the estimable parameters. It can capture the effect of infinite number of past squared residuals on current volatility with only three parameters. However, one disadvantage of the GARCH model is that it enforces a symmetric response of volatility to positive and negative shocks<sup>19</sup>. Following this limitation, other variants of the GARCH model (like IGARCH, EGARCH, Threshold – GARCH, and Component GARCH) are developed and exploited to analyse the nature and impact of shocks. Since this section of the paper is focussed on quantitative evaluation of inflation volatility, it uses only the GARCH (1, 1) process to study inflation volatility for the samples of developed and developing countries individually<sup>20</sup>.

Analysis is run on the monthly data of CPI inflation for all sample countries listed in Table 2.2A. The econometric specification of GARCH (1, 1) model is given in equations (3a) and (3b). Here, (3a) represents the conditional mean equation and (3b) is for the conditional variance equation.

$$\pi_t = \mu + \sum_{i=1}^p \alpha_i \pi_{t-i} + \sum_{j=1}^q \beta_j \varepsilon_{t-j} \dots\dots\dots (3a)$$

$$h_t = \gamma_0 + \gamma_a \varepsilon_{t-1}^2 + \gamma_g h_{t-1} \dots\dots\dots (3b)$$

In equation (3b),  $h_t$  is the conditional variance of the  $\{\varepsilon_t\}$  sequence. According to the standard procedure of the GARCH (1, 1) model, the first step is to specify a sufficient

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<sup>19</sup> According to Brunner and Hess (1993) and Joyce (1995), a positive inflation shock is more likely to increase inflation volatility via monetary policy mechanism, as compared to negative inflation shock of equal size.

<sup>20</sup> In a study about the performance of different volatility models based on their predictive ability, Hansen and Lunde, (2001) showed that GARCH (1,1) process is at least as good as any other competing model of volatility.



equation for the conditional mean of the series under investigation. The conditional mean equation has been specified by an ARMA process in which the current period inflation is considered as a function of its lagged values and moving average terms. The rationale for choosing the ARMA process is to capture the inertia of inflation generating process<sup>21</sup>. However, before going into the ARMA specification, CPI data for each country has passed through the standard unit root tests and seasonality check. Lag selection in the ARMA process is based on the correlograms, information criteria, whiteness of the residuals and the parsimony of the model. Combining the conditional mean and variance equations, (3a) and (3b) are estimated jointly. Note that the GARCH (1, 1) model is estimated for every country included in the sample of advanced and developing economies.

### **Method Three: Panel Estimation for Measuring Persistence of Inflation Volatility**

The exercise, conducted so far by the first and second methods, is based on monthly inflation data which captures short to medium run inflationary variations. However, it fails to account for the prevalence of unobserved country specific heterogeneity in the long run volatility and the persistence of volatility. To address the long run features of inflation volatility, this section will present a dynamic model which is estimated by Generalised Method of Moments (GMM) technique in a balanced panel of GARCH variance series of inflation for advanced and developing economies. In the second method discussed above, the GARCH (1, 1) model is fitted with the conditional mean

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<sup>21</sup> Grier and Perry (1998), and Joyce (1995) used the autoregressive specification as the mean equation. Cecchetti et al (2000) examined the forecasts based on autoregressive model which performed consistently well for US data.

and variance equation for all countries included in the sample of advanced and developing group. This procedure allows us to estimate the conditional variance series for each country's inflation. In other words, the conditional variability of inflation is obtained as a by-product of the GARCH (1, 1) model estimation for each country. Note that the ARMA processes which are specified as the conditional mean equation of the GARCH (1, 1) model for each country included in the sample remain unaltered. The reason is that the specified ARMA models are adequate to capture the underlying data generating process and isolate the unforeseen error components reasonably well. The joint estimation of conditional mean and variance equation yields the series of estimated conditional variance of inflation. The series of time varying variance are further deployed to extract the pattern of long run volatility and to quantify the persistence of volatility for advanced and developing economies. By combining the cross-section and time series of the estimated conditional variance of inflation in the panel data, one can obtain a more accurate and efficient measure of inflation variability. By making data available for several thousands of observations, the panel representation of conditional variability can minimise the bias in estimation. As the number of time periods is substantially larger than number of cross sections included in the sample, the potential bias for using lagged dependent variable will decline asymptotically.

A simple autoregressive model of order one with intercept term is proposed and estimated over a panel of estimated conditional variance of inflation series for the pool of advanced and developing countries. The model is specified below.

$$\hat{h}_{i,t} = \delta_i + \mu\hat{h}_{i,t-1} + v_{i,t} \dots\dots\dots (4); \text{ where, } v_{i,t} \sim N(0, \sigma_i^2)$$

In the econometric model, specified by (4),  $\hat{h}_{i,t}$  is the estimate of conditional variability of inflation which is regressed on its own lagged values, i.e.  $\hat{h}_{i,t-1}$ , given that the country-specific effects ( $\delta_i$ ) and country-specific errors ( $v_{i,t}$ ) are in place. The parameters of concern are the intercept term and the autoregressive coefficient ( $\mu$ ). Autoregressive coefficient provides the magnitude of persistence as well as provides the measure of long run volatility jointly with the estimate of intercept term.

Comprising all three methods discussed above, our analysis sheds light on the salient features of time-varying volatility of inflation. It identifies the ARCH effect in the inflation process from the analytical group data. It assesses the conditional variability of inflation from the sample of advanced and developing countries. It looks at the proportion of developing countries affected by volatile inflation compared to their advanced counterparts. Finally, controlling for country-specific heterogeneity by imposing a panel data structure of estimated conditional variance, it unveils the long run volatility and persistence of volatility.

**Methodology for Frequency Domain Analysis**

The conventional approach to discovering the stylised facts for a particular macroeconomic variable or a set of variables is to analyse the broad regularities in the statistical properties of the business cycle. As pointed out by Lucas (1977), stylised facts

come from the statistical properties of the movements of the deviations from trends of various macroeconomic variables. Following this spirit, the chapter intends to unearth the stylised fact on inflation volatility from the perspective of the business cycle component using a frequency domain approach. In this context, one can think of estimating the spectral density using a standard data window which can measure the volatility not only for the regular cycles but also for all unusual and irregular cycles at each frequency. This approach can be suitable in case of comparing the group level data, but not for the individual country-wise data. This issue has been addressed elaborately in Appendix A.1. In the next sub-sections, a detailed discussion is presented on the methodological aspects followed for our frequency domain analysis. In course of this discussion, the choice of the medium term business cycle and its decomposition into different frequency bands is rationalized. Thereafter, the motivation behind the selection of appropriate filtering technique is explained. Finally, the implication of the frequency domain analysis is mentioned.

### **Rationale behind Medium Term Business Cycle and its Decomposition**

Research in macroeconomics is often categorised into two fields. One is involved with short run analysis that leads towards the study of business cycle and the other concentrates on the long run issues. Given these two strands of research, one can conceptualise *medium run* as the transition from short run fluctuations to long run steady state<sup>22</sup>. The medium term business cycle is an emerging concept in the literature of

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<sup>22</sup> See Blanchard (1997) and Boshoff (2010).

business cycle. The novelty of the notion of medium run lies in its potential to synchronise business cycles. In other words, the long run consequences of short run fluctuations can be captured by the idea of medium run. The literature on business cycle that evolved following the work of Burns and Mitchell (1946) is mostly concerned with short run fluctuations and fails to consider long run oscillation. From the perspective of business cycle theory, the medium run can be defined as the *medium term business cycle* that captures the dynamics of all trivial and non-trivial transitory disturbances which would affect the long run steady state path<sup>23</sup>. In the context of this thesis, the medium term business cycle is introduced with the intention of extracting all the components which are transitory or relatively far from being transitory in the underlying data generating process of inflation. The implication of this exercise is to expose the volatility embedded in the persistent fluctuations of inflation emerging from the business cycle phenomena (Comin and Gertler, 2006).

While the medium term business cycle synchronises short and long run fluctuations, it inherits the heterogeneity in the data frequency and remains frequency dependent. Such dependence is due to actions taken by several agents with different term objectives. In any economy, some agents are focusing on short term movements while the others are concerned with longer horizons. As a consequence, the macroeconomic time series becomes a combination of components operating on different frequencies<sup>24</sup>. Therefore, the extracted medium term cycle of the concerned series contains data on different

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<sup>23</sup> See Solow (2000) in Boshoff (2010).

<sup>24</sup> See Aguiar-Conraria, Azevedo & Soares (2008).

frequencies. Studying the statistical properties of the medium term cycle of an economic time series at different frequencies, one can obtain a deeper understanding of the dynamics. The factors driving inflation and causing variation vary across frequencies. This necessitates frequency domain analysis using spectral techniques<sup>25</sup>. Computing the volatility of inflation at different frequency components within the medium term cycle underscores the relative importance of the each component in the cyclical variations across the frequencies. The periodicity, encompassed by medium term business cycle, has been dissected into three different bands of frequencies. These are high frequency, standard business cycle frequency and low frequency. The variability in the fluctuations of inflation over the medium term is then scrutinised according to different bands of frequencies categorically.

### **Review of Band Pass Filter Techniques**

In order to measure inflation volatility from the medium term cycle and its constituent frequency components, it is crucial to employ an appropriate de-trending procedure. Such procedure will exclude the secular trends from the inflation series and enable to obtain the sample moments of the cyclical deviations. One particular technique that dominates the extant literature on business cycle is that of Hodrick and Prescott (1980). The HP filter is a two-sided symmetric moving average filter. The basic properties of the HP filter have been examined by a number of researchers. King and Rebelo (1993) showed that the HP filter can transform a series, which are integrated of order four or less, into stationary series. However, for the purposes of extracting business cycles, the

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<sup>25</sup> See Assenmacher-Wesche & Gerlach (2007)

HP filter is subject to the Nelson-Kang critique and can generate spurious cycles when applied to integrated processes<sup>26</sup>. Due to the severe limitations of the HP filter, the band pass or frequency filter has emerged in the literature as an alternative method for filtering macroeconomic time series data.

Theory of spectral analysis provides a meticulous foundation to elucidate the notion that there are different frequency components of a time series data. This theory does not require any specific statistical model of the data, rather relies on the Spectral Representation Theorem. According to this, any time series within a broad class can be segregated into different frequency components (Christiano & Fitzgerald, 2003). A band-pass filter can be used to extract the appropriate frequency ranges of researcher's concern. The literature suggests two finite sample approximations for the ideal band-pass filter: the Baxter and King (BK, 1999) filter and the Christiano and Fitzgerald (CF, 2003) filter. The BK and CF methods of frequency filters are capable of isolating the cyclical components of a time series. Using linear filters, these filtering techniques utilise a two-sided weighted moving average of the data in which the cycles within a particular band are extracted and remaining cycles are filtered out. The resulting series are therefore relatively smooth and have well-articulated turning points. The BK filter is the fixed length symmetric variety with respect to the leads and lags used to compute the weighted moving average and, thus, the BK filter is time invariant.

However, the BK filter imposes a cost by assigning equal weights to specific number of leads and lags of the same magnitude, while the CF filter allows the data to dictate

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<sup>26</sup> It is not clear whether the results should be interpreted as facts or artifacts (Cogley & Nason, 1993).

weights. The advantage of the CF filter is that it is designed to work well on a larger class of time series data, converges to the optimal filter in the long run (Christiano & Fitzgerald, 2003) and provides highest numerical precision in real time applications (Nilsson & Gyomai, 2011). Thus, it is argued that CF filter outperforms the HP filter and is at least as good as the BK filter for quarterly data observations. In particular, the CF filter dominates BK because the former can exploit the entire data set fully. It uses all the data for each time period and allows the periodicity and frequency to vary with time and to differ from each other. CF is superior to HP because of the latter's relatively poorer performance in the tails, i.e., near the endpoints. The key advantage of CF over HP is that it also allows for examination of different frequency components of the data, which is not feasible with the HP filter. The two filters produce similar results at high frequencies, but research suggests that the CF filter outperforms the BK filter where the focus is on identifying longer-term fluctuations<sup>27</sup>.

### **Selection of an Appropriate Band Pass Filter for Frequency Domain Analysis**

Understanding its relative advantages over other filters, the Christiano and Fitzgerald (2003) method of symmetric type band pass frequency filter is used to extract the medium term business cycle and its segregation into different frequencies<sup>28</sup>. Following Comin and Gertler (2006) and Basu, *et al.*, (2011), the medium term fluctuation for inflation data series is defined with minimum periodicity of two quarters to the upper limit with one hundred quarters. Comin and Gertler (2006) took the periodicity of

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<sup>27</sup> See Zarnowitz & Ozyildirim, (2006)

<sup>28</sup> See Appendix A.1 for a short note on the description of Christiano & Fitzgerald (2003) Band Pass Filter.



medium term between two to two hundred quarters. Since the dataset under study has only forty-three years of quarterly data (1968 to 2011), the upper limit for the band pass filter is taken as one hundred quarters. This medium term fluctuation of inflation has further been decomposed into high frequency, business cycle frequency and low frequency bands. The high frequency component is assigned the periodicity of two to six quarters. The business cycle frequency components are taken for six to thirty-two quarters, which is the standard measure found in the literature. Finally, the low frequency component is taken for the periodicity of thirty-two to one hundred quarters<sup>29</sup>.

### **Inference Procedure for Frequency Domain Analysis**

Volatility of inflation is evaluated by using the standard deviations of the filtered series, obtained from the Christiano-Fitzgerald filtering technique. The standard deviations of inflation in the medium term business cycle and its different frequency bands are observed for advanced and developing countries, both for the analytical group data and for sample countries. The analysis provides a summary of observations on the magnitude of the cyclical variations in inflation. Defining volatility by instantaneous standard deviation of the inflation series, it is examined if the inflation variability is statistically significantly higher for developing countries than developed countries, both at different data frequencies as well as for the overall medium term cycle. In this regard, F-test has been conducted. The research hypothesis is set up by:

$$H_0 : \sigma_A^2 = \sigma_D^2 \text{ vs } H_1 : \sigma_A^2 < \sigma_D^2 \dots\dots\dots (5)$$

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<sup>29</sup> Assenmacher-Wesche and Gerlach (2007) have defined low-frequency inflation as the variation in these time series with a periodicity of more than 8 years, i.e. more than 32 quarters.

Where, test statistic  $F$  is defined as:  $F = \frac{s_A^2}{s_D^2}$

This is a lower than type one tailed test. The null hypothesis will be rejected if:

$$F < F_{(1-\alpha, n_A-1, n_D-1)}$$

Where,  $\alpha$  is the level of significance,  $n_A$  and  $\sigma_A^2$  are the number of observations included in the sample and inflation variance of advanced economies group and  $n_D$  and  $\sigma_D^2$  are the number of observations included in the sample and inflation variance of developing economies group.

## **2.4 Empirical Analysis**

### **2.4.1 Stylised Facts of Inflation Volatility from Time Domain Analysis**

This sub-section presents the stylised facts of inflation volatility which are obtained from the time domain analysis. In the preceding section, three methods of time domain analysis are illustrated. For all three methods, results show that volatility of inflation is significantly greater for developing countries vis-à-vis advanced countries and elucidate the same as a key stylised fact of inflation volatility. Results and observations are summarised below in accordance with the methods discussed.

#### **Results from Method One: Testing of ARCH Effect in Inflation**

Following the analytical group data on Consumer Price Index (CPI) prepared and designed by the International Monetary Fund, inflation series are computed for advanced

and developing economies<sup>30</sup>. The monthly inflation data of advanced and developing countries are integrated at order one. Therefore, the series are made stationary by taking the first difference. Further, the presence of seasonality is checked from the plots of autocorrelation.

**Table 2.3: Results of ARMA Model & ARCH-LM Test**

Estimated Coefficients	Advanced Economies	Developing Economies
Constant	-3.98E-06	-5.79E-06
AR(1)	-0.594**	-0.385**
AR(2)	-0.326**	-0.241**
AR(3)	-0.129**	-0.113*
AR(4)	-	-0.158**
MA(1)	-0.926**	-
MA(12)	-	-0.973**
Adjusted R – square	0.724	0.513
Log-likelihood	1741.85	1680.585
Akaike info criterion	-6.68	-6.606
Schwarz criterion	-6.639	-6.556
DW Test Statistic	2.017	2.028
ARCH Effect ( $\gamma_1$ )	0.355**	0.488**
ARCH-LM Test statistic	74.717	158.199

The evidence of seasonality is found for the developing economies but not for the advanced group. After the seasonality check, ARMA models are fitted to depict the inflationary process of advanced and developing economies following the specification of Equation (1). Estimation results of the ARMA models and the subsequent ARCH-LM tests by Equation (2) are given in Table 2.3. The values of the adjusted R-square

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<sup>30</sup> These grouped level or aggregated data are prepared by taking the weighted geometric mean of CPI data for all the countries incorporated in the two groups. The share of GDP of each country to the total world GDP, valued at purchasing power parities (PPPs), is considered as the ‘weight’ of that country in its group for the construction of weighted average (Source: IMF website)

indicate a reasonable fit of the proposed model with the data. The coefficients of the ARMA models are statistically significant for both groups. It can be noticed that even after differencing for annual seasonality, MA(12) parameter for the group of developing economies is appearing significant. This can be caused by the persistence of transitory component of seasonality (Harvey, 1993). Presence of such component is, however, not contaminating the key results as the diagnostic check with the Durbin-Watson test statistic confirms stationarity of the residuals. Following the results of the ARCH-LM test, one can find strong evidence for the presence of the ARCH effect in the residuals for both the advanced and emerging economies inflation. However, it is important to note that the value of the estimated slope coefficient of equation (2), i.e. ' $\gamma_1$ ' is greater in developing economies than advanced economies. This clearly indicates that conditional variability of inflationary shocks is larger in developing countries than that of advanced countries. This unveils the fact that the ARCH effect or time-varying volatility is higher in the inflation process of developing countries than that of advanced group.

### **Results from Method Two: Estimation of GARCH (1, 1) Model for Inflation Volatility**

From method one, using the analytical group data it is noticed that the ARCH effect is strongly prevailing in the inflation series of both economies but higher for developing countries. To examine if such a distinguishing feature of inflation volatility is true for individual country level data, the GARCH (1, 1) model specified by Equations (3A) and (3B) has been estimated jointly for every single country included in the sample of

advanced and developing economies. The results of the GARCH estimation are reported in Table 2.4 (A & B) for advanced and developing economies respectively. Each section of the table contains three panels presenting the estimated values of ARMA coefficients, estimates of the variance equation parameters and the summary of regression results. In the summary, the main attributes of the regression result are enumerated, such as: number of observations, adjusted R-square, log-likelihood, information criteria, the Durbin Watson test statistic, and the ARCH-LM test statistic of the residuals. The prime concern of these results is the estimates of variance equations. The intercept term ( $\gamma_0$ ) of variance equation provides some intuition regarding the unconditional volatility; the ARCH coefficient ( $\gamma_a$ ) shows the conditional volatility, and GARCH coefficient ( $\gamma_g$ ) reveals the autoregressive persistence of conditional volatility of inflation for the respective country.

It is apparent from the results of Table 2.4 (A & B) that there is a clear difference in the sample proportions having statistically significant coefficients in variance equation between two sets of economies. To illustrate this point further, the following steps can be taken.

- i) The level of statistical significance for all estimated coefficients is set at 5%, i.e. if the p-value of each estimated coefficient is less than 0.05, the estimate will be considered as statistically significant. So, the level of significance serves as a 'cut-off point' for formulating the decision rule.

- ii) Given the 'cut-off point', the numbers of countries which have statistically significant estimated coefficients for each parameters of the variance equation are noted for the sample of advanced and developing countries. This helps to compute the sample proportion for both groups of economies with respect to the intercept term ( $\gamma_0$ ), the ARCH coefficient ( $\gamma_a$ ), and the GARCH coefficient ( $\gamma_g$ ).

**Table 2.4A**

**Results of GARCH (1, 1) Estimation:**

**Evidence from the Sample of Advanced Economies (1968M01 – 2011M09)**

**Estimated Coefficients of Mean Equation**

	<b>Austria</b>	<b>Belgium</b>	<b>Canada</b>	<b>Denmark</b>	<b>Finland</b>	<b>France</b>	<b>Germany</b>	<b>Italy</b>	<b>Japan</b>	<b>Norway</b>	<b>Switzerland</b>	<b>UK</b>	<b>US</b>
Constant	-7.4E-05	1.52E-07	-4.7E-07	3.0E-06	7.4E-07	-5.1E-07	6.2E-06	4.1E-06	-0.00015*	-1.3E-06	-3.3E-07	-6.2E-06	-1.7E-08
AR(1)	0.101*	-0.608**	-0.4**	-0.582**	-0.885**	-0.553**	-0.653**	-0.712**	0.106*	0.132*	-0.723**	-0.591**	-0.452**
AR(2)		-0.528**	-0.275**	-0.413**	-0.528**	-0.48**	-0.366**	-0.42**			-0.516**	-0.529**	-0.464**
AR(3)		-0.387**	-0.115**	-0.26**	-0.377**	-0.276**	-0.222**	-0.198**			-0.516**	-0.426**	-0.343**
AR(4)		-0.129**			-0.139**	-0.21**			0.095*	-0.131*	-0.378**	-0.435**	-0.312**
AR(5)				-0.129**		-0.178**		-0.136**	0.154**		-0.348**	-0.381**	-0.164**
AR(6)	0.098*							-0.132**	0.124**			-0.169*	-0.16**
AR(7)	0.137**												
AR(8)		-0.066									-0.09**		-0.088
AR(11)	0.148**		0.451**										0.09*
AR(12)	0.111*												
MA(1)		-0.038**	-0.501**	-0.129**		-0.084**	-0.299**			-0.916**		-0.286**	-0.045*
MA(2)					-0.084*				-0.025				
MA(3)		-0.039*											
MA(11)			-0.499**				-0.139**						
MA(12)	-0.755**	-0.923**		-0.752**	-0.802**	-0.832**	-0.562**	-0.764**	-0.796**	-0.844**	-0.746**	-0.671**	-0.871**
MA(13)										0.767**			

**Estimated Coefficients of Variance Equation**

$\gamma_0$	2.3E-06	5.64E-07	1.4E-06	2.9E-07	4.05E-07	7.4E-08	5.64E-07	5.74E-08	6.93E-08	2.3E-05**	3.25E-07**	3.66E-07	4.4E-07**
$\gamma_a$	0.06	0.053	0.069	0.055**	0.088**	0.033	0.056	0.137**	0.024**	0.043	0.078**	0.11**	0.181**
$\gamma_g$	0.668**	0.874**	0.83**	0.946**	0.887**	0.81**	0.856**	0.86**	0.966**	-0.25	0.897**	0.856**	0.766**
<b>Summary of Regression Results</b>													
Number of Observations	525	525	524	518	525	525	232	525	476	509	505	265	525
Adjusted R - Square	0.302	0.624	0.516	0.615	0.731	0.57	0.625	0.563	0.439	0.698	0.546	0.557	0.598
Log Likelihood	2323.442	2353.958	2186.927	2138.316	2184.396	2473.28	1050.22	2400.972	1983.329	2060.282	2191.114	1190.851	2431.291
Akaike Info Criterion	-8.813	-8.921743	-8.309	-8.217	-8.283	-9.38	-8.967	-9.108	-8.291	-8.060	-8.634	-8.897	-9.095
Schwarz Info Criterion	-8.732	-8.824294	-8.228	-8.135	-8.202	-9.291	-8.819	-9.027	-8.204	-7.985	-8.542	-8.735	-9.164
DW Test Statistic	1.981	2.027	1.905	2.046	2.155	2.01	2.102	1.857	1.89	2.106	1.96	1.905	1.904
ARCH-LM Test statistic	0.001	2.52	0.02	0.332	1.101	0.071	0.008	1.575	10.586**	0.0014	0.991	0.0066	0.0138



**Table 2.4B**

**Results of GARCH (1, 1) Estimation:**

**Evidence from the Sample of Developing Economies (1968M01 – 2011M09)**

Estimated Coefficients of Mean Equation													
	Bangladesh	Cambodia	China	India	Indonesia	Malaysia	Myanmar	Nepal	Pakistan	Philippines	Srilanka	Thailand	Vietnam
Constant	3.87E-04	7.2E-05	0.2E-05	-1.2E-05	0.0072**	-1.2E-05	5.5E-04	2.9E-04	0.2E-05	-0.000187**	8.4E-05	-0.00014**	0.00059**
AR(1)	0.222*	0.254*	-0.765**	0.372**	-0.177**	-0.59**	0.104	0.271**	-0.706**	0.555**	0.201**	0.236**	0.439**
AR(2)		0.21	-0.568**		0.085*	-0.364**			-0.453**				0.171*
AR(3)			-0.43**	0.106*	0.719**	-0.214**			-0.201**			0.208**	
AR(4)											0.118*		
AR(5)						-0.086*							
AR(8)							0.14**						
AR(11)			0.13**										
AR(12)	0.186**											0.1*	
AR(18)								-0.131**					
AR(23)			0.095*										
MA(1)		-0.113**	-0.115**	-0.019**	0.452**		0.127**		0.058**	-0.168**	0.074**		
MA(3)					-0.684**							-0.041*	
MA(12)	-0.944**	-0.887**	-0.828**	-0.95**		0.091**	-0.873**	-0.964**	-0.918**	-0.717**	-0.9**	-0.929**	-0.851
MA(23)										-0.114**			
Estimated Coefficients of Variance Equation													
$\gamma_0$	2.78E-06	1.27E-05*	1.6E-06**	6.2E-06**	1.3E-05**	5.9E-06**	0.000112**	3.6E-06**	5.3E-06*	1.01E-05**	3.54E-06*	2.11E-06**	4.7E-06**

$\gamma_a$	0.005	0.128*	0.0914**	0.13**	0.191**	0.549**	0.402**	0.111**	0.148**	0.328**	0.012*	0.13**	0.461**
$\gamma_g$	0.933**	0.794**	0.862**	0.76**	0.74**	0.342**	0.553**	0.854**	0.788**	0.613**	0.965**	0.816**	0.453**
<b>Summary of Regression Results</b>													
Number of Obs.	193	188	334	504	520	502	477	484	491	505	504	494	185
Adjusted R Square	0.408	0.496	0.738	0.573	0.15	0.258	0.475	0.515	0.62	0.6	0.463	0.512	0.678
Log Likelihood	682.629	569.501	1271.715	1779.942	1582.456	1988.848	1092.478	1560.546	1649.03	1746.331	1522.787	1859.295	719.266
Akaike Info Criterion	-7.001	-5.973	-7.549	-7.032	-6.052	-7.888	-4.547	-6.42	-6.68	-6.884	-6.011	-7.491	-7.7
Schwarz Info Criterion	-6.883	-5.836	-7.424	-6.964	-5.978	-7.812	-4.477	-6.359	-6.603	-6.817	-5.944	-7.415	-7.578
DW Test Statistic	2.019	1.919	1.944	1.934	2.248	1.999	2.067	2.348	2.106	1.9	2.011	1.93	1.853
ARCH-LM Test: F statistic	1.192	0.812	1.153	0.029	1.108	0.509	0.089	3.593	1.6	0.0005	0.593	0.579	0.001

Note: ‘\*’ denotes statistical significance at 5% and ‘\*\*’ denotes statistical significance at 1% level.

- iii) Based on the sample proportions of advanced and developing economies with statistically significant estimated values of parameters of the variance equations, the difference in the population proportion can be inferred using simple Z-statistic. Such inference enables us to draw conclusion regarding the distinguishing feature of inflation variability between advanced and developing economies.

**Table 2.5**

**Observation based on Sample Proportion**

**(Using Statistically Significant Coefficients of Conditional Variance Equation)**

	<i>Intercept Term</i>	<i>ARCH Coefficient</i>	<i>GARCH Coefficient</i>
Advanced Countries	0.231	0.538	0.923
Developing Countries	0.923	0.923	1.000
Difference of sample proportion	-0.692	-0.385	-0.077
Z-statistic for difference of sample proportion	-3.57	-2.12	-1.02
P-value	0.0002	0.0135	0.1539

The procedure laid out above can be perceived as a variant of meta-analysis. Meta-analysis employs the statistical methods to combine the results of individual studies. Such method allows us to make the best use of all the information gathered from a systematic review by increasing the precision of estimates and power of the analysis. Similar to such analysis, our procedure also takes into account the individual outcome of GARCH (1, 1) model for each country included in the sample and based on that, it draws the conclusion. Following Table 2.4 which contains the results for individual countries from the GARCH (1, 1) estimation, Table 2.5 has been constructed to shed light on the proportional difference in inflation volatility between advanced and developing countries.

In Table 2.5, the sample proportion with statistically significant estimates for advanced and developing countries and their corresponding differences are presented. Such differences are exploited in order to conclude whether developing economies experience more volatility in inflation than the advanced group. Under the assumption of simple random sampling and normally distributed population, less than type hypothesis testing is conducted for the null hypothesis of zero difference against the research hypothesis of negative difference in population proportion. Subsequently the Z-statistics are computed and respective P-values are observed. These are also provided in the last two rows of Table 2.5. Results of this simple hypothesis tests show that the estimated variance equations are significantly different with respect to the intercept term and conditional volatility, but not in autoregressive persistence. In other words, the level of unconditional volatility and time-varying volatility – both are statistically significantly higher in developing countries than that of advanced countries. However, the nature of persistence of volatility is not substantially different.

This above conclusions highlight the striking difference in the inflation variability between the two groups of economies and emphasise that inflationary shocks have a more pronounced impact for the developing economies. Overall, results obtained from the country-level data analysis confirm substantial difference in inflation volatility between the two groups of economies. The sum of the ARCH and the GARCH coefficients remains nearly or less than unity for all the economies and replicates stationarity and stability of inflationary variance.

### **Results from Method Three: Panel Estimation for Measuring Persistence of Inflation Volatility**

Empirical analysis, by now, has put forward the evidence for greater inflation volatility in developing countries than advanced group. In addition to this evidence, research has been extended to look at the difference in long run conditional variability of inflation and the persistence of this variability. Studies available in the existing literature are mostly concerned about the persistence at first order moment of inflation. In contrast, this method for panel estimation of autoregressive model is simple but informative regarding the nature of second order persistence of inflation dynamics.

To conduct this method, the estimated GARCH series of inflation from the second method are used to construct the series of inflation variance country by country for the panel dataset. Taken together the inflation variance series for thirteen advanced countries during the time period of M10, 1992 to M08, 2011, a balanced panel is prepared. Repeating the exercise for the sample of developing countries, another balanced panel is made for the time period of M10, 1996 to M04, 2011. Using panel GMM estimation, equation (4) is estimated on the GARCH series of inflation. The results of estimation are reported in Table 2.6 (A & B). Assigning Two Stage Least Squares weighting matrix with cross section weights, the country specific fixed effect in volatility and the persistence are estimated. For estimation, lagged values of the GARCH series of inflation are used as instruments.

**Table 2.6A: Persistence of Inflation Volatility - Advanced Economies**

**Results from Dynamic Panel Estimation**

Dependent Variable: $\hat{h}_{i,t}$				
Method: Panel GMM EGLS (Cross-section weights)				
Date: 09/19/12 Time: 11:27				
Sample (adjusted): 1992M10 2011M08				
Periods included: 227				
Cross-sections included: 13				
Total panel (balanced) observations: 2951				
2SLS instrument weighting matrix				
Linear estimation after one-step weighting matrix				
Instrument specification: C $\hat{h}_{i,t-2}$ $\hat{h}_{i,t-3}$				
Constant added to instrument list				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
$\delta_i$	6.50E-07	6.52E-08	9.974804	0.0000
$\hat{h}_{i,t-1}$	0.924427	0.007469	123.7646	0.0000
Effects Specification				
Cross-section fixed (dummy variables)				
Weighted Statistics				
R-squared	0.949670	Mean dependent var	1.48E-05	
Adjusted R-squared	0.949447	S.D. dependent var	8.47E-06	
S.E. of regression	1.41E-06	Sum squared resid	5.82E-09	
Durbin-Watson stat	2.068052	J-statistic	0.036934	
Instrument rank	15	Prob(J-statistic)	0.847600	
Unweighted Statistics				
R-squared	0.922998	Mean dependent var	8.63E-06	
Sum squared resid	5.83E-09	Durbin-Watson stat	2.250512	

**Table 2.6B: Persistence of Inflation Volatility - Developing Economies**

**Results from Dynamic Panel Estimation**

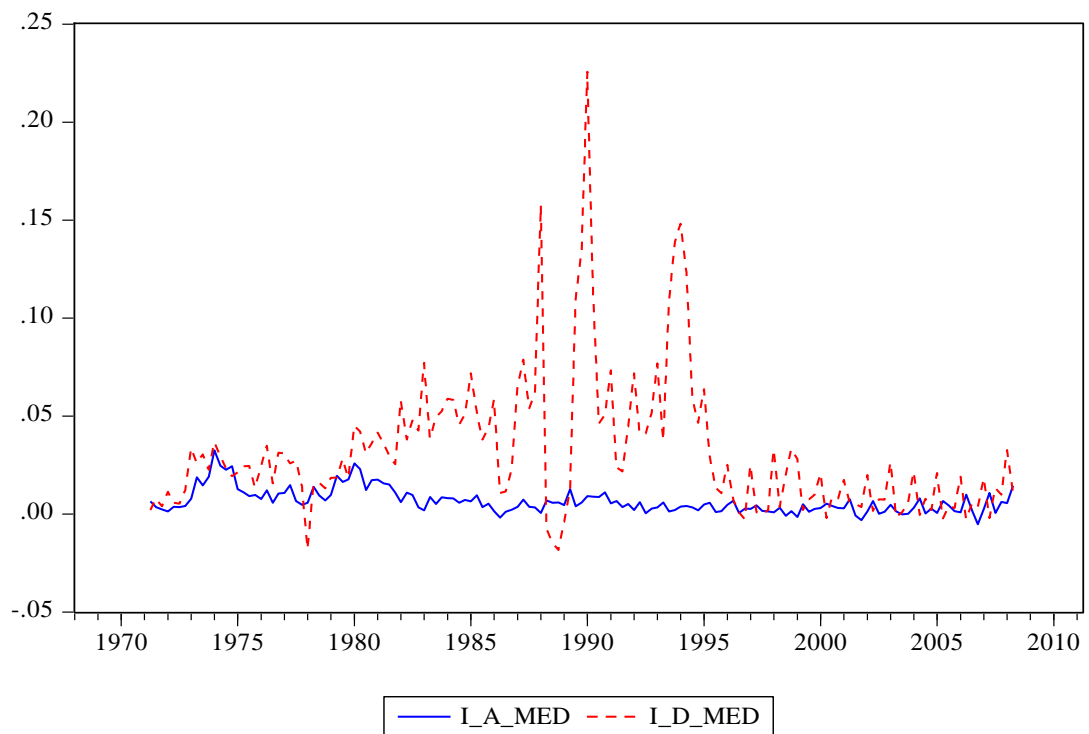
Dependent Variable: $\hat{h}_{i,t}$				
Method: Panel GMM EGLS (Cross-section weights)				
Date: 09/19/12 Time: 11:22				
Sample (adjusted): 1996M10 2011M04				
Periods included: 175				
Cross-sections included: 13				
Total panel (balanced) observations: 2275				
2SLS instrument weighting matrix				
Linear estimation after one-step weighting matrix				
Instrument specification: C $\hat{h}_{i,t-4}$ $\hat{h}_{i,t-5}$				
Constant added to instrument list				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
$\delta_i$	8.11E-06	1.01E-06	8.037706	0.0000
$\hat{h}_{i,t-1}$	0.930891	0.008610	108.1234	0.0000
Effects Specification				
Cross-section fixed (dummy variables)				
Weighted Statistics				
R-squared	0.992810	Mean dependent var	0.001208	
Adjusted R-squared	0.992769	S.D. dependent var	0.002279	
S.E. of regression	9.76E-05	Sum squared resid	2.15E-05	
Durbin-Watson stat	2.177967	J-statistic	2.310693	
Instrument rank	15	Prob(J-statistic)	0.128487	
Unweighted Statistics				
R-squared	0.756964	Mean dependent var	0.000117	
Sum squared resid	2.31E-05	Durbin-Watson stat	2.161050	

Results show that country specific effects and the autoregressive coefficients are statistically significant. The p-value of the J-statistic implies the validity of the instruments chosen for estimation. It is worth noting that the estimate of country specific fixed effect ( $\hat{\delta}$ ) is found to be larger for developing countries than advanced countries, however, it remains nearly same in the case of volatility persistence( $\hat{\rho}$ ). Given the values of estimates, long run level of conditional volatility of inflation, i.e.,  $\left(\frac{\hat{\delta}}{1-\hat{\rho}}\right)$ ; can be computed. For advanced and developing economies, it is 8.6E-06 and 1.2E-04 respectively. From these results it can be seen that in the long run, time-varying variability of inflation is thirteen to fourteen times greater for developing economies than that of the advanced group. This firmly establishes the initial observation made in Figure 1 (A & B) that inflation in the developing countries is substantially more volatile than the advanced countries. Moreover, as the difference in inflation volatility is greater in terms of country specific effects than the autoregressive coefficients, it seems that difference in the long run inflation variance between advanced and developing countries is driven by country specific factors. It can be perceived that these factors emanate from the structural differences between advanced and developing economies such as differences in productivity or preference pattern. Besides, inflation volatility experience is more diverse for developing countries than developed countries, i.e., stronger heterogeneity exists within the group of developing economies than the advanced economies.

### 2.4.2 Stylised Fact of Inflation Volatility by Frequency Domain Analysis

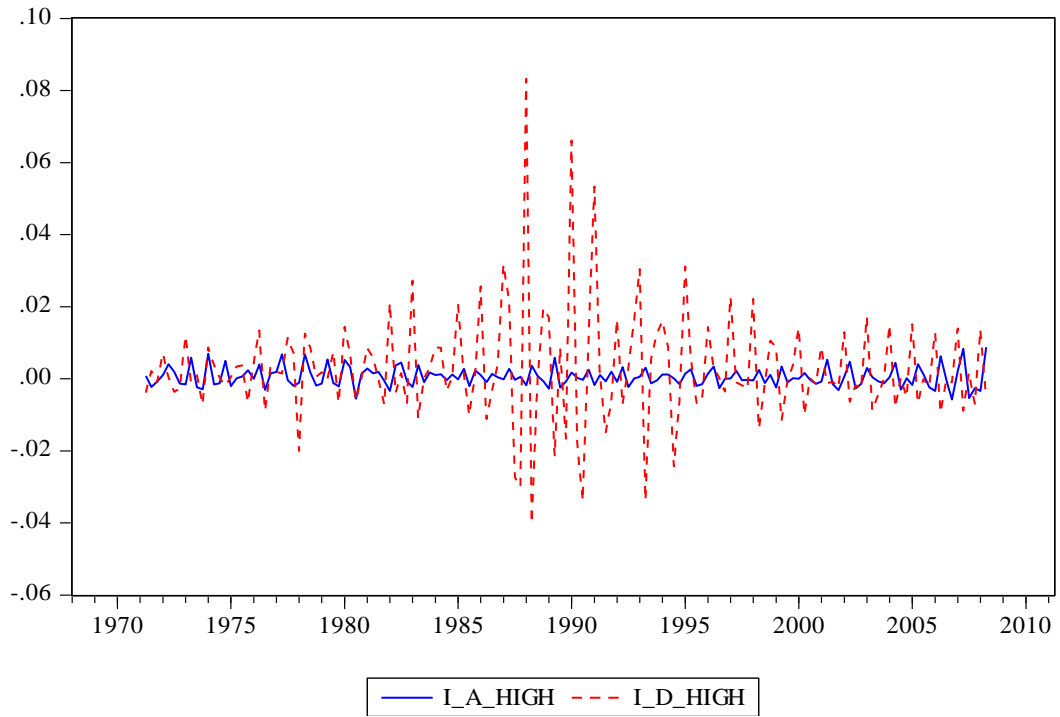
In frequency domain analysis, the symmetric type band pass filter is used over the quarterly CPI inflation data during the period of 1968 to 2011 for the analytical group level data as well as the data for each of the thirty countries chosen in the samples of advanced and developing groups. First, the medium term business cycle component has been extracted and then decomposed into three different bands of frequency, namely, high frequency, standard business cycle frequency and low frequency for analytical group level data and for individual countries included in the sample. The filtered series of medium term cycle, high frequency, standard business cycle frequency and low frequency which are obtained from the analytical group data are depicted in Figure 2.2 (A to D) respectively.

**Figure 2.2A: Plots of Medium Term Business Cycle**

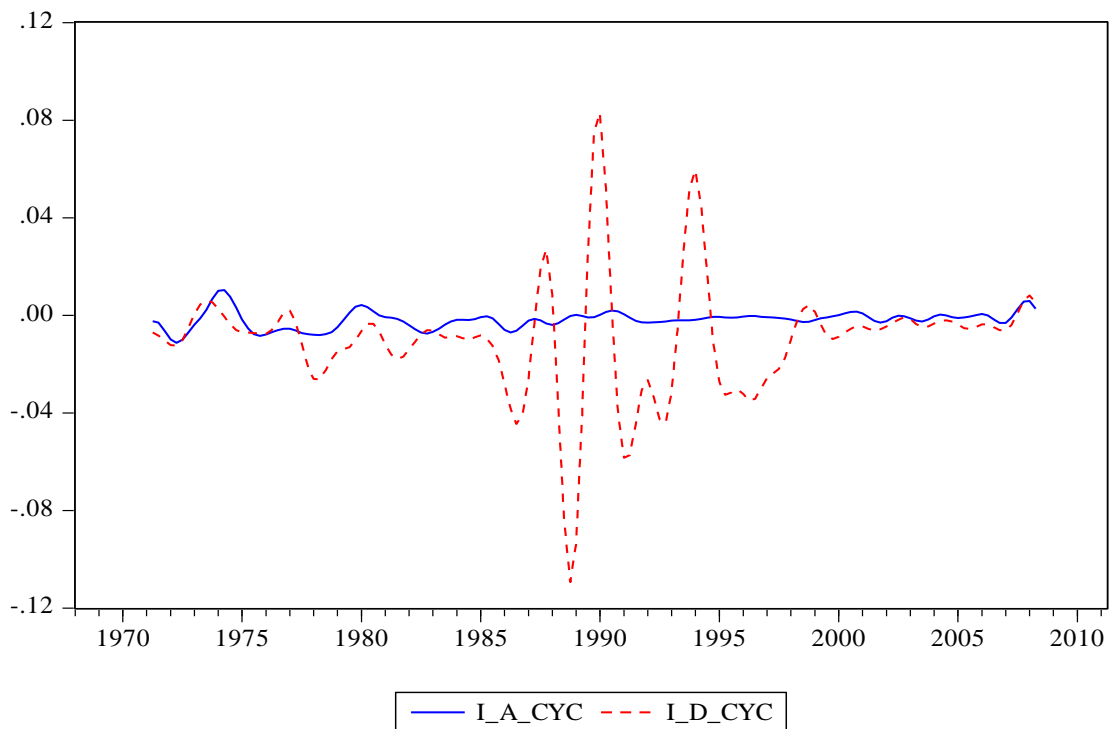




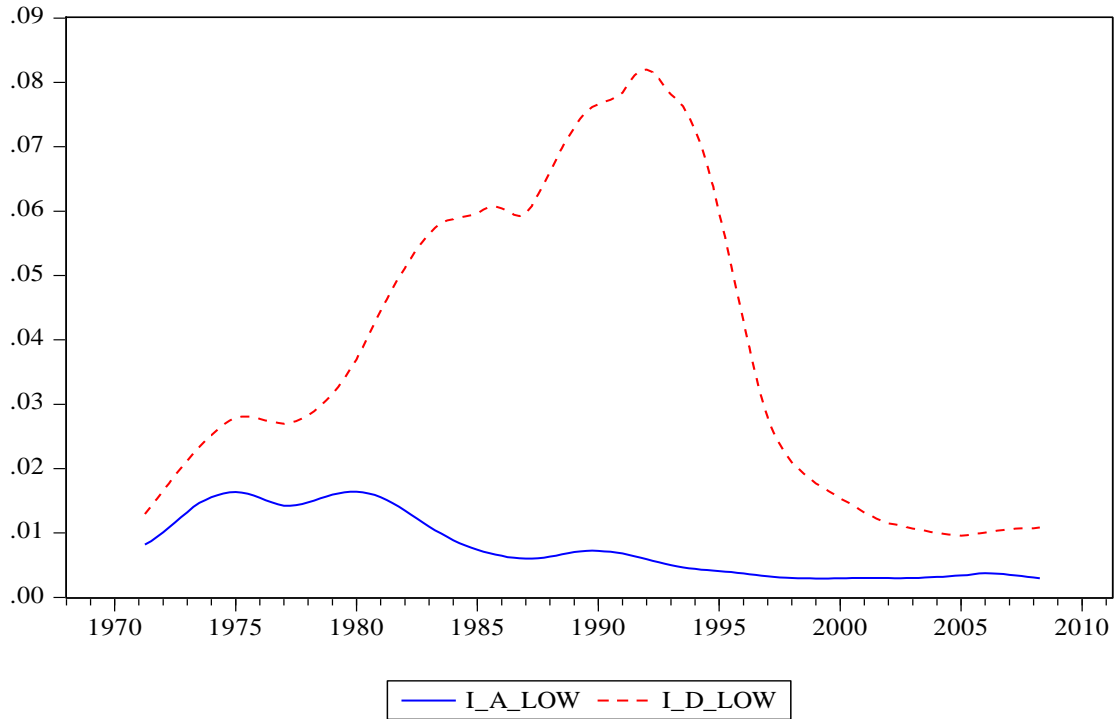
**Figure 2.2B: Plots of High Frequency Components**



**Figure 2.2C: Plots of Standard Business Cycle Components**



**Figure 2.2D: Plots of Low Frequency Components**



From Figure 2.2(A to D), it is prominent that irrespective of the bands of periodicity or across different frequencies the magnitude of the cyclical variations in inflation is clearly larger for developing countries than for advanced countries. Typically, during the period between the middle of the 1980's to the end of the 1990's, inflation in developing economies had considerably large swings, high amplitude of cycles and fluctuations. In contrast, inflation in advanced countries remained low and stable. Researchers<sup>31</sup> argue that inflation has been moderated in advanced countries like the US, the UK and EU countries due to improved monetary policy management. Monetary policy changes significantly from its accommodative stance to active inflation targeting and stabilises inflationary expectations to remove the source of economic instability. However, developing economies did not experience the same.

<sup>31</sup> See e.g. Taylor (1999), Clarida et al. (2000), Lubik and Schorfheide (2004).

The observation based on Figure 2.2 (A to D) gains support from the conventional statistical tests. Applying the tools of descriptive statistics, inflation volatility is defined by instantaneous standard deviation and computed from the filtered inflation series of the advanced and developing countries data. Then, the null hypothesis of equal inflation variance is tested against the alternative of higher inflation variability for developing countries. The test is done by standard F-test procedure. Comparing the computed F-statistic with its theoretical value, it is found that null hypothesis can be rejected in all cases at the 1% level of significance. This re-emphasises the fact that inflation variability is statistically significantly higher in the developing countries than the developed countries, both at different data frequencies and for medium term cycle. In Table 2.7 (A to D), the values of inflation volatility are enumerated corresponding to different cyclical components and frequency bands, followed by the calculated F-test statistic for analytical group data and for the individual samples of advanced and developing countries.

**Table 2.7A: Comparison of Inflation Volatility from Analytical Group Level Data**

Data Frequency	Advanced	Developing	Observations	Computed F- statistic
Medium term Cycle	0.0074	0.0217	149	0.116**
High	0.0046	0.0147	149	0.098**
Business Cycle	0.0037	0.0135	149	0.075**
Low	0.0045	0.0054	149	0.694**

*Note: Computed F-statistic, significant at 1% level are given by '\*\*',<sup>32</sup>*

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<sup>32</sup> Critical Value of F distribution for less than type one tailed test with degrees of freedom at numerator equals to 148 and denominator equals to 148 is 1.468 at 1% level of significance.

**Table 2.7B: Sample of Advanced Countries - Inflation Volatility from Frequency Filter**

Countries	Observations	Medium Term Cycle	High Frequency	Business Cycle Frequency	Low Frequency
Austria	149	0.0066	0.0054	0.0025	0.0030
Australia	149	0.0091	0.0058	0.0048	0.0055
Belgium	149	0.0064	0.0034	0.0035	0.0041
Canada	149	0.0067	0.0039	0.0034	0.0046
Denmark	149	0.0088	0.0062	0.0041	0.0054
Finland	149	0.0087	0.0048	0.0039	0.0065
France	149	0.0067	0.0029	0.0033	0.0059
Germany	57	0.0034	0.0030	0.0016	0.0005
Italy	149	0.0102	0.0044	0.0056	0.0083
Japan	149	0.0105	0.0074	0.0067	0.0057
Norway	149	0.0082	0.0057	0.0041	0.0049
New Zealand	149	0.0110	0.0055	0.0068	0.0076
Switzerland	149	0.0069	0.0050	0.0032	0.0031
UK	69	0.0068	0.0059	0.0021	0.0016
US	149	0.0065	0.0037	0.0040	0.0037

**Table 2.7C: Sample of Developing Countries - Inflation Volatility from Frequency Filter**

Countries	Observations	Medium Term Cycle	High Frequency	Business Cycle Frequency	Low Frequency
Bangladesh	47	0.0128	0.0111	0.0051	0.0023
Cambodia	42	0.0258	0.018	0.0165	0.0046
China	98	0.0090	0.0047	0.0046	0.0068
Fiji	144	0.0133	0.0115	0.0066	0.0051
India	149	0.0217	0.0158	0.0131	0.0037
Indonesia	149	0.031	0.0177	0.0229	0.0073
Malaysia	149	0.0093	0.0054	0.0063	0.003
Myanmar	141	0.0466	0.0326	0.0308	0.0124
Nepal	148	0.0307	0.0274	0.0121	0.0036
Pakistan	149	0.0187	0.0136	0.0104	0.0053
Philippines	149	0.025	0.0128	0.0198	0.007
Papua New Guinea	135	0.0195	0.0151	0.0103	0.0042
Srilanka	148	0.0199	0.0135	0.0131	0.0043
Thailand	149	0.0133	0.0073	0.0092	0.0049
Vietnam	41	0.019	0.0116	0.012	0.0056

**Table 2.7D: Inflation Volatility Obtained from Pooled Standard Deviation based on Sample**

Data Frequency	Advanced Countries	Developing Countries	Computed F- statistic
Medium Run	0.0082	0.0238	0.119**
High	0.0051	0.0167	0.092**
Business Cycle	0.0044	0.0151	0.084**
Low	0.0053	0.006	0.789**

*Note: Computed F-statistic, significant at 1% level are given by '\*\*',<sup>33</sup>.*

In sum, defining volatility by instantaneous standard deviation of the filtered inflation series, it is found that inflation volatility is statistically significantly higher for the developing countries than the developed countries, both at different data frequencies and as well as for the overall medium term cycle<sup>34</sup>. Thus, it appears that the stylised fact of inflation volatility is robust for both the time and frequency domain analysis. Irrespective of analytical perspective and methodology, this empirical observation holds.

## **2.5 An Evaluation of Welfare Cost of Inflation Volatility by Central Bank's Loss Function**

So far, the empirical regularities of inflation volatility have been analysed. In this section, an evaluation of the welfare consequences of the observed regularities is provided. Following the New Keynesian paradigm, a framework of the Central Bank's Loss Function is considered to assess the welfare loss due to inflation volatility in

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<sup>33</sup> Critical Value of F distribution for less than type one tailed test with degrees of freedom at numerator equals to 2048 and denominator equals to 1838 is 1.124 at 1% level of significance.

<sup>34</sup> In fact, developing countries show greater inflation volatility at all frequencies. This claim is further substantiated by comparing the spectrum of these two groups of countries as seen in Figure A.1 presented in the Appendix A.1.

developing countries relative to advanced countries. The underlying structural model of the loss function is borrowed from Chapter 3 of Gali (2008), where economy is featured by imperfect goods market with Calvo-type price adjustment of firms. Further, in the Appendix of Chapter 4 of Gali (2008), the average welfare loss per period of a central bank is derived from the second order approximation of utility losses experienced by the representative consumer as a consequence of deviations from the efficient allocation. The welfare based loss function provided by Gali (2008) is defined in (6.1).

$$\mathbb{L} = \omega_y var(\tilde{y}_t) + \omega_\pi var(\pi_t) \dots\dots\dots (6.1);$$

Where,  $\tilde{y}_t$  is output gap,  $\pi_t$  is inflation,  $\omega_y$  is the weight of output gap variance and  $\omega_\pi$  is the weight of inflation variance in the loss function. These weights consist of several structural parameters and according to Gali (2008), they are defined as:

$$\omega_y = \left[ \frac{1}{2} \left\{ \sigma + \left( \frac{\varphi + \alpha}{1 - \alpha} \right) \right\} \right] \dots\dots\dots (6.2)$$

$$\omega_\pi = \left[ \frac{1}{2} \left\{ \frac{\varepsilon \theta (1 - \alpha + \alpha \varepsilon)}{(1 - \theta)(1 - \beta \theta)(1 - \alpha)} \right\} \right] \dots\dots\dots (6.3)$$

Following Gali (2008) and Woodford (2003), derivation of the loss function for central bank (given by the Equation 6.1, 6.2, and 6.3) is shown in Appendix A.15. The structural parameters are defined in Table 2.8A. Exploiting the loss function of the central bank, the respective weights of output gap and inflation variance are modified into their relative shares and specified in (6.4) as:

$$\mathbb{L} = \varpi_y^j var(\tilde{y}_t) + \varpi_\pi^j var(\pi_t) \dots\dots\dots (6.4); \quad j = \textit{Advanced, Developing}$$

Where,  $\varpi_y^j = \left( \frac{\omega_y}{\omega_y + \omega_\pi} \right) \dots\dots\dots (6.5)$

$$\bar{\omega}_{\pi}^j = \left( \frac{\omega_{\pi}}{\omega_y + \omega_{\pi}} \right) \dots\dots\dots (6.6)$$

**Table 2.8A: Structural Parameterization for Advanced and Developing Economy**  
**Relative Weights for Welfare Loss Function**

<i>Structural Parameters</i>		<i>Advanced</i>	<i>Developing</i>
$\sigma$	Relative risk aversion coefficient	1.85	2.14
$\varphi$	Frisch Elasticity of Labour Supply	5	6
$\alpha$	Measure of Decreasing Returns	0.36	0.38
$\varepsilon$	Elasticity of Demand	7.17	7.01
$\theta$	Index of Price Stickiness	0.67	0.57
$\beta$	Discount Factor	0.99	0.98
$\bar{\omega}_y^j$	Relative weight of Output Gap Variance in Loss Function	0.503	0.598
$\bar{\omega}_{\pi}^j$	Relative weight of inflation Variance in Loss Function	0.497	0.402

**Table 2.8B: Volatility of Inflation and Output Gap**  
**Sample Period: 1968, Q2 – 2011, Q4**

<i>Data Frequency</i>	<i>Advanced</i>		<i>Developing</i>	
	Inflation	Output Gap	Inflation	Output Gap
Medium Term Cycle	0.006	0.144	0.036	0.265
High	0.003	0.015	0.016	0.028
Business Cycle	0.004	0.047	0.024	0.088
Low	0.005	0.175	0.024	0.325

According to the microstructure provided by Gali (2008), it can be seen from (6.2) and (6.3) that  $\omega_y$  and  $\omega_{\pi}$  are ‘given’ to the central bankers depending on the structure of respective economies. Estimates of the structural parameters, therefore, are required for both advanced and developing countries to compute the weights of inflation and output gap variance in their corresponding loss functions. From the existing DSGE literature (Gabriel et al., 2011, Gali, 2005) estimates of the structural parameters are assimilated

and presented in Table: 2.8A. Since the objective is to compare the share of welfare loss between advanced and developing economy due to inflation volatility, two different sets of parameters are considered for the hypothetical structure of an advanced and a developing economy. Based on these parameterizations, first, the absolute weights and then their shares in the total weight in the welfare loss function are computed for advanced and developing countries. So, sum of the relative shares of  $\overline{\omega}_y^j$  and  $\overline{\omega}_\pi^j$  is equal to one for each economy. For the purpose of welfare cost evaluation, the group level data on GDP volume index and CPI inflation for the period of 1968, Q2 to 2011, Q4, are considered for advanced and developing economies. After logarithmic transformation of the raw data, Christiano-Fitzgerald (2003) symmetric type band pass filter is used to generate the series of output gap and inflation for medium term cycle, high frequency, standard business cycle and low frequency.

Using (6.4), one can obtain the output equivalent welfare loss ( $\mathbb{L}_y$ ) incurred due to inflation volatility. See Appendix A.15, equation (A.15.20) for the analytical form of the output equivalent welfare loss. It can be defined as:

$$\mathbb{L}_y = -\left(\frac{1-\alpha}{\alpha}\right) \overline{\omega}_y^j var(\tilde{y}_t) + \overline{\omega}_\pi^j var(\pi_t) \dots\dots\dots (6.7)$$

From these series of different frequencies and over the cycles, volatility of output gap and inflation are calculated by simple instantaneous variance. Results of inflation and output gap variances are shown in Table 2.8B. It is noticeable that inflation and output gap are both more volatile for the developing countries than the advanced countries. Further, relative weights of inflation and output gap variability in the loss function of central banks are available from last two rows of Table 2.8A. Inserting the results of



variances and the relative weights of output gap and inflation into Equation (6.7), the output equivalent loss of welfare for the central banks of advanced and developing countries are calculated corresponding to each data frequency. Finally, the percentage of output loss due to volatility of inflation are worked out for each economy and presented in Table 2.8C.

**Table 2.8C: Output Equivalent Welfare Cost from Central Bank's Loss Function (in %)**

Data Frequency	<i>Advanced Economy</i>	<i>Developing Economy</i>
Medium Term Cycle	13.4	28.2
High	1.6	3.8
Business Cycle	4.6	10.2
Low	16.1	33.3

From Table 2.8C, it can be observed that across the different frequencies, share of welfare cost incurred by the central bank of developing countries due to inflation volatility is strictly higher than the same of advanced economies. Overall, comparison in terms of percentages of output equivalent welfare loss shows that inflation volatility causes approximately two to two and half times greater welfare cost for the developing countries.

Thus, it is evident that greater variability in inflation causes a greater magnitude of welfare cost for developing countries relative to advanced countries. This measure of welfare cost highlights the severity of inflation volatility as a major economic problem and calls for further research on this issue.

## 2.6 Conclusion

The chapter aims to study the empirical features of inflation variability with reference to advanced and developing economies. Primarily, the difference in the inflationary process of two prototype economies, advanced and developing, motivates to look into their volatility component. Following primary observations, a thorough investigation is undertaken over the monthly and quarterly CPI data during the period 1968 to 2011, using time and frequency domain analysis respectively. It is observed that the nature of volatility is an innate trait that can create striking difference in inflation dynamics between advanced and developing countries. All through this analysis, results show the stylised fact that inflation in developing countries is highly volatile than their advanced counterparts. In time domain analysis, the ARCH-LM test shows that the ARCH effect is much stronger for the developing countries in the analytical group data of inflation. Estimation of the GARCH (1, 1) model on the sample of advanced and developing countries indicates that the proportion of developing economies affected by volatile inflation is significantly higher than that of advanced economies. Controlling the country-specific heterogeneity by introducing a panel data structure of estimated conditional variance obtained from GARCH (1, 1), an autoregressive model is estimated which unveils that even in terms of long run volatility inflation in developing countries is approximately thirteen to fourteen times greater than in advanced economies. The observations obtained from the time domain analysis are supported by findings from frequency domain analysis. Using a purely descriptive method of statistics for inflation variance and F-test statistic, it is noticed that the attribute of volatility is quite predominant for developing economies over the medium term cycle and across the

different segments of frequency in the time series process of inflation. As a whole, the empirical analysis substantiates the robustness of the stylised fact on inflation volatility. In addition to empirical analysis, welfare consequence of the stylised fact of greater inflation volatility in developing economies has been examined relative to advanced economies. It is found that greater volatility of inflation results in approximately two to two and half times greater welfare loss for the central bank of developing countries than advanced countries. Such a high welfare cost of inflation volatility underscores the significance of the stylised fact and emphasizes the worthiness of the same as a research problem.

The empirical regularities observed in this chapter have not received sufficient attention in the current literature<sup>35</sup>. Existing research has studied inflation variability / uncertainty by different models of volatility but overlooked the striking difference in inflation variability between advanced and developing economies. Particularly, during the period of post 1980's in which inflation becomes moderated in advanced countries, developing countries experienced diametrically reverse dynamics of inflation. A large body of empirical literature has investigated the sources of the Great Moderation in different ways. For example, better monetary policy (Clarida et al., 2000; Lubik and Schorfheide, 2004), structural changes in inventory management (Kahn et al., 2002), smaller macroeconomic shocks (Stock and Watson, 2002; Sims and Zha, 2006) and endeavoured to explain the inflation stability observed since the end of the 1980s. Much less effort has been given to study the high and volatile inflation process of developing

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<sup>35</sup> A study done by Edmonds and So (1993) considers inflation variability for developed and developing economies together.

countries. As pointed out by Fielding (2008), “While studies on the determinants of inflation are abundant in the literature, scholars have not yet extensively investigated the causes of inflation volatility - surprisingly so, given its potential ill effects on growth”. The stylised fact of greater inflation volatility in developing countries than developed ones has not been treated seriously in the literature, empirically nor theoretically, even when it is costly for economic welfare. Therefore, this thesis now intends to investigate why is inflation more volatile in developing countries than in developed countries? Is this because of the inability of monetary policy to stabilise the economy or because of the structural differences between advanced and developing or both? Answers to these questions are sought in the forthcoming chapters.

## **Chapter Three**

# **Inflation Volatility: Estimating Monetary Policy Activism by Taylor Rule**

### **3.1 Introduction**

The previous chapter substantiates the stylised fact of greater inflation volatility in developing countries over advanced countries. Such difference in inflation volatility between two groups of economies casts doubt on the role of monetary authorities in developing countries compared to advanced countries. The immediate question arises of whether this phenomenon is an upshot of inadequate management of monetary policy. If the response of monetary authorities to inflationary fluctuations is strong enough, i.e. if monetary policy targets inflation aggressively, one can observe a more stable inflation rate in the economy and vice versa. So, a possible hypothesis for the greater volatility of inflation can be that the monetary authorities in developing economies are not aggressively fighting inflation as it is done by the central banks of advanced economies. Difference in the magnitude of inflation targeting in the policy frameworks between advanced and developing economies can make significant difference to the variability of inflation. Therefore, this chapter aims to examine whether inflation is aggressively targeted in the monetary policy and plans to undertake this task by estimating the Taylor rule for advanced and developing economies.

Taylor type interest rate rule has gained extensive support in the macroeconomic literature for modelling the monetary reaction function. Although it is contentious whether the Taylor rule is classified as a policy rule or discretion, but using such rule one can distinguish between ‘active’ and ‘passive’ monetary policy. In addition, this rule has crucial implication for the theoretical models of Old and New Keynesian paradigm. In a standard New Keynesian model, inflation and its variability – are both monotonically decreasing function of inflation coefficient of the Taylor type monetary reaction function<sup>36</sup>. Policy parameter of inflation in the Taylor rule critically determines the stability of inflation dynamics. Depending on the nature of monetary policy, whether it is active or passive, the issue of inflation stability is resolved. According to the New Keynesian doctrine, active monetary policy should react to inflation by adjusting the policy interest rate more than one-to-one. The key point is that if the coefficient of inflation in the monetary reaction function takes value of more than one, it implies that the monetary policy is active and is aggressively targeting to curb inflationary fluctuation by adjusting the real interest rate in the economy. On the other hand, if the policy parameter of inflation is less than one, it implies ‘passive’ monetary policy which only accommodates the inflation but cannot stabilise its pressure. This conjecture on monetary policy explains eloquently the case of inflation stabilisation in the US economy during the period of Great Moderation and fits well with the features of the data<sup>37</sup>.

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<sup>36</sup> See Sims (2008).

<sup>37</sup> See Clarida *et al.* (2000).

Following this conventional wisdom, this chapter has been motivated to study the activism of monetary policy of the developing economies in comparison to the advanced economies assuming that short term interest rate is the policy instrument of monetary authority. The Taylor type interest rate rule is estimated for developing and advanced economies given the research hypothesis that the estimate of inflation coefficient is larger than one. Due to Cochrane's (2007) criticisms on determinacy and identification, the simplest form of the Taylor rule has been estimated following the structure provided by Henry, Levine & Pearlman (2012). Such simple rule ensures determinacy for that particular class of model, overcomes the problem of identification, and provides the framework for strict inflation targeting. After estimating the simple form, interest rate reaction function has been extended to its generalised version which considers output gap stabilisation and interest rate smoothing in addition to inflation stabilisation. This generalised version of Taylor rule may be identified in a richer theoretical framework which is beyond the scope of this chapter.

For the empirical investigation, quarterly data are collected on three major macroeconomic variables, namely, short term nominal interest rate, inflation rate and aggregate output for thirteen advanced and six Asian developing countries as sample from the database of International Financial Statistics. The quarterly data are selected to obtain the business cycle movement from the series of output as well as of inflation. This enables us to examine how central banks in advanced and developing countries are responding to the cyclical variations of inflation and output and if there exists any significant difference in the policy rule parameters between their monetary reaction

functions. To compare the policy rule parameters of monetary reaction function, the Taylor rule is estimated based on two sets of panel data. One is for developed countries and the other is for developing countries. Motivation for considering panel data is to control the unobserved heterogeneity across the countries belonging to one particular group. Moreover, the sample of advanced countries includes some of the economies which have joined the Euro zone during the period of study. Therefore, they share the common monetary policy and hence, the same Taylor rule applies. The sample period of balanced panel for developed countries starts from 2<sup>nd</sup> Quarter of 1991 and ends at 2<sup>nd</sup> Quarter of 2011. On the other hand, sample period of balanced panel for developing countries include data from 1<sup>st</sup> Quarter of 1997 to 1<sup>st</sup> Quarter of 2011. At the outset, the Panel GMM estimation technique is applied and thereafter, the Arellano and Bover (1995) method of dynamic panel estimation is used to estimate the policy parameters for simple or baseline model and generalised model respectively. All through the investigation, it is found that inflation is actively targeted by the monetary authorities of the advanced countries but not by those in the developing economies. The difference is so striking that the inflation stabilising coefficient turns out substantially greater than one for the advanced group and remains much below than the same for developing economies. This finding strengthens the argument for the research hypothesis that the policy authorities in developing economies tend to accommodate with inflationary pressure passively and therefore, fails to stabilise the inflation. This chapter concludes by stating that such a shortcoming on the part of monetary policy-makers in developing economies may be one of the reasons to explain the stylised fact of greater inflation volatility in developing countries.



The rest of this chapter is organised into the following sections. Section 3.2 provides the background to the study. Section 3.3 presents the econometric model of interest including the research hypothesis. In Section 3.4, data and methodologies for the empirical analysis are discussed. Results of analysis are presented and explained in Section 3.5. Section 3.6 concludes.

## **3.2 Background of Study**

### **3.2.1 Review of the Literature on Taylor Rule as Monetary Reaction Function**

The Monetary Reaction Function is an important tool to evaluate the performance of central banks in response to various economic shocks. It provides a hypothetical path of the policy instrument given the changes in target variables and reveals the conjecture of the monetary authority. Evaluation of monetary reaction function by a comprehensive macro-econometric model is an arduous task. It is the seminal work of Taylor (1993) and his subsequent works (Taylor, 1995, 1998, 1999) which provide a guideline to study the behaviour of monetary authorities. The basic formulation of a monetary reaction function proposed by Taylor suggests that for effective monetary policy intervention central banks should respond by adjusting the policy interest rate if inflation and / or output deviate from the targeted level and / or potential level. Taylor (1993) introduced this idea by analysing the FED's behaviour intensively. His proposed reaction function, which is well known as the 'Taylor Rule', gives a benchmark as to how policy might respond to changes in major economic indicators.

Following the influential work of Taylor (1993), empirical studies have taken shape to assess the monetary reaction function of central banks. According to Judd & Rudebusch (1998), simple Taylor-type policy functions were found to perform almost optimal forecast-based reaction functions that incorporate all the information available in the models examined. In addition, the simple specification was found to perform nearly as well as reaction functions that explicitly include a variety of additional variables. These results appear to be fairly robust across different macroeconomic models. Thus, the general form of Taylor rule is considered to be a good device for capturing the key ingredients of a policy regime. There is a vast literature that offers generous support to this view. Studies, including Clarida et al. (1997), Mehra (1999), Hsing and Lee (2004), Chang (2005), Adam et al. (2005), and Hsing (2005), mention that the Taylor rule can be used to describe the behaviour of policy-maker well, and can provide the cornerstone for policy discussions. In general, the empirical literature of monetary policy reaction function based on the Taylor rule, has been addressed mainly for developed countries. Relatively less attention has been given to developing economies. For example, Frömmel and Schobert (2006) studied a variation of the Taylor rule by adopting forward looking elements for Central and Eastern European countries over the period 1994-2003. Schmidt-Hebbel and Tapia (2002) did the same for Chile and Shortland and Stasavage (2004) for the West Africa economies.

Researchers have extended the Taylor rule from a closed economy to an open economy framework. Most of the empirical studies such as Clarida et al. (1998), have reported the importance of adding external factors for open economies. Ball (2000) suggested a Taylor rule with exchange rate on small open economies. He argued that the original

Taylor rule should be modified for an open economy by including the exchange rate in the interest rate rule. Svensson (2000) estimated the Taylor rule including the foreign interest rate, the foreign exchange risk premium, as well as the real exchange rate in a forward-looking framework. Further, a significant number of studies are conducted by adding more variables to policy reaction function such as: nominal or real exchange rate, stock prices, foreign interest rates, long-term interest rates, and monetary aggregates (Kim, 2002; Hsing and Lee, 2004; Chang, 2005; Brouwer and Gilbert, 2005; Adam et al., 2005). These studies provide evidence that monetary policy reacts to these additional variables too.

### **3.2.2 Taylor Rule, Active Monetary Policy & Inflation Stabilisation**

Although the rule was developed empirically, the key implication of interest rate based reaction function in our context is regarding the stabilisation of inflation. As shown by Taylor (1993), Levin, Wieland and Williams (1999) and Rudebusch and Svensson (1998), such reaction functions can stabilize inflation (and output gap also) reasonably well in a variety of macro models when it is calibrated or estimated with an IS curve and a backward looking or expectation augmented Phillips Curve. Though the Taylor rule was designed for the level of operating targets, it actually relates the value of the intermediate target relying on the aggregate demand channel and transmission via changes in the interest rate. This feature has later been exploited by Old and New Keynesian schools to explicate the non-neutrality of money. In these paradigms, the Taylor type interest rate rule represents the monetary policy. Along with the dynamic IS relation, it also provides the aggregate demand of the model economy. The salient point

to note is that the Taylor rule serves as the basis for inflation determination in both ‘Old’ and ‘New’ Keynesian models. Determinacy in these models, albeit in a different way, require more than one-to-one response of the short term interest rate to inflation. Old Keynesian model requires this condition to obtain a unique stable solution by solving backward looking expectation structure. On the contrary, in a sticky price model with forward looking expectation, an inflation coefficient greater than one implies a dynamically unstable path which an economy needs to head off to arrive at a unique and stable equilibrium<sup>38</sup>. Such parametric restriction in the Taylor rule posits that monetary authority should respond to inflation aggressively by raising the real interest rate. This conjecture is known as active policy intervention of central banks in the literature. From a theoretical point of view, it elucidates the worthiness of the Taylor type monetary reaction function for defining active monetary policy regime and ensuring the stability of inflation dynamics. Based on this definition of activism, the nature of monetary policy can be critically assessed according to the inflation coefficient in the interest rate feedback rule of policy authority. Moreover, monotonically decreasing relation between the Taylor rule coefficient of inflation and inflation volatility provides a theoretical underpinning for the role of monetary policy activism to stabilise an economy<sup>39</sup>. With reference to the US economy, research shows that before the era of Great Moderation, the inflation coefficient of the policy rule was below than one. For example, it was reported as 0.81 in Taylor (1993), and 0.83 in Clarida et al. (2000). However, during the period of moderation, estimates of the coefficient were greater than one. In Taylor

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<sup>38</sup> See Bullard & Mitra, 2002, Woodford, 2001, 2003.

<sup>39</sup> See Sims (2008).

(1993) it was reported as 1.53 and in Clarida et.al. (2000) it was 2.15. This shows that the ability to switch from a passive to an active monetary policy regime facilitates the US economy to overcome the period of unstable inflation. While examining monetary activism for the US economy, estimates of the inflation coefficient of the Taylor rule found by Orphanides (2004) indicates that monetary policy became more aggressive in the period of moderation. During the period of high and unstable inflation (1966-1979) it was 1.49 and it became 1.89 during the period of low and stable inflation (1979 – 1995). Clarida et al. (2000) argue that the volatility of inflation varies inversely with the magnitude of the coefficient on inflation. According to them, when the coefficient on inflation rises from one to two, the volatility of inflation declines by more than half. Therefore, if the monetary policy response is sufficiently large to adjust the real rate of interest, exogenous shocks will have little impact on inflation and its volatility.

**3.2.3 Taylor Rule and Inflation Volatility: A Simple New Keynesian Model**

The discussion on the relation between choice of policy parameter of inflation in the Taylor rule and inflation variability can be illustrated using a simple New Keynesian model. Let us consider the standard three equation New Keynesian framework with dynamic IS curve, New Keynesian Phillips curve and Taylor type interest rate rule<sup>40</sup>.

$$x_t = E_t\{x_{t+1}\} - \sigma[r_t - E_t\{\pi_{t+1}\} - \delta] + g_t \dots\dots\dots (1)$$

$$\pi_t = \beta E_t\{\pi_{t+1}\} + \kappa x_t + u_t \dots\dots\dots (2)$$

$$r_t = \delta + \phi_\pi \pi_t + \phi_x x_t + v_t \dots\dots\dots (3)$$

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<sup>40</sup> One can find the micro-foundation of such model specification in Woodford (2001, 2003), Gali (2008).

In the above structural form of the New Keynesian system,  $x_t$  is the output gap,  $\pi_t$  denotes the inflation rate,  $r_t$  stands for short term nominal interest rate, and  $g_t$ ,  $u_t$  and  $v_t$  are the exogenous shocks signifying preference shock, cost push shock and monetary shock respectively. Exogenous shocks follow an *i.i.d* process with mean zero and variance:  $\sigma_g^2$ ,  $\sigma_u^2$  and  $\sigma_v^2$  respectively. Micro-foundation similar to the model as specified by equations (1) – (3) is discussed in Chapter 4 where Dynamic IS curve, New Keynesian Phillips curve and Taylor type monetary policy rule are presented in a two sector framework. Using the method of undetermined coefficients, the closed form analytical solution for variance of inflation can be derived. See Appendix A.2 for derivation of inflation variance in terms of exogenous shocks. The analytical expression of inflation variance will take the following form:

$$var(\pi_t) = \psi_1\sigma_g^2 + \psi_2\sigma_u^2 + \psi_3\sigma_v^2 \dots\dots\dots (4); \text{ where, } \psi_i = f_i(\phi_\pi);$$

Equation (4) provides an intuition that if monetary authority targets inflation explicitly and therefore, raises the value of the inflation stabilising coefficient, it can control the volatility of inflation given the variance of exogenous shocks. In fact, calibration exercise demonstrates that all  $\psi_i$ -s are inversely related to  $\phi_\pi$  and therefore, with every increments in the inflation parameter of policy rule, variability of inflation declines persistently. For the purpose of calibration, the values of the parameters are taken from the DSGE literature (Blanchard & Gali, 2005; Gali, 2009; Ireland, 2004). In Table 3.1A, the parameterizations of the model and the shock variables are presented. In Table: 3.1B, simulated values of inflation coefficient and the resultant values of each  $\psi_i$  coefficients and the variance of inflation are reported. Note that in course of simulation,

the condition of  $\phi_\pi > 1$  has been maintained to ensure the determinacy condition of the model. It is evident from the result that targeting inflation by raising the inflation coefficient in policy rule monetary authority can restrain the volatility.

**Table 3.1A: Calibration of Model Specified by Equations 1, 2 & 3**

<i>Structural Parameters</i>						<i>Shock Parameters</i>					
$\sigma$	$\beta$	$\delta$	$\kappa$	$\phi_\pi$	$\phi_x$	$\rho_g$	$\rho_u$	$\rho_v$	$\sigma_g^2$	$\sigma_u^2$	$\sigma_v^2$
1.0	0.99	0.01	0.176	1.5	0.125	0.8	0.9	0.5	0.0405	0.0109	0.0031

**Table 3.1B: Relation between Inflation Stabilising Coefficient and Inflation Variance**

$\phi_\pi$	$\psi_1$	$\psi_2$	$\psi_3$	$var(\pi_t)$
1.1	386.26	212.54	0.72	0.0838
1.2	112.05	61.66	0.63	0.05
1.3	52.46	28.87	0.55	0.0332
1.4	30.31	16.68	0.48	0.0236
1.5	19.71	10.85	0.43	0.0177
1.6	13.84	7.61	0.39	0.0137
1.7	10.25	5.64	0.35	0.0109
1.8	7.89	4.34	0.31	0.0089
1.9	6.26	3.45	0.29	0.0074
2	5.09	2.80	0.26	0.0063
2.1	4.22	2.32	0.24	0.0054
2.2	3.56	1.96	0.22	0.0047

**Table 3.1C: Calibration of Model Specified by Equations 1, 2 & 5**

$\phi_\pi$	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
$var(\pi_t)$	0.0227	0.0178	0.0144	0.0119	0.0101	0.0086	0.0075	0.0065	0.0058	0.0051

The form of the Taylor rule proposed by equation (3) can be extended to explore another scenario. In addition to inflation and output gap stabilisation, if interest-rate smoothing is considered in the policy framework by responding to the lagged values of policy rate, it can improve central bank's performance by incorporating desirable history-dependence which benefits private-sector inflation expectations (Rotemberg and Woodford, 1999; Woodford 1999). Therefore, inserting an interest rate smoothing term with one period lag in the right hand side of the Taylor rule expression of (3), the generalised version of Taylor rule is produced in Equation (5), and considered to check the impact of inflation coefficient on inflation volatility by calibration.

$$r_t = \delta + \rho r_{t-1} + (1 - \rho)[\phi_\pi \pi_t + \phi_x x_t] + v_t \dots\dots\dots (5)$$

With this generalised version of the Taylor rule, it is difficult to get an exact solution for the relation between inflation variability and the inflation coefficient of the Taylor rule. In this occasion, using the simulation exercise directly, it is examined whether a gradual increase in the inflation coefficient can be effective enough to bring down the volatility of inflation. In Table 3.1C, the simulated values of the inflation coefficient of the Taylor rule is presented along with the corresponding variance of inflation generated from the model. It clearly re-emphasises the fact that the values of inflation stabilising coefficient and inflation variability are inversely related. Intuition behind this observation is that targeting inflation actively and aggressively in the policy framework by monetary authority can check the volatile behaviour of inflation.

Therefore, analysis from the simple model underlines that if the value of the inflation coefficient in monetary reaction function is low, i.e. the priority for inflation targeting is



less, one can expect to see greater volatility in inflation and vice versa. The key observation stems up from this illustration is that central bank has to adopt an active policy regime in response to inflation developments to stabilise the economy.

### **3.2.4 Recent Debates on the Taylor Rule: Issues of Determinacy and Identification**

In the contemporary research Taylor type reaction function of monetary authority is extensively incorporated as a part of the theoretical foundation of rational expectation augmented New Keynesian models. This trend has opened up a new debate on how active the central bank should be in order to achieve determinacy. As mentioned in the earlier sub-sections, the existing literature postulates that determinacy (i.e. a locally bounded non-explosive equilibrium of the model) is obtained when the inflation coefficient on the latent rule is greater than one. The underlying motivation behind this conjecture is that the central bank will restore the unique stable equilibrium to eliminate the possibility of sunspots or self-fulfilling inflation. However, the legitimacy of ruling out the possibility of explosive equilibrium does not come from any transversality condition (Cochrane, 2007).

Criticising the New Keynesian presumption on the Taylor rule, Cochrane (2007) argues that the single-stable-solution<sup>41</sup> (SSS) condition, i.e. policy activism, is not sufficient to guarantee the determinacy in the typical New Keynesian models. He contends that the New Keynesian model when combined with the Taylor type monetary policy rule can lead to multiple solutions with non-local equilibrium or explosive inflation. This

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<sup>41</sup> As it has been termed in McCallum (2012).

possibility can be eliminated only by an arbitrary dictum. While agreeing with this specific proposition of Cochrane, McCallum (2009) reinstates the ground of the New Keynesian models with Taylor rules by bringing ‘learnability’ in the system. According to McCallum, the unique bounded local equilibrium is the only solution that is *least-square learnable* for the economic agents while the non-local explosive equilibria are not. Therefore, explosive solutions can be ruled out. He suggests that such learnability should be considered as a necessary condition for the solution of the model’s prediction regarding the economy’s behaviour. This is subject to a feasibility condition that pertains to quantitative information available to individual agents. However, the question remains of, how such policy rule can be learnt when the policy parameters are not identified<sup>42</sup>. McCallum (2012) argues that identification of the parameters of policy rule matters for an econometrician studying the economy and policy process, but not for the private-sector agents in the model. These agents learn by forecasting inflation and output in the model economy from a reduced form perspective which is independent of identification issue of the central bank’s policy behaviour.

### **3.2.5 Is the Taylor Rule Vulnerable to Problem of Identification?**

While acknowledging the problem of the indeterminacy of Taylor type reaction function with reference to recent debate, I would now like to argue that policy rule parameter can still be recovered from single equation estimation providing that the right instruments are chosen for the estimation. Sims (2008) shows that Cochrane’s conclusion of non-identification is not a generic implication of the model, but is rather the result of a

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<sup>42</sup> It is the unbounded equilibria which are learnable but not the bounded one (Cochrane, 2009)

particular assumption on the policy rule. Under standard specifications of the nominal interest rate rule the policy parameters are identified and may be estimated consistently using conventional techniques. As mentioned by Sims (2008), two facts need to be taken into account. First, in the New Keynesian set up non-policy shocks can determine the equilibrium values of inflation and output gaps, i.e. they are orthogonal to structural error terms. Second, inflation in this model is monotonically decreasing function of policy rule parameter. The impact response, as well as the size of variation in inflation, is subject to the choice of policy rule parameter. These two facts lend necessary support to identify the policy parameter of the central bank since they indicate that the proper choice of instruments can facilitate the identification of the Taylor rule coefficients. Sims (2008) demonstrates that a standard linear regression, with proper instrumental variables, will in fact consistently estimate the central bank's policy parameters.

The central point to note here is, if the observed variation in inflation is only due to policy shock, then the inflation coefficient in monetary reaction function is not identifiable. Identification will come from the interaction of non-policy shocks with inflation and output gap. If single equation estimation is done by Ordinary Least Squares estimators, consistent estimates of policy rule parameters cannot be obtained. This is because inflation and output gaps both are jump variables in a fully specified NK model and, thus, can be contemporaneously correlated with structural error term. Therefore, consistent estimation of policy rule parameter needs valid instrumental variables. For the purpose of instrumental variable estimation, Sims (2008) argues to instrument the flexible price output or natural output. Since the natural output is affected by the non-

policy factors, in reality it is possible to observe and record the occurrence of these factors. Such variable can be a valid instrument for inflation and output gap to estimate a reduced form policy reaction function. This observation also holds true for the Taylor reaction function with interest rate smoothing.

In a similar line but in a different manner, Carrillo (2008) argues that the framework used by Cochrane (2007) overlooks an essential issue about the dynamics of inflation and output inherent to actual data, which is *persistence*. According to Carrillo, inflation inertia and output gap persistence contain the necessary information that would help to identify the parameters of the Taylor rule. In his words, “These two features of aggregate data can help to identify the parameters of the interest rate rule, at least partially, even using a single-equation approach” (Carrillo, 2008)<sup>43</sup>. The reason is explained by Mavroeidis (2005) in Carrillo (2008), who recalls that higher order dynamics or moderate persistence of the regressors (or instruments) is a necessary condition for the generic identification of a structural model.

Therefore, it appears that with proper selection of instrumental variables and given the property of persistence in the aggregate data, single equation estimation of the Taylor type policy reaction function can still provide necessary information regarding the inflation stabilising coefficient chosen by monetary authority.

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<sup>43</sup> This result is already provided by purely backward-looking models (see Carare and Tchaidze 2005).

### **3.3 Model Specification and Research Hypothesis**

#### **3.3.1 Econometric Model of Monetary Reaction Functions**

Bearing in mind the potential problem of determinacy and identification in single equation estimation of the Taylor rule as postulated by Cochrane (2007), the baseline reduced form econometric specification of monetary reaction function has been taken from Henry, Levine & Pearlman, (2012). According to Cochrane (2009) and Cochrane (2011), the necessary condition for a system to exhibit saddle path stability is that the system is learnable and the rule is identifiable. It is important to note that without the second condition, i.e., if the rule is not identifiable, it will become observationally equivalent to an infinite number of other structurally equivalent rules on the saddle path equilibrium - or will be relevant only off the saddle path equilibrium. In their paper, Henry *et al.*, (2012) argue that simplest form of the Taylor rule is not subject to Cochrane's criticism. According to them, if a rule is simple enough then it will satisfy the necessary conditions for local stability. If agents know the parameters and structure of the rest of the economy, then it turns out that a Taylor rule feeding back on both inflation and output is sufficient to be identified. To summarise their argument, a system of equations need to be considered, composed of a set of backward looking variables, forward looking variables and a policy variable. Further, it should be assume that a simple policy rule is in place which expresses the policy variable as a linear combination of backward and forward looking variables and meets the condition of saddle path stability. Such a system will be learnable and the rule will be identified given that the number of non-zero elements in the associated matrix of the target variables in the policy rule is less than or equal to the number of backward looking variables.

Following the illustration of Henry, Levine & Pearlman, 2012; (HLP), let us consider a New Keynesian model with habit formation (denoted by the parameter ‘ $h$ ’) and a simple Taylor rule of inflation targeting.

$$x_t - hx_{t-1} = E_t\{x_{t+1}\} - hx_t - \sigma[r_t - E_t\{\pi_{t+1}\}] \dots\dots\dots (1.HLP)$$

$$\pi_t = E_t\{\pi_{t+1}\} + \kappa x_t \dots\dots\dots (2.HLP)$$

$$r_t = \phi_\pi \pi_t + \epsilon_t \dots\dots\dots (3.HLP)$$

Substituting the policy variable  $r_t$  in Equation of (1.HLP), a state space representation of the above system can be obtained which has exactly one stable root. This implies the jump variables can be expressed in terms of predetermined  $x_{t-1}$  and  $\epsilon_t$  as:

$$x_t = \gamma_0 x_{t-1} + \gamma_1 \epsilon_t \dots\dots\dots (4.HLP)$$

$$\pi_t = \theta_0 x_{t-1} + \theta_1 \epsilon_t \dots\dots\dots (5.HLP)$$

It is shown that a stable saddle path specified above by (4.HLP) and (5.HLP) can produce a locally bounded equilibrium and be exploited to identify the inflation coefficient of the policy rule. Since,  $r_t$  and  $\pi_t$  both are correlated with  $\epsilon_t$ , Ordinary Least Square regression of  $r_t$  on  $\pi_t$  will lead to inconsistent estimate of inflation stabilising coefficient. However, estimation by instrumenting the pre-determined variable like lagged output gap (i.e.,  $x_{t-1}$ ) which is uncorrelated to  $\epsilon_t$ , can yield a consistent estimate of  $\phi_\pi$  and it will be identified. This instance elucidates that the simplest form of inflation targeting Taylor rule can overcome Cochrane’s critique. Following the spirit of their work, a simple and identifiable inflation targeting interest

rate rule is specified in Equation (6) and considered as the Baseline Model for our analysis:

$$r_{it} = \phi_{\pi}\pi_{it} + e_{it} \dots\dots\dots (6); \text{ where, } e_{it} = \delta_i + \varepsilon_{it} ;$$

In Equation (6), ‘*i*’ stands for country and ‘*t*’ stands for time period.  $r_{it}$ ,  $\delta_i$ ,  $\pi_{it}$  and  $\varepsilon_{it}$  are the nominal interest rate, inflation and the white noise error term of *i*-th country at period *t*.  $\delta_i$  presents country specific effects in the behaviour of interest rate setting and  $\phi_{\pi}$  measures the reaction of central banks over the cyclical variations of inflation. This model is estimated in the panel of developed and developing economies by the instrumental variable where lagged output gaps are chosen as the instruments following the arguments of Henry, Levine & Pearlman (2012).

After estimating the identifiable baseline Taylor type reaction function (6), the generalised version of interest rate reaction function that has been studied mostly in the literature, is taken into consideration. The generalised specification is given in equation (7).

$$r_{it} = \rho r_{it-1} + (1 - \rho)[\phi_{\pi}\pi_{it} + \phi_x x_{it}] + e_{it} \dots\dots\dots (7); \text{ where, } e_{it} = \delta_i + \varepsilon_{it}$$

Here, ‘ $\rho$ ’, is the interest rate smoothing parameter of central bank,  $x_{it}$  is the output gap in *i*-th country at period *t* and  $\phi_x$  is the output gap stabilising coefficient. Note that  $\phi_x$  is taken equal to zero in the baseline model of (6) and therefore, the baseline model can be considered as the inflation targeting specification of monetary reaction function.

The generalised specification of (7) can be obtained by augmenting (6) with a one period lagged interest rate and relaxing the assumption of  $\phi_x$  equals to zero. The motivation behind this is to incorporate the objectives of interest rate smoothing and output gap stabilisation of central banks in the reaction functions. In reality, it has been observed that there is a strong inertia in interest rate which essentially reveals the ‘gradualism’ of monetary authority to respond to the macroeconomic outcomes. Therefore, this needs to be captured by interest rate smoothing factor. Parallel to this, keeping actual output near to its potential level for fostering economic growth is another important objective of central banks and thus, taken into model specification. The issue of identification raised by Cochrane (2007) may be tackled by providing a richer theoretical model; the model, in which such generalised version of the Taylor type reaction functions would be identified. Such an endeavour is beyond the scope of this chapter.

### **3.3.2 Specification of Research Hypothesis**

At this point, it is imperative to put forward the main research hypotheses of the forthcoming empirical analysis. The investigation is now concerned to examine if the estimated value of ‘ $\phi_\pi$ ’, is greater than one for advanced and developing countries. Thus, the necessary hypothesis testing can be constructed as:

$H_0: \phi_\pi^j \leq 1$  against  $H_1: \phi_\pi^j > 1$  ; where,  $j =$  Advanced / Developing country



The presumption of this research hypothesis is to check whether the estimate of ' $\phi_\pi$ ' is greater than one for advanced economies but less than one for developing countries. If this presumption turns out to be statistically significant, then the conventional argument will be in place, i.e. active monetary policy in advanced countries has stabilised the inflation dynamics while it is absent in the developing economies. In other words, if the estimated value of ' $\phi_\pi$ ' is found to be less than one for developing economies, it can be argued that due to accommodative response of monetary policy, inflation has not been stabilised and therefore, it remains strongly volatile in the emerging countries. The research hypotheses mentioned above has been tested for both econometric models given in (6) and (7) to assess the role of monetary authority critically.

### **3.4 Data & Methodology**

#### **3.4.1 Data**

For empirical investigation, quarterly data are collected on three major macroeconomic variables, viz., short-term nominal interest rate, inflation rate and aggregate output for thirteen advanced and six Asian developing countries<sup>44</sup> as sample from the database of International Financial Statistics. The quarterly data are selected to obtain the business cycle movement from the series of output gap as well as of inflation. This, in turn, allows the investigation of how central banks in advanced and developing countries respond over the cyclical variations of inflation and output and if there exist any significant difference in policy rule parameters between their monetary reaction functions. To compare the policy rule parameters of monetary reaction function, the

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<sup>44</sup> The IMF classification of Advanced and Developing countries is followed to choose the sample for the study.

Taylor rule is estimated on two sets of panel data. One is for developed countries and the other is for developing countries. Lack of reliable and organised macroeconomic data on developing countries poses an obstacle to extending the number of developing economies in the panel for the empirical assessment. Nonetheless, effort is given to make strongly balanced panels for both groups of economies. The sample period of the balanced panel for developed countries starts from the 2<sup>nd</sup> Quarter of 1991 and ends at the 2<sup>nd</sup> Quarter of 2011. The sample period of the balanced panel for developing countries include data from the 1<sup>st</sup> Quarter of 1997 to the 1<sup>st</sup> Quarter of 2011.

### 3.4.2 Treatment with Data

**Table 3.2: Selection of Policy Rate**

<i>Country Code</i>	<i>Advanced Countries</i>	
1	Austria	Govt. Bond Yield
2	Belgium	Treasury Bill Rate
3	Canada	Treasury Bill Rate
4	Denmark	Govt. Bond Yield
5	Finland	Govt. Bond Yield
6	France	Treasury Bill Rate
7	Germany	Govt. Bond Yield
8	Italy	Treasury Bill Rate
9	Japan	Treasury Bill Rate
10	Norway	Govt. Bond Yield
11	Switzerland	Govt. Bond Yield
12	United Kingdom	Treasury Bill Rate
13	United States	Treasury Bill Rate
<i>Country Code</i>	<i>Developing Countries</i>	
1	China	Central Bank Discount Rate
2	India	Govt. Bond Yield
3	Indonesia	Central Bank Discount Rate
4	Malaysia	Treasury Bill Rate
5	Philippines	Central Bank Discount Rate
6	Thailand	Govt. Bond Yield

As the instrument of monetary policy, short-term interest rate is chosen either from the Treasury bill rate, from the government bond's yield or from the central bank discount rates, according to the availability of data. A logarithmic transformation is taken on the series of interest rate data given in a percentage form for each country selected in the panels. In Table: 3.2, the choice of interest rates is produced for the sample countries included in the panel.

Like interest rate, inflation rate has also been calculated in the percentage form after taking the logarithmic difference of consumer price indices between two consecutive periods. For the output series, the volume index of Gross Domestic Product has been taken for almost every country other than India and Malaysia. Due to the lack of data, for these two countries, the index of industrial production has been utilised as the proxy measure of aggregate output series. Once again, log-transformation is taken over the original series of output indices.

Finally, the cyclical component of inflation and output gap are obtained by applying the Christiano-Fitzgerald (2003) asymmetric band pass filter on the inflation and output with the assumption that the original data generating process of inflation and aggregate output time series are integrated at order one.<sup>45</sup> Thus the data is prepared for each country and is stacked according to country code to form a balanced panel for advanced and developing group.

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<sup>45</sup> Christiano & Fitzgerald (2003) noted in their paper that, in general, the original data generating process of macroeconomic time series are integrated at order one. Their presumption is followed here.

### **3.4.3 Methodology for GMM Estimation in Panel Data**

First, the baseline model of (6) is estimated in the panel data set of advanced and developing economies. The motivation for considering panel data is to control the unobserved heterogeneity across the countries belonging to one particular group. In other words, the idiosyncratic behaviour of central banks in interest rate setting across the countries of each group can be controlled and a pattern can be found from the estimated coefficients of the monetary reaction function via response of policy instrument. However, regressions using aggregate time-series and pure cross-section data are likely to be contaminated by the effects of a time-invariant individual effect which captures the unobservable individual heterogeneity and the usual random noise term. In presence of such effects, standard OLS estimates of the parameters could be seriously biased and statistical inference can be misleading. A number of studies have developed alternative GMM estimation methods to circumvent the problem of biased estimates. This estimation method results in consistent and asymptotically efficient parameter estimates in a wide variety of settings and properties of the data generating processes. To conduct the GMM estimation in the panel of developed and developing economies, lagged output gaps are chosen as the instruments. Under the assumption of zero correlation between instrument and error terms, the moment condition can be obtained which is sufficient to identify the inflation stabilising coefficient of monetary reaction function. Using the White diagonal instrument weighting matrix with cross-section specific Panel Corrected Standard Errors (PCSE), the GMM estimation is computed for advanced and developing economies.

### 3.4.4 Methodology for Dynamic Panel Estimation

To estimate the generalised version of monetary reaction function given by the econometric specification of (7), two approaches are followed. At first the usual Panel GMM estimation technique is applied and thereafter, Arellano and Bover (1995) method of dynamic panel estimation is used. Since the explanatory variables in the econometric specification of (7) include the lagged dependent variable, it becomes a dynamic model which allows feedback from current or past shocks to current values of the dependent variable. In simple dynamic panel models, it is well known that the usual fixed effects estimator is inconsistent when the time span is small (Nickell, 1981), as the ordinary least squares (OLS) estimator is based on first differences. In such cases, the instrumental variable (IV) estimator (Anderson and Hsiao, 1981) and generalised method of moments (GMM) estimator (Arellano and Bond, 1991) are both widely used. Estimation of such model requires typical toolkits of dynamic panel estimation as the general estimation procedure would suffer from the problem of weak exogeneity of instruments.<sup>46</sup> However, dynamic modelling includes several advantages. One not only takes into account (temporal) autocorrelation in the residuals, but one is also able to reduce the amount of potential spurious regression, which may lead to wrong inferences and inconsistent estimation in static models. Static models may lead to an overestimation of the effects of the exogenous variables. Furthermore, the coefficient of the lagged dependent variable is itself of interest.

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<sup>46</sup> A major problem with such scenario is that inference using estimated asymptotic standard errors can be very unreliable in small samples for the efficient version of the GMM estimator, because the estimated standard errors are downward biased (Eigner, F., 2009). However, since this panel dataset considers a large number of time periods, the bias can die out asymptotically (See Roodman, 2006).

The generalised version of Taylor type reaction function is estimated in the first instance by standard Panel GMM estimation with help of lagged rate of interest, lagged cyclical component of inflation, and lagged output gap. In the second attempt, Arellano-Bover's (1995) method is followed to avoid the weak exogeneity problem of instruments. To increase efficiency of the estimates of the parameters, an additional moment condition is suggested by Arellano and Bover (1995) in the form of an assumption regarding the initial condition. According to them, it is valid to assume that the change in any instrumenting variable is uncorrelated with the fixed effects. Thus, a transformation should be taken for the differences of instruments to make them exogenous to the fixed effects. This entails the assumption of zero correlation between first difference of instrument and error terms. With this additional moment condition, the parameters of generalised Taylor type monetary reaction function is estimated using the White diagonal instrument weighting matrix with cross-section specific Panel Corrected Standard Errors (PCSE) for advanced and developing economies.

### **3.5 Results and Analysis**

#### **3.5.1 Observations from Plots**

Before embarking on a formal estimation procedure, it is constructive to illustrate the variables used in this study. In Figure 3.1(A & B) and 3.2(A & B), the macroeconomic aggregates of advanced and developing countries are presented. Figure 3.1A shows that the plot of short term interest rate and the cyclical component of inflation are positively related, but the turning points of time path exhibits that the latter takes the lead and the interest rate follows. A similar pattern is found in Figure 3.1B, where short term interest

rate and output gap are depicted. However, comparing two figures of 3.1A & 3.1B, it is noticeable that movements in interest rate follow the cyclical components of inflation more closely than the movements of output gap. Overall, in the sample period, the trajectory of interest rate in advanced economies features structural drifts and reveals the sign of monetary easing with sharp plunge in the era of financial crisis. Considering Figure 3.2A, from the plots of interest rate and cyclical component of inflation for developing countries it is observed that movements of interest rate, although following broad regularities of inflation, is significantly less sensitive compared to the advanced economies. In Figure 3.2B, the turning points in the output gap are infrequently followed by positive movements of the interest rate. Overall, during the sample period, the policy rate behaves like step function with an indication of sluggish adjustment in the policy instrument of monetary authority.

Altogether from Figures 3.1(A & B) and 3.2(A & B), three salient observations can be made regarding the behaviour of macroeconomic aggregates of advanced and developing countries. Firstly, the cyclical components of inflation are more pronounced in developing countries than in the advanced group elucidating the persistent volatility of inflation. Secondly, the output gaps in developing countries are subject to large swings with relatively smaller peak-to-peak amplitude of business cycle compared to the developed economies. Finally, the movement of policy rate in the developing countries is substantially more sedentary, with a few jumps over the cyclical developments of inflation and output. This is contrast with the same of advanced countries and signals a strong gradualist approach of the monetary authority.

### 3.5.2 Observations from Descriptive Statistics

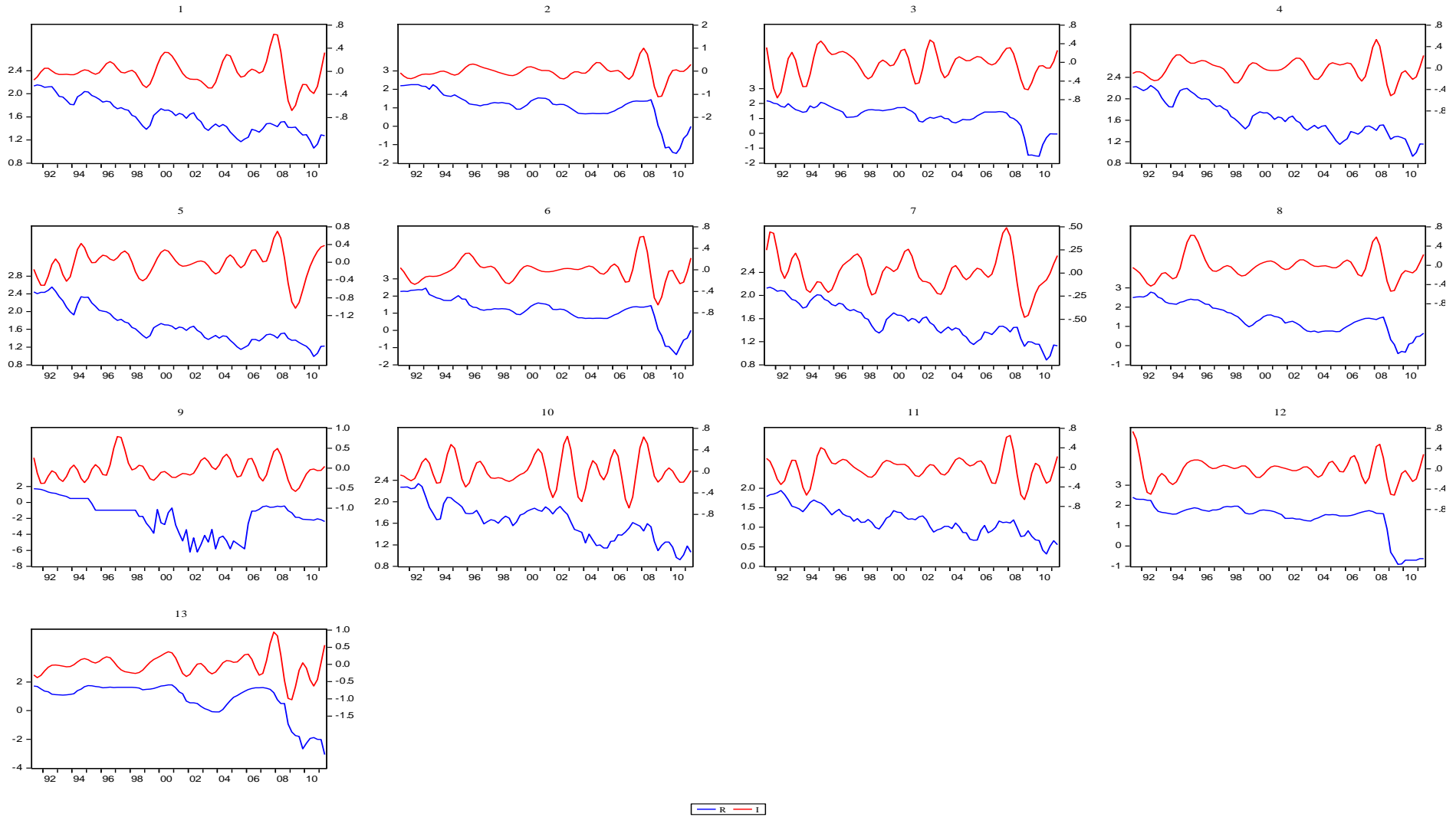
In addition to observations from the plots, summary statistics are taken into consideration to analyse the general traits of macroeconomic variables of our interest. In Tables 3.3A and 3.3B, the summary statistics on short-term interest rate, cyclical component of inflation and output gap are produced for advanced and developing economies respectively. Comparing the first and second order moments, i.e. mean and standard deviation of inflationary cycles and output gap, it can be stated that developing countries are experiencing greater variations in fluctuations of the macroeconomic fundamentals than advanced economies. Looking at the interest rates, the mean value of policy rate is higher for developing countries but the variance is strikingly lower than advanced countries.

**Table 3.3A: Summary Statistics of Macroeconomic Aggregates - Advanced Countries**

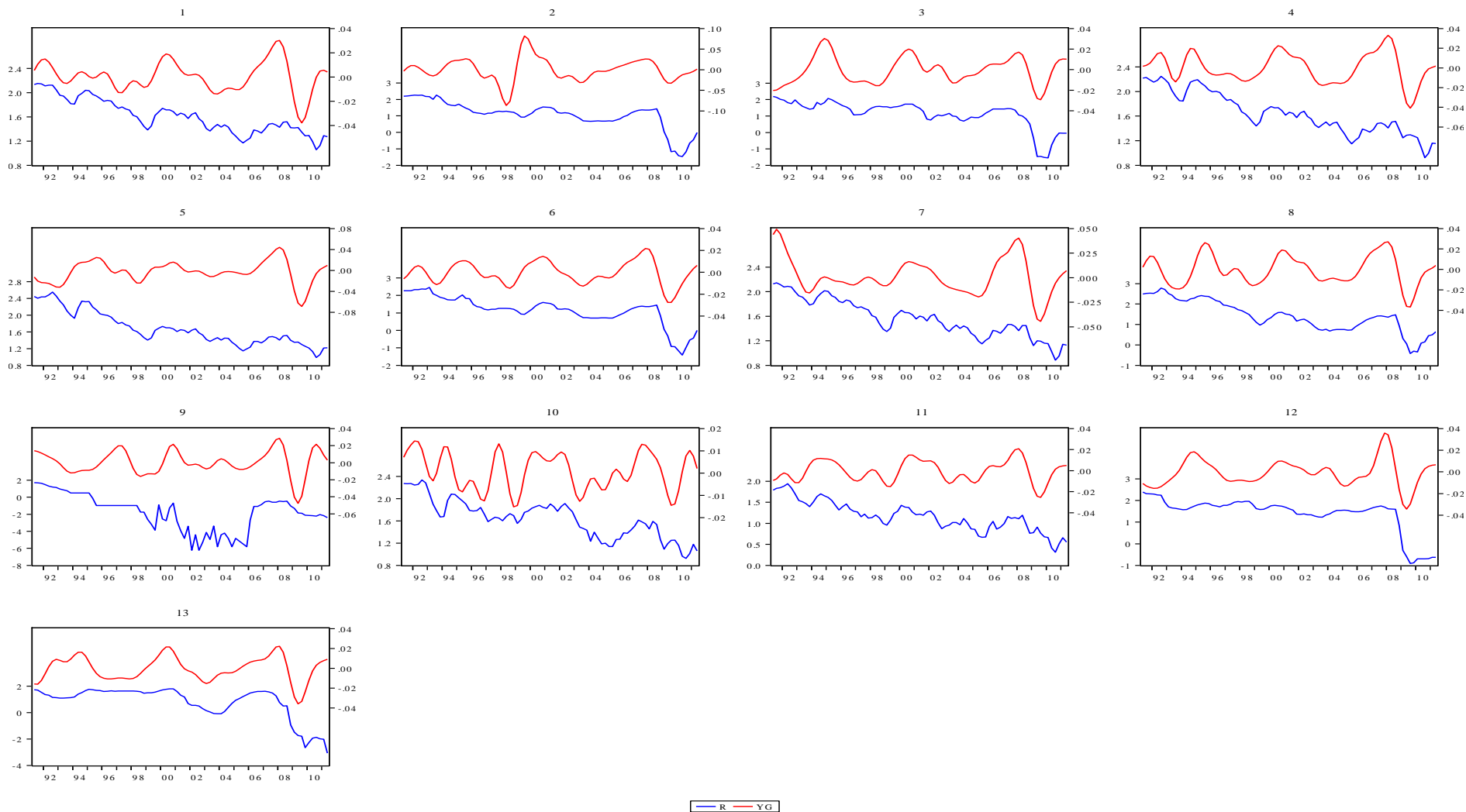
	Interest Rate (R)	Inflation (I)	Output Gap (YG)
Mean	1.111282	-0.020852	-0.000367
Median	1.423188	-0.017825	-0.000984
Maximum	2.780464	1.002156	0.081720
Minimum	-6.214608	-1.112413	-0.086712
Std. Dev.	1.234030	0.252462	0.015540
Skewness	-2.896885	-0.083297	-0.170488
Kurtosis	13.35019	5.102401	6.647327
Jarque-Bera	6172.957	195.1491	588.7700
Probability	0.000000	0.000000	0.000000
Sum	1170.180	-21.95712	-0.386516
Sum Sq. Dev.	1602.017	67.05115	0.254050
Observations	1053	1053	1053



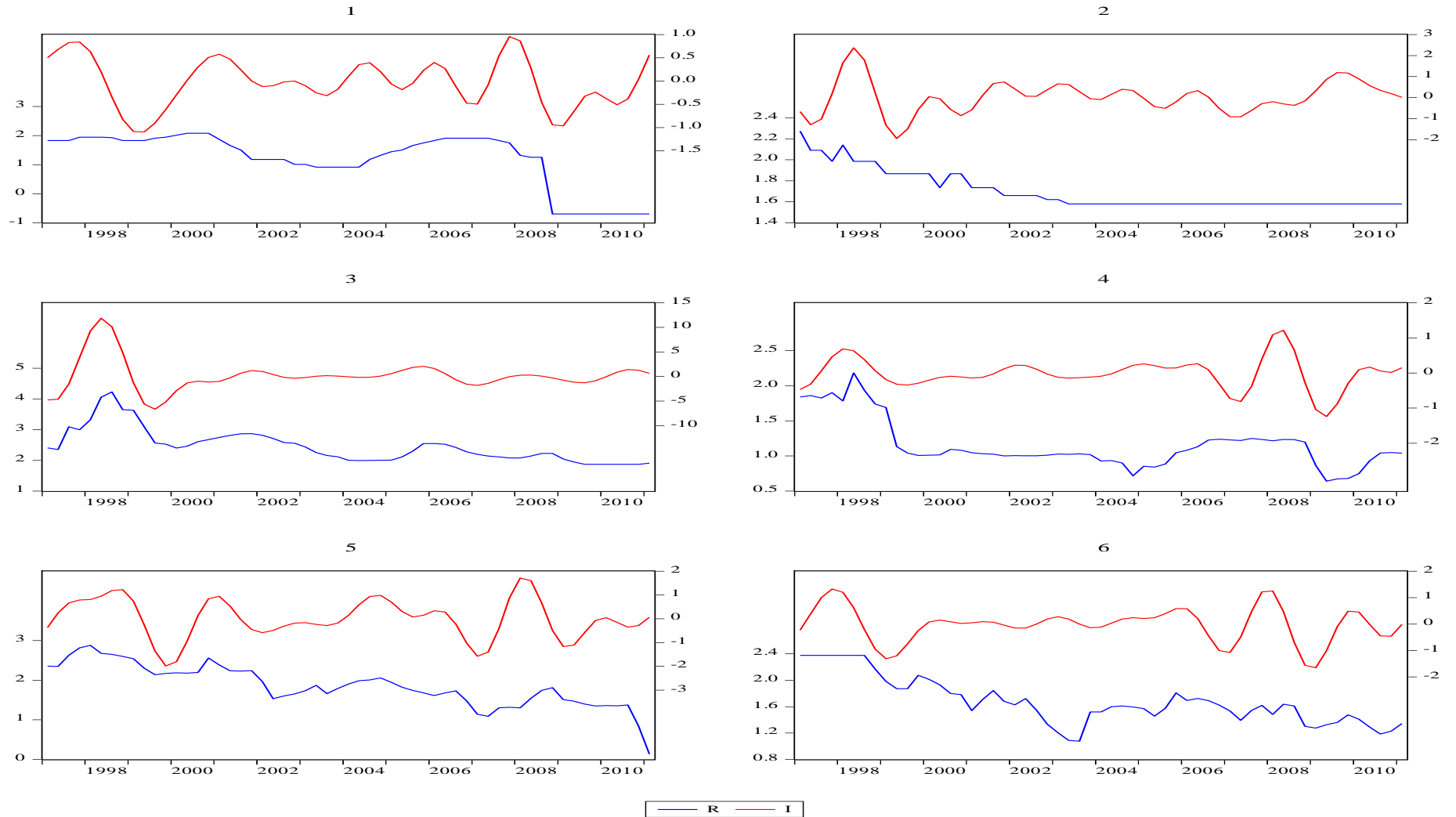
**Figure 3.1A: Plot on Interest Rate and Cyclical Component of Inflation for Advanced Economies**



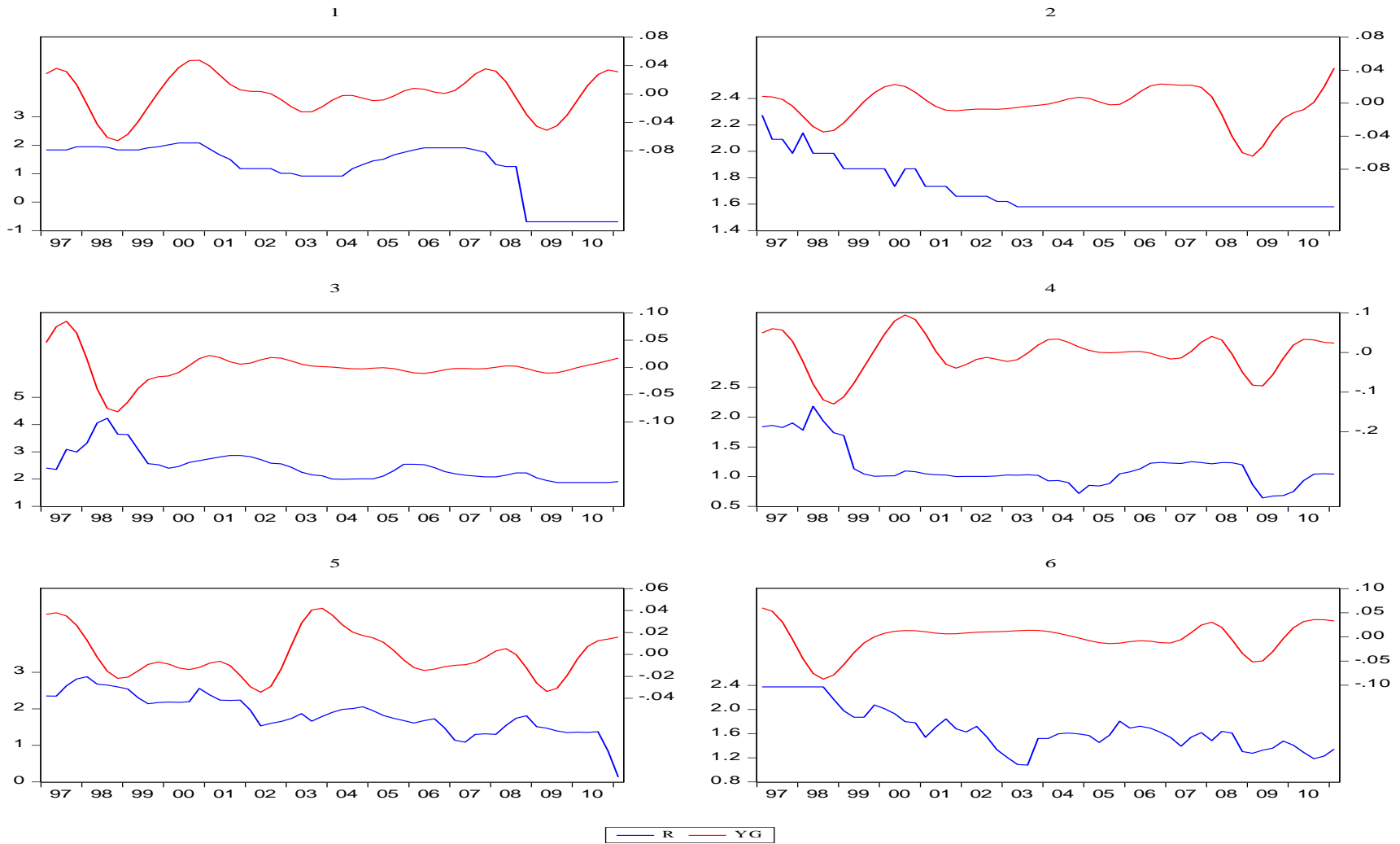
**Figure 3.1B: Plot on Interest Rate and Output Gap for Advanced Economies**



**Figure 3.2A: Plot on Interest Rate and Cyclical Component of Inflation for Developing Economies**



**Figure 3.2B: Plot on Interest Rate and Output Gap for Developing Economies**



**Table 3.3B: Summary Statistics of Macroeconomic Aggregates - Developing Countries**

	Interest Rate (R)	Inflation (I)	Output Gap (YG)
Mean	1.672435	0.015531	-0.001419
Median	1.669835	-0.004716	-0.000405
Maximum	4.230622	11.86156	0.094799
Minimum	-0.693147	-6.674493	-0.129780
Std. Dev.	0.691643	1.421477	0.030485
Skewness	-0.575172	2.865650	-0.643437
Kurtosis	6.296253	31.23146	5.357190
Jarque-Bera	173.6872	11825.55	102.7765
Probability	0.000000	0.000000	0.000000
Sum	571.9728	5.311771	-0.485390
Sum Sq. Dev.	163.1243	689.0238	0.316909
Observations	342	342	342

Thus, the key point is that monetary authorities of advanced economies are reacting more frequently to inflation and output gap by adjusting their policy instrument, This is reflected in the greater variance of interest rate coupled with lower variability of inflation and output gap. However, in the case of developing countries, the scenario is the exactly opposite and indicates a lack of concern or ineffectiveness of monetary authority to stabilise the economy.

### 3.5.3 Results from Panel GMM Estimation of Baseline Model

The primary intuition obtained from the diagrammatic exposition and descriptive statistics gains support from the results of GMM estimation of the baseline model in the panel data of advanced and developing countries. Results of the estimation are reported in Table 3.4A. The intercept term, i.e. the country-specific effect, is found to be positive and statistically significant for both groups of economies. This highlights the idiosyncrasies in the behaviour of the central bank in manipulating its policy instrument. The inflation coefficient is found with the expected sign for both

groups but higher for advanced countries (1.85) than the developing countries (0.204). Moreover, for advanced countries it takes a value greater than one while it remains less than one for developing countries. This clearly shows that inflation is actively targeted by the monetary authority of the advanced countries but not in developing economies. From the value of adjusted R-square, it seems that the model fits to data moderately.

**Table 3.4A: Results from Baseline Model by GMM Estimation**

GMM Estimation with Cross Section Effect		
	Advanced	Developing
<i>Intercept</i>	1.039***	1.639***
<i>Inflation</i>	1.85***	0.204***
Adj. R square	0.501	0.41
S.E. of Regression	0.863	0.535
J statistic	0.406	1.57
P-value of J statistic	0.524	0.21

Note: ‘\*’ denotes statistical significance at 10%, ‘\*\*’ denotes statistical significance at 5% level, and ‘\*\*\*’ denotes statistical significance at 1% level.

Since the lagged output gap has been used as the instrument to estimate the model, the value of the J-statistic has been scrutinised. For both groups, based on p-values, it is observed that the null hypothesis of the J-test cannot be rejected. Thus, the lagged output gap is considered as a valid instrument for the estimation process.

#### **3.5.4 Results from Panel GMM Estimation of Generalised Model**

Next to the baseline model, the generalised model with interest rate smoothing has been estimated in the panel of advanced and developing countries. Results are reported in Table 3.4B. All estimated coefficients are appearing with expected sign, i.e. they are positive. In case of advanced countries, the coefficient of interest rate

smoothing term and inflation are statistically significant. On the other hand, for the developing economies, coefficients of interest rate smoothing, inflation and output gap are found to be statistically significant. It can be seen the estimate of inflation coefficient of advanced countries (0.122) is larger than the developing countries (0.031). However, note that these estimates are non-linear function of  $\rho$  and  $\phi_\pi$ . Given the property of a consistent estimator, the estimates of  $\phi_\pi$  is recovered for advanced and developing economies, and it yields the values 2.302 and 0.596 respectively. Therefore, the reaction of a monetary authority towards inflation is strongly active for the advanced economies but passive for developing economies.

**Table 3.4B: Results from Generalised Model by GMM Estimation**

GMM Estimation with Cross Section Effect		
	Advanced	Developing
<i>Intercept</i>	0.037	0.062
<i>lagged interest rate</i>	0.947***	0.948***
<i>Inflation</i>	0.122**	0.031***
<i>output gap</i>	1.097	0.659*
Adj. R square	0.945	0.942
S.E. of Regression	0.279	0.168
J statistic	0.945	0.466
P-value of J statistic	0.28	0.495

Note: ‘\*’ denotes statistical significance at 10%, ‘\*\*’ denotes statistical significance at 5% level, and ‘\*\*\*’ denotes statistical significance at 1% level.

Looking at the interest rate smoothing parameter, it is evident that a gradualist approach is quite prevalent for both set of countries. There is evidence that monetary authority of developing economies are trying to stabilise the output gap intensively. Apart from the estimates of policy reaction parameters, the result of adjusted R-square is worth noting. Its value for advanced (0.945) and developing (0.942) countries panel estimation has remarkable improved from the baseline model due to

inclusion of lagged interest rate term and output gap in the policy reaction function. Moreover, comparing the regression results of the generalised model with the results of baseline model, it is noticeable that the standard error of regression has reduced for both groups. This shows the goodness of fit of the model to data. Finally, the validity of lagged interest rate, lagged inflation cycle and lagged output gap as instruments is checked by the J-test statistic. As with other instrumental variable estimators, for the GMM estimator to be identified, there must be at least as many instruments as there are parameters in the model. J-statistic is used as a test of over-identifying moment conditions. Based on the p-value of the J-statistic, the decision can be made whether the null hypothesis of the instrument's validity will be rejected. In the present case, from the p-value of J-statistic, one cannot reject the null hypothesis of validity of the instruments.

### 3.5.5 Results from the Arellano-Bover Dynamic Panel Estimation of Generalised Model

The GMM estimation of the generalised model based on panel data exposes the stark difference in the responses of monetary authority of advanced and developing economies over the inflationary fluctuations. To check the robustness of the findings further, Arellano-Bover's method of dynamic panel estimation has been exercised.

**Table 3.4C: Results from Generalised Model by Arellano-Bover Estimation**

Dynamic Panel Estimation: Arellano-Bover Method		
	Advanced	Developing
<i>lagged interest rate</i>	0.947***	0.951***
<i>Inflation</i>	0.116**	0.031***
<i>output gap</i>	1.051	0.675*
S.E. of Regression	0.284	0.168
J statistic	1.418	0.396
P-value of J statistic	0.234	0.53



Note: ‘\*’ denotes statistical significance at 10%, ‘\*\*’ denotes statistical significance at 5% level, and ‘\*\*\*’ denotes statistical significance at 1% level.

Given the fact that the model incorporates a lagged dependent variable and is estimated by instrumental variables, there may remain a possibility of weak exogeneity of the instrumental variables which would affect the estimates. Arellano-Bover’s method of panel estimation can overcome this problem. Using this method, the policy rule parameters of the generalised model are estimated and results are given in Table 3.4C. The main conclusion remains unaltered. The inflation coefficient of advanced countries stands higher than that of developing countries. The interest rate smoothing parameter for developing countries becomes slightly greater than the advanced group. The output gap stabilising coefficient is statistically significant for the developing group but not for the advanced economies.

### **A Robustness Check of Indeterminacy**

Inflation targeting rule, one of the alternative monetary strategies, prescribes that central bank should use nominal interest rate to feed back on inflation. If strict inflation targeting is considered as the policy stance of monetary authority (as seen in the baseline model of Equation (6)), more than one to one response of the policy rate to inflation is the necessary condition for inflation stabilization. Estimation results of the baseline model clearly show the difference in policy response between the monetary authorities of advanced and developing countries. However, instead of the strict inflation targeting, monetary authority can control inflation indirectly using other policy targets such as output gap, and influence inflation with a lag. In case of the generalized model where central bank targets the output gap in addition to inflation, a passive monetary policy can still circumvent the problem of

indeterminacy by providing feedback on inflation through the channel of aggregate demand. This issue is worthy of investigation as the estimated coefficient of output gap for developing economies are appearing unusually large (12.67). It is intriguing to see if such huge feedback of central bank can pass on to inflation and stabilize the same.

There are two ways to deal with this large coefficient of output gap. First, one can ignore the coefficient of the output gap for developing countries because its significance level is not in the 5% tail, and therefore, the simple NK model as specified by Equations (1), (2) and (3) will have only one unstable eigenvalue. This could lead to expectational bubbles which continually emerge and die out (Batini and Pearlman, 2002), and explain developing countries' high inflation volatility. Second, if the estimate of output gap is taken seriously, then it is important to check with some plausible parameterization for developing economies if the simple New Keynesian model leads to determinacy, i.e., if one can find two unstable Eigen values with the relatively small estimated coefficient of inflation and large estimate of output gap. This task is undertaken by using the system of equations given by (1), (2) and (3) and presented below. Substituting ' $r_t$ ' by Equation (3) into Equation (1), the system of equations is reduced to 2 x 2 and can be written with matrix representation as:

$$A_0 X_t = A_1 E_t X_{t+1} + A_2 Z_t \dots\dots\dots (8)$$

Where,

$$X_t = [x_t \quad \pi_t]'; Z_t = [g_t \quad u_t \quad v_t]';$$

$$A_0 = \begin{bmatrix} 1 + \sigma\phi_x & \sigma\phi_\pi \\ -\kappa & 1 \end{bmatrix}; A_1 = \begin{bmatrix} 1 & \sigma \\ 0 & \beta \end{bmatrix}; A_2 = \begin{bmatrix} 1 & 0 & -\sigma \\ 0 & 1 & 0 \end{bmatrix}$$

Expression of (8) can be written as:

$$X_t = B_0 E_t X_{t+1} + B_1 Z_t ; \text{ where, } B_0 = A_0^{-1} A_1 ; \text{ and } B_1 = A_0^{-1} A_2$$

The matrix of  $B_0$  is of our interest. It can be written as:

$$B_0 = \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}$$

Where,

$$b_{11} = [1 + \sigma\{\phi_x + \kappa\phi_\pi\}]^{-1}$$

$$b_{12} = \sigma(1 - \beta\phi_\pi)[1 + \sigma\{\phi_x + \kappa\phi_\pi\}]^{-1}$$

$$b_{21} = \kappa[1 + \sigma\{\phi_x + \kappa\phi_\pi\}]^{-1}$$

$$b_{22} = [\kappa\sigma + \beta(1 + \sigma\phi_x)][1 + \sigma\{\phi_x + \kappa\phi_\pi\}]^{-1}$$

Let us consider,  $\lambda I = \begin{bmatrix} \lambda & 0 \\ 0 & \lambda \end{bmatrix}$  where, I is a 2 x 2 Identity matrix and  $\lambda$  is a scalar.

To compute the Eigen values,  $|B_0 - \lambda I| = 0$

$$\Rightarrow (b_{11} - \lambda)(b_{22} - \lambda) - b_{12}b_{21} = 0$$

$$\Rightarrow \lambda^2 - (b_{11} + b_{22})\lambda + (b_{11}b_{22} - b_{12}b_{21}) = 0$$

$$\Rightarrow \lambda_{1,2} = \frac{1}{2} \left[ (b_{11} + b_{22}) \pm \sqrt{(b_{11} + b_{22})^2 - 4(b_{11}b_{22} - b_{12}b_{21})} \right] \dots\dots\dots (9)$$

**Table 3.5: Parameterization for Developing Economy**

<i>Parameters</i>		<i>Developing Economy</i>
$\sigma$	Relative risk aversion coefficient	2.14
$\varphi$	Frisch Elasticity of Labour Supply	6
$\alpha$	Measure of Decreasing Returns	0.38
$\varepsilon$	Elasticity of Demand	7.01
$\theta$	Index of Price Stickiness	0.57
$\beta$	Discount Factor	0.98
$\kappa$	Slope of NKPC	0.78
$\phi_\pi$	Inflation Stabilizing Coefficient	0.63
$\phi_x$	Output gap Stabilizing Coefficient	12.67

If the two Eigen values of  $B_0$  are unstable, i.e. greater than one, the simple New Keynesian model will lead to determinacy. To check this, let us consider the

parameterization for the developing economy (as it is provided in Chapter 2, Table 2.8A). Based on the parameterization given in Table 3.5, one can calculate the elements of the matrix  $B_0$ . These are:

$$b_{11} = 0.034 ; b_{12} = 0.03 ; b_{21} = 0.027 ; b_{22} = 0.134$$

Using the above results and inserting them into the Equation (9), it is found that:

$$|\lambda_i| < 1 ; \quad \forall i = 1, 2$$

Thus, none of the Eigenvalues is unstable corresponding to the forward looking variables. This reinforces the fact that even if there exists a very strong response of the central bank to stabilize the output gap, it is not sufficient to stabilize inflation.

### **3.6 Conclusion**

The policy reaction function of monetary authority is a contingency plan that clearly specifies the circumstances under which a central bank should change the instruments of monetary policy. In present case, Taylor's rule has been deployed as the policy reaction function of monetary authority for advanced and developing economies to examine if there is any difference in activism of policy intervention. Estimating such a policy reaction function provides insight into the approach of the central banks of the respective economies to tackle inflation as the policy target. Since the motivation is to scrutinise the performance of monetary policy for inflation stabilisation, the prime concern is to observe the inflation coefficient in the policy rule. From the estimates of this coefficient, one can understand how the monetary anchors are being implemented and if inflation is targeted successfully by monetary authorities. Estimates of policy parameters of inflation from empirical exercises reveal a significant difference in the activism of

policy intervention of a monetary authority between advanced and developing economies. Summarising the main findings from empirical investigation on baseline model and recovering the estimated values of inflation coefficient from the generalised monetary reaction function, Table 3.6 has been produced showing strong difference in the inflation-targeting coefficient between advanced and developing countries.

**Table 3.6: Summary of Results - Measuring Activism of Monetary Policy**

Computed Coefficients of Inflation Stabilisation		
	Advanced	Developing
<i>Baseline Model</i>	1.85	0.204
<i>Generalised Model (1)</i>	2.302	0.596
<i>Generalised Model (2)</i>	2.189	0.633

For each of the three estimation procedures, it can be observed that parameter of inflation in the policy reaction function takes the value greater than one for the advanced group but less than one for the developing group. This indicates that inflation in the advanced countries is dynamically stable they have an active monetary policy compared to developing countries. Following Taylor (1993), this result can be used to explain greater inflation volatility of developing countries compared to advanced countries. Table 3.6 shows that Taylor rule coefficient of inflation is less than unity for developing economies. This means passive response of the monetary authority. Such inadequate response of the monetary authority to rising inflation implies that, if the inflation rate rises, the real interest rate declines. The decline in the real interest rate stimulates aggregate demand and fuels inflationary pressures further. This kind of policy leads to instability as inflation is able to increase without bound. In contrast, if the coefficient of inflation is greater than unity, as it is in case of advanced economies, an increase in inflation will result in an

increase in the real interest rate which curbs the inflationary pressure and would generate stability.

In developed countries, stabilising inflation has been chosen as the sole policy target of monetary authority and to achieve this goal, the key instrument is the policy rate or short term interest rate. Given the inflationary experience of early 1970's, central banks in developed economies have considered stable and low inflation as the primary mandate in their policy framework. Intellectual support for such monetary policy stance came from the New Keynesian School who argued that stabilising inflation leads to stabilising output gap<sup>47</sup>. Indeed, maintaining the constant level of inflation rate is the optimal response of monetary policy that can also ensure zero output gap even in the presence of imperfections in the economy. Moreover, stability of inflation as policy target enables inflation expectations to remain well anchored. On the contrary, it appears that monetary policy is quite passive in developing countries. From the estimates of the inflation coefficient in the policy rule, it is clear that inflation is not targeted actively in the developing countries, as it is in developed countries. This may be one explanation for the difference of inflation volatility between advanced and developing countries. It seems that central banks of developing countries are accommodating the cyclical variation of inflation by adjusting their policy instrument partially and even less than proportionately. Less than one- to-one response of nominal interest rate via the monetary reaction function also indicates that the monetary authority of developing countries is reducing the real rate of interest and imposing the inflationary tax across the economy which is obviously welfare deteriorating. Furthermore, such monetary reaction is de-

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<sup>47</sup> This observation has been termed as *Divine Coincidence* in the literature (Blanchard & Gali, 2007).

stabilising too. It can generate an inflationary spiral through the channel of forward looking expectation. Fall of real interest today can raise the future aggregate demand and therefore, the future expected inflation. Hence, an inflationary spiral would appear in the economy. As mentioned by Castelnuovo (2006), trying to stabilise inflation by targeting it under a passive monetary policy regime can eventually be counterproductive and result in a more volatile situation.

## **Chapter Four**

# **A New Keynesian Explanation for Inflation Volatility**

### **4.1 Introduction**

Empirical regularities underline the stylised fact of greater inflation volatility in developing countries compared to developed countries. In the previous chapter, effort has been given to explain this striking feature of inflation dynamics in terms of the difference in policy activism of monetary authorities in developing and advanced countries. Although based on standard New Keynesian ideas and using Taylor rule, the analytical set up of the empirical investigation in the last chapter lacks a fully specified structural model with requisite micro-foundations. This chapter, therefore, aims to address this. In addition to policy issues, this chapter will study the structural differences between advanced and developing economies in order to explain the stylised fact. This chapter considers food and non-food inflation as the key constituents of aggregate inflation. It produces a two sector sticky price model of food and non-food, following the spirit of New Keynesian economics. A prototype economy is constructed with composite consumption and labour index. The labour supply aggregator is featured by distribution parameter and inelastic labour substitution between two sectors. The aggregate dynamic IS (DIS) equation and inflation equations (NKPC) for individual sectors and aggregate level are derived. The model is closed by including simple Taylor type interest rate rule as the stand of monetary authority. Further, the model incorporates three kinds of shocks. These are



preference shock, productivity shock and monetary shock. The model explicates transmission mechanism of exogenous shocks on endogenous variables. It is revealed that the generalised New Keynesian Phillips curve for aggregate inflation of the model economy is characterised by heterogeneous nominal rigidity associated with output gap across the sectors. This model provides the cornerstone for the development of two distinct structures of advanced and developing economies through two different sets of parametric configuration, following the existing DSGE literature. These two different sets of parameterization work as a baseline for advanced and developing economies and help to distinguish them. Calibrating the baseline model for each type of economy, it is observed that the demand disturbance generated by preference shock is the fundamental force for inflation volatility. This observation reemphasises the need for aggressive anti-inflationary monetary policy for developing countries. Numerical simulation of the inflation coefficient of the Taylor rule lends support to this. In addition to the policy parameter, sensitivity analysis on structural parameters show that frequency of price adjustment, share of labour in the food sector and elasticity of labour substitution are the critical factors which cause greater volatility of inflation in developing economies when compared to advanced group. The price stickiness index directly controls the elasticity of inflation to the deviation of real marginal cost from its steady state for each sector. Labour distribution along with physical constraint in substitution across the sectors critically controls the propagation of shocks to inflation volatility by determining the prominence of food over non-food sector.

The rest of this chapter is divided into four sections. In Section 4.2, the motivation behind modelling the behaviour of aggregate inflation by food and non-food

inflation using New Keynesian paradigm is discussed. In Section 4.3, the Two Sector New Keynesian model is developed. Section 4.4, the calibration of the baseline model is described with data and model comparison, variance decomposition and sensitivity analysis. Finally, Section 4.5 concludes with the key observations and future directions for research.

## **4.2 Motivations for Theoretical Model**

### **4.2.1 Inflation and New Keynesian Paradigm**

Since the early 1980's, New Keynesian theory has emerged as the new class of models that aims to appraise the relationship between inflation, business cycle and monetary policy rules in macroeconomic research<sup>48</sup>. These new generation models are based on a dynamic stochastic general equilibrium framework. This framework is characterized by imperfect competition and nominal rigidities as frictions in the model, and micro-founded with rational expectations. Following the optimisation behaviour of consumers and firms, the equilibrium conditions for aggregate variables are derived. In recent years, this trend of research has received a broad academic consensus on the use of the *New-Keynesian Phillips Curve* (NKPC) to study the dynamics of inflation. NKPC considers the output gap derived from the real marginal cost and forward looking expectation as the key driving force of underlying fluctuations in inflation (Christiano, Eichenbaum and Evans, 2005; Gali, 2008).

### **Real Marginal Cost, Output Gap and Inflation**

The concept of the output gap, which is derived from the real marginal cost, occupies the central role in the new optimising sticky price models. This acts as driving force

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<sup>48</sup> See the works done by Rotemberg (1982), Blanchard & Kiyotaki (1987), Mankiw (1990), Ball & Romer, (1990), Woodford (2003), Gali (2008).

for the underlying fluctuations of inflation. Essentially, the coefficient of real marginal cost is constructed on several structural parameters, and captures the inherited persistence of fluctuations that propels the inflation process outside the practice of nominal price setting. Previously, the traditional models of Phillips curve which were keen to find some empirical support for inflation-output gap relation were naive due to their ad-hoc and mostly a-theoretical nature. In the new paradigm, however, the output gap has a specific meaning. It is the deviation of output from its equilibrium level in the absence of nominal rigidities. Under some assumptions on technology and preferences, it is possible to measure the output gap that is theoretically comprehensive. The benefits of using the output gap as the source of inflationary pressure are of twofold. First, if inflation is induced by non-monetary factors such as supply shocks, then the natural level of output will alter and change the output gap subsequently. Second, if there is a dominant role of demand side factors, the actual output will deviate from its natural level and the transmission mechanism will be captured in the inflation process. Therefore, it appears that the standard output gap model of NKPC provides an improvised theoretical explanation of inflation fluctuations (Domaç & Yücel, 2003; Dua, 2009).

There is substantial evidence in favour of inflation and the output gap relation as predicted by the traditional Phillips Curve for different developed countries like the US, the UK, Euro areas, and Australia. This is mainly at the aggregate level and partly for the disaggregated level of the economy. In comparison to the advanced economies, it is relatively difficult to find the inflation and output gap relation for the developing economies. This is due to dominance of supply side shocks and weak transmission mechanism between interest rates and aggregate demand for

underdeveloped financial sector. Nevertheless, researchers have found some empirical evidence in line with traditional Phillips curve (e.g. Dua, 2009, Paul (2009), Majumdar (2011)).

**Table 4.1: Dynamic Cross Correlation between Inflation and Output Gap**

Correlation Coefficients within 95% Confidence Band				
Order (i)	Lag [Output Gap, Inflation (- i )]		Lead [Output Gap, Inflation (+ i )]	
	Advanced Economy	Developing Economy	Advanced Economy	Developing Economy
0	0.0127	0.0061	0.0127	0.0061
1	-0.0253	-0.0472	0.0387	0.0572
2	-0.0743	-0.0927	0.053	0.09
3	-0.1296	-0.1154	0.061	0.0961
4	-0.1696	-0.1141	0.062	0.079
5	-0.1821	-0.081	0.0607	0.0528
6	-0.1644	-0.0275	0.0524	0.0336

However, in contrast to the studies on the traditional Phillips curve, it is relatively difficult to obtain the necessary empirical support for the New Keynesian Phillips curve (NKPC). Although NKPC is theoretically interesting, it is subject to critical empirical assessments. In particular, the pattern of dynamic cross-correlation between inflation and de-trended output observed in the data suggests that output leads inflation, i.e., the data appears to be more consistent with a traditional backward-looking Phillips curve than the new version. Following this criticism, I make an attempt to examine the dynamic cross correlations between inflation and output gap in the context of advanced and developing economies. Considering a sample period of 2<sup>nd</sup> quarter, 1968 to 4<sup>th</sup> quarter, 2011, the correlation between output gap and inflation is computed over the six period's leads and lags from the group level data of advanced and developing economies. Output gap is computed by

using asymmetric Christiano-Fitzgerald band pass filter of GDP volume index.<sup>49</sup> Results are presented in Table 4.1. These results lend modest evidence in favour of New Keynesian explanation. As emphasized by Gali and Gertler (1999), the NKPC implies that the inflation rate should lead the output gap over the cycle in the sense that a rise (or, decline) in current inflation rate should signal a subsequent rise (or, decline) in output gap. In other words, current output gap is positively correlated with leads of inflation and negatively correlated with lags of inflation. Although the correlation coefficients are not substantial, but their signs are consistent with the theoretical conjecture of New Keynesian argument. It is apparent from the results that over the lags and leads of six quarters, output gap and inflation are negatively and positively correlated respectively for both the groups of economies. These findings provide motivation to adopt the New Keynesian paradigm to study the volatility of inflation<sup>50</sup>.

### **Nature of Expectation and Inflation**

Comparing the traditional or neo-classical expectation augmented Phillips curve with NKPC, the main difference lies in the nature of expectation, i.e. forward looking expectation. This difference has crucial implication. Under rational expectation, future expected inflation can differ from the actual inflation which can make a wedge between actual output and the natural level of output and therefore leaves room for active policy intervention. In NK models, firm's price setting behaviour is subject to future expectations on cost and demand conditions. As a consequence of

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<sup>49</sup> Source of data is the database of International Financial Statistics.

<sup>50</sup> With reference to South-East Asian developing countries, empirical estimates for NKPC can be found in Bhanthumnavin (2002) for Thailand and Funke (2006) for China.

current pricing decisions of firm, the aggregate price level changes and generates inflation which contains forward looking component. This property is expressed through the formal presentation of NKPC. It is evident from the works of Gali and Gertler (1999), Gali, Gertler and Lopez-Salido (2001, 2005) and Sbordone (2005) that when the coefficient of real marginal costs becomes more significant the NKPC tends to become more forward looking. This is consistent with the idea that inflation dynamics is not intrinsic to the model but driven largely by marginal costs, then expectations about future prices should matter more.

### **Nominal rigidities and Inflation**

Following the inception of rational expectations in the literature, macroeconomic research has focused on investigating micro foundations of macroeconomic theory to elucidate the transmission channels of monetary policy. For this purpose, New Keynesian macroeconomists have instrumented the assumption of nominal rigidity with explicit modelling on the optimal behaviour of individuals and firms (Rotemberg & Woodford, 1999; Woodford, 2003). In order to have real effects on monetary policy in the short run, New Keynesian models heavily rely on nominal frictions such as price or wage stickiness. This provides a clear demarcation between NK models and classical monetary frameworks in explaining the behaviour of inflation. In the NK model, the transmission of monetary policy shocks to real variables works through the conventional interest rate channel. Many New Keynesian authors, including Taylor (1980) and Mankiw (1990), have pointed out that nominal disturbances can have effects on real economic activity if prices are sticky and output is demand-determined. In addition to being a source of monetary non-neutralities, the presence of sticky prices may also have strong implications for

the economy's response to non- monetary shocks. The economic agents, although optimize their wage-setting rationally and consider price making decision inter-temporally, are unable to adjust wages and prices immediately as shocks occur due to presence of nominal rigidities within the economy. These rigidities give rise to a trade-off between inflation and excess demand in the short run, which allows monetary policy to affect real variables (Dua, 2009). Inflation is more responsive to departures of output from its natural level if the current price level becomes less sticky. Thus, in the formal expression of NKPC, the index of price stickiness appears as a crucial parameter, associated to the output gap and reveals the response of the economy on the face of structural or policy shocks.

### **Evidence for Micro Level Price Stickiness**

There is convincing empirical evidence for price stickiness based on both aggregated data and micro level data. The results although vary depending on the assumptions used and the methodology employed, the presence of nominal rigidity and sluggish adjustment in price setting behaviour is recognised in the literature. Under a wide range of identifying assumptions, Christiano, Eichenbaum and Evans (1999) found, that following an unexpected monetary policy tightening, aggregate price indices remain unchanged for about a year and a half and start declining thereafter. Bils and Klenow (2002) showed that the median duration for a price change was only 4.3 months. From a micro-data analysis, Dhyne et al. (2005) has documented the average monthly frequency of price adjustment is 15% for the Euro area, which clearly suggests that prices are more rigid in the Euro area than in the US. All of these works suggest that a sizeable fraction of prices remain constant for many months. For developing economies, limited numbers of studies are available on price

stickiness. A case study is done for Sierra Leone by Kovanen (2006). Morandey and Tejada (2008) find similar evidence for Latin American countries. They observe that prices in these economies are fixed for a period of approximately three months. In case of Pakistan, a micro level study is done by Malik, Satti and Sagir (2010) who have found that firms change their price once in a year. Further, it is evident that stickiness can be heterogeneous across the sectors within an economy. Examples can be found in Dhyne et al. (2005) and Morandey and Tejada (2008). Such empirical features of heterogeneity in price stickiness need to be incorporated in a fully specified DSGE models.

#### **4.2.2 Economy - as a Composition of Food and Non-food Sectors**

In this chapter, the model economy is viewed as a composition of the food and non-food sectors. There are a couple of reasons to consider the economy as a composition of the food and non-food sectors.

Firstly, there is a clear asymmetry in the consumption basket between advanced and developing economies. Food takes up a considerable share in composition of CPI for all the developing countries, specifically in Asia compared with other regions. This share is comparatively larger than that of advanced countries. The share of food consumption in the emerging Asian CPI basket varies between forty and sixty per cent. In India and Indonesia, the CPI share of food is higher than the Asian average (Arora & Cardarelli, 2010). Supporting evidence is provided in Table: 4.2. While the average share of expenditure on food consumption is around 21% for advanced countries, it remains more than 50% for developing countries. Moreover, in addition to dominating in the CPI, food price inflation is significantly more variable than that



of non-food items owing to the influence of natural factors. In Figure: 4.1, the coefficient of variation is plotted for food and non-food inflation for advanced and developing economies, over a sample of thirteen countries in each group. It is evident from the plot that food inflation is considerably more volatile than non-food inflation. From Figure 4.2, it is apparent that irrespective of economy, twenty one countries out of twenty six are subject to greater inflation variability in the food sector.

**Table 4.2: Share of Food Expenditure in Advanced and Developing Countries**

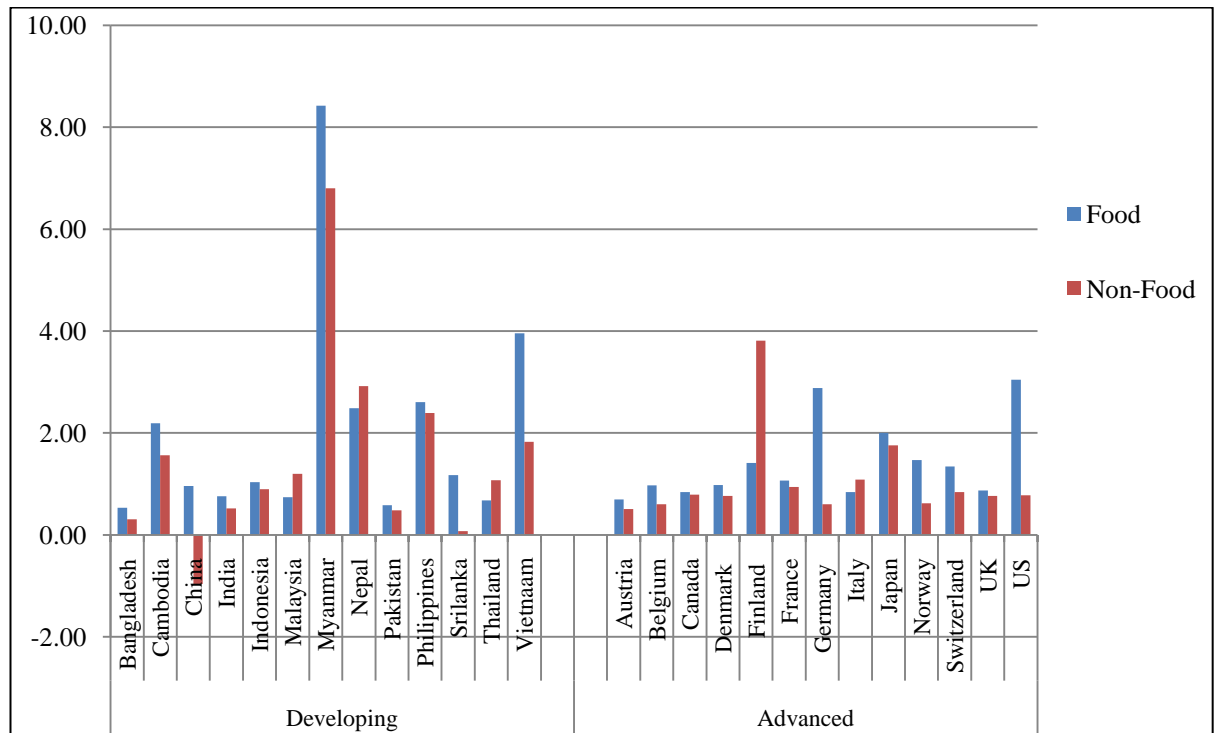
<b>Advanced Countries</b>	<b>Share of Food Expenditure (%)</b>	<b>Developing Countries</b>	<b>Share of Food Expenditure (%)</b>
Australia	21.69	Bangladesh	59.24
Austria	20.02	Cambodia	63.45
Belgium	20.58	China	45.92
Canada	21.48	India	56.75
Denmark	18.39	Indonesia	52.90
Finland	21.31	Malaysia	37.10
France	20.23	Myanmar	72.63
Germany	19.35	Nepal	54.00
Italy	27.05	Pakistan	46.21
Japan	28.80	Philippines	49.28
New Zealand	19.20	Sri Lanka	53.68
Norway	18.58	Thailand	39.67
Switzerland	21.89	Viet Nam	51.08
UK	22.55	Lao's People's Democratic	56.30
US	16.05	Fiji	39.75
<b>Overall Average</b>	<b>21.14</b>	<b>Overall Average</b>	<b>51.86</b>

Source: ILO database

Looking into this variability further, it is observed that the variance of aggregate inflation and food price inflation are highly correlated with value of 0.96. This is statistically significant at 0.1% level for developing countries. It can be noted that such correlation takes the value of 0.48 with significance level at 10% for advanced

economies. It appears that the structural idiosyncrasies of developing economies are responsible for transmitting the exogenous shocks, which impinge on the food sector across the economy and exacerbate inflationary fluctuations at the aggregate level.

**Figure 4.1: Coefficient of Variation of Food & Non-food Inflation**

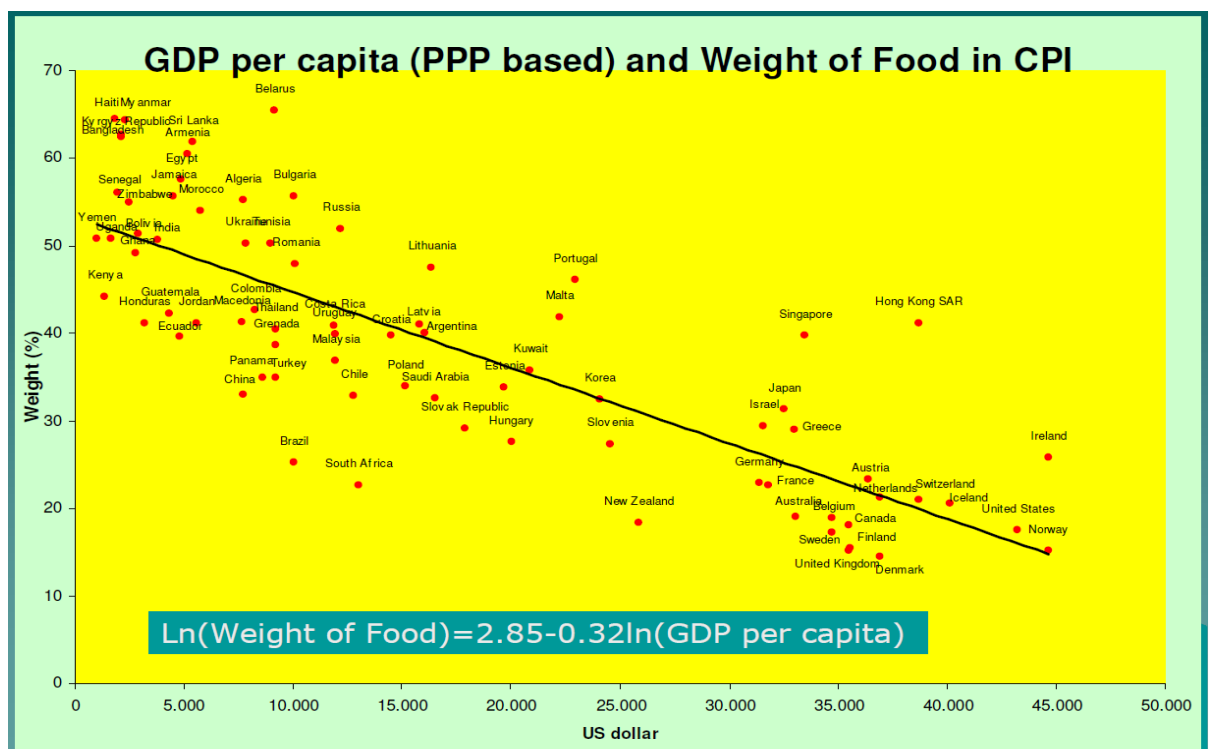


Source: ILO Database & Author's Calculation

Mohanty and Klau (2001), who studied the experience of fourteen emerging market economies in the 1980s and 1990s, found that exogenous supply shocks, in particular those to food prices, play an important role in the inflation process. Thus, the movement of food price inflation can, not only affect the short-run inflation according to their high weight in CPI, but also produce a sustained increase in the inflation rate via inflationary expectations (Dua, 2009). As a result, it is necessary to consider food items exclusively as a sector in the analysis.

Secondly, due to high economic growth rate in developing countries, per capita GDP has risen over time. This has two effects on consumption pattern; due to re-distribution effect the low income group is expected to demand more food while following Engel's Law, the high income group will lean towards luxurious consumption of non-food items. Using data from International Labour Organization, Yorukoglu (2008) has shown the inverse relation between per capita GDP and weight of food in CPI. His observation is presented in the following figure which highlights the prevalence of Engle's Law.

**Figure 4.2: Evidence for Engle's Law**



Source: Reproduced from Yorukoglu (2008)

As income growth takes place, the pattern of consumption substitutability between food and non-food commodities is expected to shift and gradually consumption of food appears to be 'inferior' in comparison to non-food. Micro-level evidence from

cross sectional data suggests that a higher share of total expenditure goes to food for poor households than the rich households (Houthakker, 1957). This evidence has been complemented by the time series results of Ogaki (1992) who showed that the expenditure share on food declines as the economy grows. According to his estimates from the aggregate time series data, the total expenditure elasticity for food (excluding alcoholic beverages) has gone down in the US from 0.531 to 0.492 during the period 1945 to 1988. In the case of a developing country like India, it has fallen from 0.623 to 0.599 during the period 1960 to 1987. All of these findings, in sum, indicate that the proportion of income spent on food varies inversely and disproportionately with the different levels of income in an economy. Such variation gives rise to backward bending non-linear Engle curve. This feature of consumer's behaviour need to be addressed as it can influence the aggregate inflation via internal terms of trade and resource allocation. Hence, it is important to categorise the consumption / production by 'food' and 'non-food' items.

Based on the reasons discussed above, the model economy in this chapter is shaped by combining food and non-food as two distinct sectors. To the best of the author's knowledge, this is the first attempt to analyse the aggregate inflation by food and non-food inflation in a New Keynesian set up.

### **4.3 Two Sector New Keynesian Model of Food and Non-food**

#### **4.3.1 Environment of the Model**

In this section, following Gali (2008), an outline of a New Keynesian dynamic stochastic general equilibrium model is provided which comprises two sectors of

food (F) and non-food (N). The key features of the model are as follows. Firstly, money is considered as a unit of account to quote the price of goods and hence, it justifies the existence of nominal prices. Secondly, imperfect competition is prevailing in the goods market due to differentiated goods produced by firms for which they can set the price. However, the labour markets are perfectly competitive and therefore, the wages remain fully flexible. Thirdly, nominal rigidities are emerging from the Calvo (1983) type price setting behaviour of intermediate goods producing firms. Fourthly, the probability of price adjustment in each period remains the same within the sector but varies across the sector. This allows heterogeneity in nominal stickiness in the model. The building blocks of the prototype economy are:

- A representative household.
- A representative firm from the continuum of final goods producing firms of food sector, indexed by  $i \in [0, 1]$ .
- A representative firm from the continuum of intermediate goods producing firms of food sector, indexed by  $i \in [0, 1]$ .
- A representative firm from the continuum of final goods producing firms of non-food sector, indexed by  $i \in [0, 1]$ .
- A representative firm from the continuum of intermediate goods producing firms of non-food sector, indexed by  $i \in [0, 1]$ .
- Central Bank.

### **4.3.2 Description of Model**

#### **Representative Household**

The economy is populated by a continuum of households within a unit interval. The representative household enters each period  $t = 0, 1, 2 \dots \infty$  with nominal bonds. Each

bond will pay one unit of money tomorrow if it is bought today. At date  $t$ , the household redeems one period bonds purchased in the previous periods, which pays  $B_{t-1}$  additional units of money. At the beginning of the period, the household also receives a lump-sum monetary transfer  $T_t$  from the central bank.

The household is structured in two layers, one is head of the household and the other is the members of the household. During the period ' $t$ ', members of the household supplies raw labour for food ( $N_{F,t}$ ) and non-food sector ( $N_{N,t}$ ) as it is demanded by the head of the household. In return, they demand for food ( $C_{F,t}$ ) and non-food ( $C_{N,t}$ ) consumption, which are provided by head of the household. Using CES type technology, head of the household produces aggregate consumption and labour supply. Head of the household interacts with the various intermediate goods-producing firms of the food and non-food sector to sell the labour of  $N_{F,t}$  and  $N_{N,t}$  units and earns the wage income of  $W_{F,t}N_{F,t}$  and  $W_{N,t}N_{N,t}$ , where  $W_{F,t}$  and  $W_{N,t}$  denote the nominal wages of both the sectors.

Next, head of the household goes to finished goods producing firms to purchase  $C_{F,t}$  and  $C_{N,t}$  units of food and non-food items. He purchases the same at the nominal prices of  $P_{F,t}$  and  $P_{N,t}$  respectively. The household also uses some of this money to purchase new bonds of value  $Q_t B_t$ , where  $Q_t$  is the bond price and  $1/Q_t$  denotes the gross nominal interest rate between  $t$  and  $(t + 1)$  period.

Overall, the representative household chooses the sequences of  $C_{F,t}$  ,  $C_{N,t}$  ,  $N_{F,t}$  ,  $N_{N,t}$  (using aggregation technology), and  $B_t$ , to maximise the present value of life time expected utility function which is given by:

$$E_t \sum_{t=0}^{\infty} \beta^t U(C_t, N_t) \dots\dots\dots (1)$$

Subject to the periodical budget constraint of:

$$P_t C_t + Q_t B_t \leq B_{t-1} + W_t N_t + T_t \dots\dots\dots (2)$$

Where,

The household's utility function of aggregate consumption and labour index is additively separable and specified as:

$$U(C_t, N_t) = \rho_{p,t} \left( \frac{C_t^{1-\sigma}}{1-\sigma} \right) - \left( \frac{N_t^{1+\varphi}}{1+\varphi} \right) \dots\dots\dots (3)$$

$$\text{Aggregate Consumption Expenditure: } P_t C_t = P_{F,t} C_{F,t} + P_{N,t} C_{N,t} \dots\dots\dots (4)$$

$$\text{Aggregate Wage Income: } W_t N_t = W_{F,t} N_{F,t} + W_{N,t} N_{N,t} \dots\dots\dots (5)$$

The utility function, given by (3) reveals that the representative household derives utility from consumption of the food and non-food basket and bears the disutility for supplying labour to both the sectors. The aggregate consumption 'C<sub>t</sub>' and aggregate labour index 'N<sub>t</sub>' over two sectors are considered as a generalised form of Constant Elasticity of Substitution (CES) function of food and non-food sectors and presented in (6) and (7). Such form of consumption and labour aggregator gives freedom in the calibration process for parameterization. Besides, 'ρ<sub>p,t</sub>' stands for the preference shock which is considered on consumption.

$$C_t = \left[ \alpha^{\frac{1}{\varepsilon}} (C_{F,t} - \Lambda)^{\frac{\varepsilon-1}{\varepsilon}} + (1 - \alpha)^{\frac{1}{\varepsilon}} C_{N,t}^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}} \dots\dots\dots (6); \Lambda > 0; 0 < \alpha < 1; \varepsilon > 0;$$

$$N_t = \left[ v^{\frac{1}{\gamma}} N_{F,t}^{\frac{\gamma-1}{\gamma}} + (1-v)^{\frac{1}{\gamma}} N_{N,t}^{\frac{\gamma-1}{\gamma}} \right]^{\frac{\gamma}{\gamma-1}} \dots\dots\dots (7); \quad v, \gamma \in [0, 1]$$

From the consumption aggregator ( $C_t$ ) in (6), it can be observed that this sub-utility function exhibits *non-homothetic* preference in consumption between food and non-food. This feature is incorporated by introducing a subsistence level of consumption of food. In (6), the subsistence level of food consumption is given by ‘ $\Lambda$ ’. It implies that utility from food consumption is only generated when this consumption is greater than a specified level ‘ $\Lambda$ ’, i.e. the minimum consumption requirement for subsistence. In contrast, any positive unit of non-food consumption creates utility for the household. The parameter ‘ $\Lambda$ ’ controls the degree of inter-temporal non-homotheticity in the model. In the special case of  $\Lambda = 0$ , the consumption aggregator converts to the standard form of homothetic preferences. The key implication of non-homotheticity is to capture the transitional dynamics in the expenditure pattern on food and non-food goods in course of economic growth, as indicated by Engel’s law. Consumption aggregator shows the household’s preference between food and non-food consumption. The parameters ‘ $\alpha$ ’ reveals the share of food in the aggregate consumption. From Table 4.2, significant difference in the share of food expenditure between advanced and developing country is visible. This provides an idea of higher consumption allocation for food in developing countries compared to advanced countries. Such difference in allocation of consumption between food and non-food may have strong implication for the difference in inflationary process between two groups of economies. The parameter ‘ $\varepsilon$ ’ denotes the elasticity of substitution between food and non-food consumption.



Equation (7) represents a technology of producing effective labour ( $N_t$ ) using two types of sector specific raw labour,  $N_{F,t}$  and  $N_{N,t}$ . Head of the household decides about the efficient (cost minimizing) allocation of his family members between the food sector (e.g. farming) and the non-food sector (e.g. textile industry). While reallocating labour between these two sectors, he takes into account that shifting a family member from one sector to another could break off her bonding with her current occupation and is likely to make her fatigued. This lack of substitutability is featured by the parametric restriction on  $\gamma$  while  $v$  is the standard share parameter of labour in each sector. It will be shown later that this imperfect substitutability amplifies the propagation of shocks to inflation volatility.

As in the spirit of Galí (2002), the head of the household thus minimizes the cost for producing one unit of effective labour which means minimization of (5) subject to (7). This leads to two raw labour demand functions for food and non-food and the wage aggregator ( $W_t$ ) as follows:

$$N_{F,t} = v \left( \frac{W_{F,t}}{W_t} \right)^{-\gamma} N_t \dots\dots\dots (8)$$

$$N_{N,t} = (1 - v) \left( \frac{W_{N,t}}{W_t} \right)^{-\gamma} N_t \dots\dots\dots (9)$$

$$W_t = \{vW_{F,t}^{1-\gamma} + (1 - v)W_{N,t}^{1-\gamma}\}^{\frac{1}{1-\gamma}} \dots\dots\dots (10)$$

Note that,  $\gamma \in [0, 1]$  implies that reallocation of labour between the sectors is painful. One can consider two special cases. First, if  $v = 0$ , then the household will work only in the non-food sector, and second, if  $v = 1$ , the household will work only in the food sector.

In the utility function of the household, the law of motion of preference shock, ‘ $\rho_{p,t}$ ’, is defined as:

$$\left(\frac{\rho_{p,t}}{\rho}\right) = \left(\frac{\rho_{p,t-1}}{\rho}\right)^{\rho} \exp\{\epsilon_{p,t}\} \dots\dots\dots (11);$$

Where,  $\{\epsilon_{p,t}\}$  is an *i.i.d* with  $\{0, \sigma_p^2\}$  and  $\rho$  is the steady state value of the preference shock.

The consumption bundle of food and non-food is constituted by a variety of differentiated items produced by the continuum of identical firms, distributed over unit interval. Equations (12) and (13) express the composition of aggregate food and non-food consumption respectively.

$$C_{F,t} = \left[ \left\{ \int_0^1 C_{F,t}^{\frac{\epsilon_F-1}{\epsilon_F}}(i) di \right\}^{\frac{\epsilon_F}{\epsilon_F-1}} \right] \dots\dots\dots (12)$$

$$C_{N,t} = \left[ \left\{ \int_0^1 C_{N,t}^{\frac{\epsilon_N-1}{\epsilon_N}}(i) di \right\}^{\frac{\epsilon_N}{\epsilon_N-1}} \right] \dots\dots\dots (13)$$

Here, the parameters,  $\epsilon_F$  and  $\epsilon_N$  represent the elasticity of substitution in consumption, within the food and non-food sectors respectively. Similar to the consumption, the labour supplied by the household to each sector, is aggregated over the continuum of firms and given by (14) and (15):

$$N_{F,t} = \int_0^1 N_{F,t}(i) di \dots\dots\dots (14);$$

$$N_{N,t} = \int_0^1 N_{N,t}(i) di \dots\dots\dots (15);$$

Further to note for the budget constraint, given by (2):

$$P_{F,t}C_{F,t} = \int_0^1 P_{F,t}(i)C_{F,t}(i) di \dots\dots\dots (16);$$

$$P_{N,t}C_{N,t} = \int_0^1 P_{N,t}(i)C_{N,t}(i) di \dots\dots\dots (17);$$

$$W_{F,t}N_{F,t} = \int_0^1 W_{F,t}(i)N_{F,t}(i) di \dots\dots\dots (18);$$

$$W_{N,t}N_{N,t} = \int_0^1 W_{N,t}(i)N_{N,t}(i) di \dots\dots\dots (19);$$

Where, (16) – (19) are implying aggregate expenditure on food consumption, non-food consumption, earnings by working in food sector and non-food sector.

The household decides on optimal allocations of consumption expenditures among the different goods of both food and non-food sectors. This involves minimisation of aggregate expenditures for both sectors subject to one unit of aggregate consumption. Such optimisation exercise yields two sets of demand equations for the food and non-food sectors, given in equations (20) and (21) respectively. See Appendix A.3 for the derivation of demand schedules of food and non-food sector.

$$C_{F,t}(i) = \left( \frac{P_{F,t}(i)}{P_{F,t}} \right)^{-\varepsilon_F} C_{F,t} \dots\dots\dots (20)$$

$$C_{N,t}(i) = \left( \frac{P_{N,t}(i)}{P_{N,t}} \right)^{-\varepsilon_N} C_{N,t} \dots\dots\dots (21)$$

The price indices of food and non-food are:

$$P_{F,t} = \left\{ \int_0^1 P_{F,t}^{1-\varepsilon_F}(i) di \right\}^{\frac{1}{1-\varepsilon_F}} \dots\dots\dots (22)$$

$$P_{N,t} = \left\{ \int_0^1 P_{N,t}^{1-\varepsilon_N}(i) di \right\}^{\frac{1}{1-\varepsilon_N}} \dots\dots\dots (23)$$

See Appendix A.3 for the derivation of individual sector's price index.

Note that, in addition to the flow budget constraint of (2), the representative household is subject to a solvency constraint that prevents it to engage in the Ponzi-type scheme,

$$\text{i.e. } \lim_{T \rightarrow \infty} E_t\{B_T\} \geq 0 ; \forall t .$$

### Representative Final Goods Producing Firm

The production functions of the final goods producing firms for the food and non-food sectors are defined in the following way:

$$Y_{F,t} = \left[ \int_0^1 Y_{F,t}^{\frac{\varepsilon_F-1}{\varepsilon_F}}(i) di \right]^{\frac{\varepsilon_F}{\varepsilon_F-1}} \dots\dots\dots (24)$$

$$Y_{N,t} = \left[ \int_0^1 Y_{N,t}^{\frac{\varepsilon_N-1}{\varepsilon_N}}(i) di \right]^{\frac{\varepsilon_N}{\varepsilon_N-1}} \dots\dots\dots (25)$$

Therefore, the nominal value of aggregate output in the economy can be expressed by the sum of two sector's nominal output, i.e.

$$P_t Y_t = P_{F,t} Y_{F,t} + P_{N,t} Y_{N,t} \dots\dots\dots (26)$$

Where,  $P_t$  denotes the price aggregator of the economy and is defined as:

$$P_t = \Lambda P_{F,t} + \left\{ \alpha P_{F,t}^{1-\varepsilon} + (1-\alpha) P_{N,t}^{1-\varepsilon} \right\}^{\frac{1}{1-\varepsilon}} \dots\dots\dots (27)$$

See Appendix A.4 for the derivation of Price Aggregator.

The final goods producing firms in both sectors take its price as given (i.e. they are competitive) and combine intermediate inputs to minimise their production costs and

provides the final output for the household's consumption. In the course of their production, they yield the following demand schedule for the intermediate goods producing firms in each sector:

$$Y_{F,t+k|t} = \left( \frac{P_{F,t}^*}{P_{F,t+k}} \right)^{-\varepsilon_F} Y_{F,t+k} \dots\dots\dots (28)$$

$$Y_{N,t+k|t} = \left( \frac{P_{N,t}^*}{P_{N,t+k}} \right)^{-\varepsilon_N} Y_{N,t+k} \dots\dots\dots (29)$$

Where, the above set of demand schedule which comes from the representative household's expenditure minimisation exercise, shows that the intermediate goods producing firms in each sector forecast their prospective market demand (i.e.,  $Y_{F,t+k|t}$  and  $Y_{N,t+k|t}$ ) taking into consideration the re-optimised prices (i.e.,  $P_{F,t}^*$  and  $P_{N,t}^*$ ).

**Representative Intermediate Goods Producing Firm**

Intermediate goods producing firms are monopolistically competitive, facing iso-elastic demand functions and producing differentiated goods for final goods producing firms. The production functions for the food and non-food sectors are as follows:

$$Y_{F,t}(i) = A_{F,t} N_{F,t}^{1-\alpha_F}(i) \dots\dots\dots (30); 0 < \alpha_F < 1$$

$$Y_{N,t}(i) = A_{N,t} N_{N,t}^{1-\alpha_N}(i) \dots\dots\dots (31); 0 < \alpha_N < 1$$

Here,  $A_{F,t}$  represents the aggregative productivity shock experienced by all intermediate firms existing in the food sector,  $Y_{F,t}(i)$  represents the output produced as food items by  $i^{\text{th}}$  firm in food sector,  $N_{F,t}(i)$  denotes the labour input employed for food production,  $(1 - \alpha_F)$  shows the share of labour across the firms. Similarly,

$A_{N,t}$ ,  $Y_{F,t}(i)$ ,  $N_{N,t}(i)$  and  $(1 - \alpha_N)$  represents the aggregative productivity shock, output produced, and necessary labour input for the  $i$ -th firm of non-food sector respectively. The laws of motion of productivity shocks are specified as:

$$\left(\frac{A_{F,t}}{A_F}\right) = \left(\frac{A_{F,t-1}}{A_F}\right)^{\rho_f} \exp\{\epsilon_{f,t}\} \dots\dots\dots (32)$$

$$\left(\frac{A_{N,t}}{A_N}\right) = \left(\frac{A_{N,t-1}}{A_N}\right)^{\rho_n} \exp\{\epsilon_{n,t}\} \dots\dots\dots (33)$$

Where, the terms  $\{\epsilon_{f,t}\}$  and  $\{\epsilon_{n,t}\}$  are white noise process with  $\{0, \sigma_F^2\}$  and  $\{0, \sigma_N^2\}$ .

$A_F$  and  $A_N$  are the steady state level of productivity shocks.

From the relations of (14), (15), (20), (21), (30) and (31), by aggregation, one can obtain the relations among output, employment and productivity shocks of each sector. These are as follows:

$$N_{F,t} = \left(\frac{Y_{F,t}}{A_{F,t}}\right)^{\left(\frac{1}{1-\alpha_F}\right)} \int_0^1 \left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\left(\frac{\epsilon_F}{1-\alpha_F}\right)} di \dots\dots\dots (34)$$

$$N_{N,t} = \left(\frac{Y_{N,t}}{A_{N,t}}\right)^{\left(\frac{1}{1-\alpha_N}\right)} \int_0^1 \left(\frac{P_{N,t}(i)}{P_{N,t}}\right)^{-\left(\frac{\epsilon_N}{1-\alpha_N}\right)} di \dots\dots\dots (35)$$

Since the production functions are identical across all firms of the food and non-food sector, the expression of average marginal productivity of labour of a generic  $i$ -th firm obtained from (30) and (31) will remain the same for the aggregate level for respective sectors of the economy.

$$MPN_{F,t} = (1 - \alpha_F) A_{F,t} N_{F,t}^{-\alpha_F} \dots\dots\dots (36)$$

$$MPN_{N,t} = (1 - \alpha_N) A_{N,t} N_{N,t}^{-\alpha_N} \dots\dots\dots (37)$$

These relations are important for obtaining the expression for the deviation of the real marginal cost from steady state.

Intermediate goods producing firms take a crucial role in determining the dynamics of inflation by their price re-optimisation mechanism which follows Calvo (1983) type random price duration. It is assumed that the intermediate firms in the food and non-food sectors reset their prices in any given period with the probability of  $(1 - \theta_F)$  and  $(1 - \theta_N)$  which is independent of the pricing strategy of other firms and the time elapsed since the last adjustment. Thus,  $\theta_F$  and  $\theta_N$  measure the fraction of firms who keep their prices unchanged. If  $P_{F,t}^*$  and  $P_{N,t}^*$  denote the optimal price set by the firms in the food and non-food sectors in period 't', the evolution of food and non-food prices can be specified in the following way.

$$P_{F,t} = \left[ \theta_F (P_{F,t-1})^{1-\varepsilon_F} + (1 - \theta_F) (P_{F,t}^*)^{1-\varepsilon_F} \right]^{\frac{1}{1-\varepsilon_F}} \dots\dots\dots (38)$$

$$P_{N,t} = \left[ \theta_N (P_{N,t-1})^{1-\varepsilon_N} + (1 - \theta_N) (P_{N,t}^*)^{1-\varepsilon_N} \right]^{\frac{1}{1-\varepsilon_N}} \dots\dots\dots (39)$$

It should be noted that the exact form of the equation describing aggregate inflation dynamics depends on the way sticky prices are modelled.

To solve the optimal price setting problem, firms of food and non-food sector will maximise the discounted value of their expected profits subject to the sequence of their demand constraints. This can be written in the following way:

For Food Sector:

$$\text{Max}_{P_{F,t}^*} \sum_{k=0}^{\infty} \theta_F^k E_t [Q_{t,t+k} \{ P_{F,t}^* Y_{F,t+k|t} - \Psi_{F,t+k}(Y_{F,t+k|t}) \}] \dots\dots\dots (40)$$

Subject to  $Y_{F,t+k|t} = \left(\frac{P_{F,t}^*}{P_{F,t+k}}\right)^{-\varepsilon_F} Y_{F,t+k}$ ; where,  $\Psi_{F,t+k}(\cdot)$  is the cost function of food sector and  $Q_{t,t+k}$  is the stochastic discount factor.

For Non-food Sector:

$$\text{Max}_{p_{N,t}^*} \sum_{k=0}^{\infty} \theta_N^k E_t [Q_{t,t+k} \{P_{N,t}^* Y_{N,t+k|t} - \Psi_{N,t+k}(Y_{N,t+k|t})\}] \dots\dots\dots (41)$$

Subject to the sequence of demand constraints:  $Y_{N,t+k|t} = \left(\frac{P_{N,t}^*}{P_{N,t+k}}\right)^{-\varepsilon_N} Y_{N,t+k}$ ; where,  $\Psi_{N,t+k}(\cdot)$  is the cost function of non-food sector and  $Q_{t,t+k}$  is the stochastic discount factor.

### Monetary Policy

To close the model, it is assumed that the monetary authority is following a simple Taylor rule which considers nominal interest rate as the policy instrument and responds to the deviations of inflation and aggregate output from their steady state level. Such a rule is specified as:

$$I_t = \left(\frac{1}{\beta}\right) \left(\frac{\Pi_t}{\Pi}\right)^{\phi_\pi} \left(\frac{Y_t}{Y}\right)^{\phi_y} \xi_t \dots\dots\dots (42); \phi_\pi > 1; \phi_y > 0$$

Where,  $I_t$  is the nominal interest rate,  $\Pi_t = \frac{P_t}{P_{t-1}}$  is the gross inflation which values one at steady state ( $\Pi$ ),  $Y_t$  is the aggregate output with steady state value  $Y$  and  $\xi_t$  is the monetary policy shock. The law of motion for policy shock is:

$$\left(\frac{\xi_t}{\xi}\right) = \left(\frac{\xi_t}{\xi}\right)^{\rho_m} \exp\{\epsilon_{m,t}\} \dots\dots\dots (43);$$

Where,  $0 < \rho_m < 1$ ;  $\epsilon_{m,t} \sim N(0, \sigma_m^2)$



### 4.3.3 Log-linear Version of Model

In this sub-section, the analytical core of the model is presented. It consists of the equations which are obtained by taking a log-linear approximation of the equilibrium conditions of the original nonlinear model around the deterministic steady state.

**Table 4.3: List of Key Equations**

$$\tilde{y}_t = E_t\{\tilde{y}_{t+1}\} - \frac{1}{\sigma}[i_t - E_t\{\pi_{t+1}\} - r_t^n] + \left(\frac{1-\rho_p}{\sigma}\right) \ln\rho_{p,t} \dots\dots\dots (44)$$

$$r_t^n = \delta + \sigma E_t\{\Delta y_{t+1}^n\} \dots\dots\dots (45)$$

$$y_t^n = \varsigma_f y_{F,t}^n + \varsigma_n y_{N,t}^n \dots\dots\dots (46)$$

$$\pi_t = d_f \pi_{F,t} + (1 - d_f) \pi_{N,t} \dots\dots\dots (47)$$

$$\pi_{F,t} = \beta E_t\{\pi_{F,t+1}\} + \vartheta_f^F \tilde{y}_{F,t} + \vartheta_n^F \tilde{y}_{N,t} \dots\dots\dots (48)$$

$$\pi_{N,t} = \beta E_t\{\pi_{N,t+1}\} + \vartheta_f^N \tilde{y}_{F,t} + \vartheta_n^N \tilde{y}_{N,t} \dots\dots\dots (49)$$

$$i_t = \delta + \phi_\pi \pi_t + \phi_y \tilde{y}_t + \xi_t \dots\dots\dots (50)$$

$$\Delta y_{F,t}^n = \psi_p^F \Delta \ln\rho_{p,t} + \psi_f^F \Delta a_{F,t} + \psi_n^F \Delta a_{N,t} \dots\dots\dots (51)$$

$$\Delta y_{N,t}^n = \psi_p^N \Delta \ln\rho_{p,t} + \psi_f^N \Delta a_{F,t} + \psi_n^N \Delta a_{N,t} \dots\dots\dots (52)$$

$$\ln\rho_{p,t} = \rho_p \ln\rho_{p,t-1} + \epsilon_{p,t} \dots\dots\dots (53)$$

$$a_{F,t} = \rho_F a_{F,t-1} + \epsilon_{f,t} \dots\dots\dots (54)$$

$$a_{N,t} = \rho_N a_{N,t-1} + \epsilon_{n,t} \dots\dots\dots (55)$$

$$\xi_t = \rho_m \xi_{t-1} + \epsilon_{m,t} \dots\dots\dots (56)$$

In general, the variables are defined in the following form:  $x_t = \ln\left(\frac{X_t}{X}\right)$  i.e. log-deviations of actual values ( $X_t$ ) from their steady state values ( $X$ ). The only exceptions are inflation and interest rates which are expressed in levels. Further details regarding the First Order optimisation condition derived from the micro-foundation of the model can be found in the Appendix A.5. The parameters appearing in the equations capture the primitive structure of the economy.

**Dynamic IS Curve**

The consumption Euler equations is the key to obtain standard dynamic IS curve relation for the two sectors in the economy. Dynamic optimisation exercise of the representative household for aggregate consumption yields a generic consumption Euler equations for the economy as a whole. See Appendix A.6 for the derivation of consumption Euler equation. The dynamic allocation of consumption reflected from Euler equations depends on inter-temporal elasticity of substitution. Moreover, consumption Euler equation contains the preference shock. Using market clearing condition for the aggregate economy in consumption Euler equations, the dynamic IS curve is obtained in (44). See Appendix A.7 for the derivation. From the dynamic IS equation, it is clear that the current period output gap positively depends on the expected future output gap and is negatively related to the expected real rate of interest. If the expected real rate of interest goes up, household will do the necessary inter-temporal adjustment in its consumption according to the degree of risk aversion. Further, the preference shock appears in the IS relations and influences the

movement of the aggregate output gap as a demand side shock positively for the whole economy. It is pertinent to notice the term of  $r_t^n$  in the equation of Dynamic IS. It denotes the real natural rate of interest of the economy and is defined by equation (45). It can be seen that real natural rate of interest depends on the natural level of output which is driven by the exogenous shocks. Therefore, the impacts of shocks pass through to the output gap via the channel of real natural interest rate. Finally, expected real interest rate is subject to the future period's inflation, which is a linear combination of food and non-food inflation.

### **New Keynesian Phillips Curve (NKPC)**

The staggered price setting behaviour of the intermediate firms of both the food and non-food sectors features the inflation dynamics for the individual sector as well as for the aggregate inflation. Firm's inability to adjust prices optimally every period implies the existence of a wedge between output and its natural level for which the deviation of real marginal cost from its steady state can be substituted by output gap under specific assumptions<sup>51</sup>. The deviation of real marginal cost from the steady state is replaced in terms of output gap to obtain the standard forms of NKPC for each sector. See the derivations of NKPCs in Appendices A.10 and A.11. Equation (47) defines the aggregate inflation for the economy. See Appendix A.4 for the derivation of inflation aggregator. Equations (48) and (49) stand for inflation equations of the food and non-food sectors respectively.

The NKPCs for each sector consists of forward looking term and the output gaps of both sector. This provides an insight that fluctuations of inflation in each sector can

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<sup>51</sup> See Gali (2002).

be propelled by the fluctuations of its own output gap as well as by the other one. This connection between inflation and sectoral output gaps stems up from the microstructure of labour allocation across the sectors. Since labour is the only input in the model, the shocks that perturbs the equilibrium labour allocation between the sector, leads to the misalignment of actual and natural level of output and hence, the output gaps. It is important to note that depending on the inelastic nature of labour substitution across the sectors, the effect of exogenous disturbance will be transmitted to aggregate inflation. Besides, the share of labour for food sector, embedded within the coefficients of output gaps can critically determine the ‘magnitude of pass through’ of exogenous disturbance. Inelastic labour adjustment and the share of labour for food sector together control the persistence of fluctuations in inflation through the channel of real marginal cost. As it appears from the standard New Keynesian idea, furthermore, the impact of output gap fluctuations on inflation also depends on the elasticity of real marginal costs of that sector along with the other structural parameters.

Finally, aggregate inflation has been obtained as the weighted sum of food and non-food inflation, where the weight is subject to elasticity of substitution in consumption, distribution of consumption between food and non-food and the subsistence level of food consumption.

### **Taylor – type Interest Rate Rule of Central Bank**

The central bank constitutes the monetary block for the model. The log-linearized form of interest rate rule governed by the central bank is specified in (50). Note that,  $\phi_\pi$  and  $\phi_y$  are the coefficients of inflation and output gap stabilisation.

## Natural Level of Output and Exogenous Shocks

Using the definition of real marginal cost, the natural level of output in each sector can be derived and their evolution can be expressed as the functions of productivity shocks and preference shock. These are given in (51) and (52). See A.12 for the derivation of natural output as the function of exogenous shocks.

### Exogenous shock process

In this model, there are four exogenous variables. These are preference shock on aggregate consumption ( $\ln \rho_{p,t}$ ), productivity shock in the food ( $a_{F,t}$ ) and non-food ( $a_{N,t}$ ) sector and monetary policy shock ( $\xi_t$ ). Contemporaneous covariances among the shocks are assumed to be zero. Log-linear forms of the forcing process are given in equations of (53) to (56).

### 4.3.4 Equilibrium Determination

The two-sector New Keynesian model is specified by the linear system of equations mentioned in the last subsection, from Equation (44) to (56). In these thirteen equations, we have thirteen unknowns, comprises of nine endogenous variables and four exogenous variables. The analytical solution of the model cannot be obtained. Instead, using the linear system of equations, the model is calibrated to obtain the equilibrium.

### 4.4 Calibration

The model, developed in Section 4.3, has twenty structural parameters and eight parameters for the exogenous shock process. Two different sets of parametric configuration are taken to construct the baseline for advanced and developing

economies. All parameters of the model are calibrated for quarterly data frequency. For the purpose of individual characterisation of advanced and developing economies, values of the parameters are taken mostly from the Dynamic Stochastic General Equilibrium literature and few of them are calculated by author. Since the variables included in the model are taken as the log-deviation from their steady state level, so the values of their first order theoretical moments remain zero by construction. Therefore, instead of level, the second order moments of the major six endogenous variables of the model are targeted to match with data of advanced and developing countries, such as: aggregate output gap, individual output gaps of food and non-food sectors, aggregate inflation and individual inflation of food and non-food sectors. Given the target, the baseline model has been parameterized for advanced and developing economies and calibrated. Table: 4.4A, 4.4B, and 4.4C, provide complete parameterization of the model and Table 4.4D shows the comparison between the data and the model on the key variables.

#### **4.4.1 Parameterization**

Starting with the relative risk aversion coefficient, it is considered that economic agents in the developing economies are more risk averse in nature than in the advanced economies. Gali (2005) showed that the value of this coefficient can vary from 1 to 5. Discount factor, the benchmark of forward looking behaviour, is taken as 0.99 and 0.98 for developed and developing economies respectively, in order to keep the consistency with real interest rate differential. In the case of inverse of the Frisch elasticity of labour supply, the value is taken from Gali and Blanchard (2007) for developed countries. For developing economies, the elasticity of employment is measured by Goldberg (2010) as 0.15-0.17 and following this, the baseline value is

taken as 6. Following Brooks (2010), the steady state share of food production in total output for developing countries (0.14) is taken substantially larger than the developed countries (0.05).

The share of food consumption in the aggregate consumption basket varies between 50-65% for East and South-East Asian developing countries and therefore, it is taken as 0.57 for these economies (Hoyos & Lessem, 2008). As the evidence suggests in Seale, et al., (2003), the share of food consumption in aggregate consumption expenditure is significantly lower in developed countries, so, it is set at 0.16. However, as a certain level of calorie is required for economic agents to survive irrespective of the economy, the level of subsistence consumption remains the same for both advanced and developing economies and is taken as 0.38 following Gollin et al., (2004). Regarding the elasticity of substitution between food and non-food consumption, it depends on the per capita income of households. Since, developed countries have higher per-capita income and developing countries are on their way to catching up with this, it is plausible to find a more elastic nature of substitutability in consumption for advanced countries than developing group and accordingly, value of the parameter is chosen as 1.5 and 1.2 respectively<sup>52</sup>.

In case of the labour aggregator, the parameters of labour share and elasticity of labour substitution can be chosen freely from their specified parametric range. It is assumed that due to land attachment and ethnic background, households of developing economies are involved more to work in the food sector than that of advanced countries. Further, a greater integrity of the households with work schedule

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<sup>52</sup> See Masao Ogaki (1992).

across the food and non-food sectors in developing countries entails greater physical constraint for them to reschedule it when compared to the households of advanced countries.

**Table 4.4A: Parametric Configuration for Advanced Economy**

Parameters		Values
$\sigma$	Risk aversion coefficient	2
$\varphi$	Inverse of the elasticity of labour supply	5
$\beta$	Discount Factor	0.99
$\delta$	$-\ln\beta$	0.01
$s_F$	Share of Food production in Aggregate output at steady state	0.05
$\alpha$	Share of food in consumption	0.16
$\varepsilon$	Elasticity of substitution between food to non-food consumption	1.5
$v$	Share of labour in food sector	0.06
$\gamma$	Elasticity of substitution of labour supply between food and non-food sector	0.75
$\Lambda$	Subsistence level of food consumption	0.38
$\varepsilon_F$	Intra-sector elasticity of substitution for food sector	11
$\varepsilon_N$	Intra-sector elasticity of substitution for non-food sector	15
$\theta_F$	Degree of price stickiness in food sector	0.25
$\theta_N$	Degree of price stickiness in non-food sector	0.67
$\frac{N_F}{N}$	Steady state labour allocation for food sector in the aggregate labour	0.08
$\frac{N_N}{N}$	Steady state labour allocation for non-food sector in the aggregate labour	0.92
$\alpha_F$	Measure of decreasing returns in food sector production	0.36
$\alpha_N$	Measure of decreasing returns in non-food sector production	0.55
$\phi_\pi$	Coefficient of inflation stabilisation	1.5
$\phi_y$	Coefficient of output gap stabilisation	0.125



**Table 4.4B: Parametric Configuration for Developing Economy**

Parameters		Values
$\sigma$	Risk aversion coefficient	2.2
$\varphi$	Inverse of the elasticity of labour supply	6
$\beta$	Discount Factor	0.98
$\delta$	$-\ln\beta$	0.02
$s_F$	Share of Food production in Aggregate output at steady state	0.14
$\alpha$	Share of food in consumption	0.57
$\varepsilon$	Elasticity of substitution between food to non-food consumption	1.2
$v$	Share of labour in food sector	0.4
$\gamma$	Elasticity of substitution of labour supply between food and non-food sector	0.15
$\Lambda$	Subsistence level of food consumption	0.38
$\varepsilon_F$	Intra-sector elasticity of substitution for food sector	7
$\varepsilon_N$	Intra-sector elasticity of substitution for non-food sector	10
$\theta_F$	Degree of price stickiness in food sector	0.2
$\theta_N$	Degree of price stickiness in non-food sector	0.65
$\frac{N_F}{N}$	Steady state labour allocation for food sector in the aggregate labour	0.42
$\frac{N_N}{N}$	Steady state labour allocation for non-food sector in the aggregate labour	0.58
$\alpha_F$	Measure of decreasing returns in food sector production	0.2
$\alpha_N$	Measure of decreasing returns in non-food sector production	0.33
$\phi_\pi$	Coefficient of inflation stabilisation	1.2
$\phi_y$	Coefficient of output gap stabilisation	0.15

**Table 4.4C: Parameterization of Shock Structure**

Shock Parameters	Values for Advanced Economy	Source	Values for Developing Economy	Source
$\rho_p$	0.947	Ireland, 2004	0.78	Peiris & Saxegaard, 2007
$\rho_F$	0.95	Ireland, 2004	0.85	Annicchiarico, et al., 2008
$\rho_N$	0.962	-	0.9	Ahmad, et al., 2012
$\rho_m$	0.7	-	0.5	Peiris & Saxegaard, 2007
$\sigma_p$	0.0405	Ireland, 2004	0.065	Peiris & Saxegaard, 2007
$\sigma_F$	0.014	-	0.022	Annicchiarico, et al., 2008
$\sigma_N$	0.012	Ireland, 2004	0.018	Ahmad, et al., 2012
$\sigma_m$	0.0031	Ireland, 2004	0.013	Peiris & Saxegaard, 2007

This underlines the fact that substitutability of labour between the two sectors is more inelastic for households of developing countries than for advanced ones. Keeping such conjecture in place, the exact values of these parameters are chosen from computational exercise. The values of labour share for the food sector are taken as 0.4 for developing and 0.06 for advanced country while the values of inter-sector elasticity of labour substitution are chosen as 0.15 and 0.75 respectively. Overall, these two parameters of labour share for food and elasticity of labour substitution govern the movement of labour supply within economy.

The measure of decreasing returns for the food and non-food sector, for both economies, is picked up from Gollin et al., (2004). The difference in choice reflects greater share of labour for developing economies. The intra-sector elasticity of substitution for both sectors is chosen with presumption that intermediate goods producing firms of advanced economies face more competition and have less market power than that of developing economics. The values are taken to keep a clear demarcation of mark up between the two economies. Moreover, due to a lack of close substitutes of food compared with non-food, monopolistic power can indulge

the firms to charge a greater mark up in the food sector than that of the non-food sector. Considering the degree of price stickiness for the advanced group, the food sector exhibits substantially less stickiness of price compared with the non-food and therefore, the values are chosen for developed countries to capture a reasonable difference in price stickiness. Using historical commodity prices collected from different markets of developing countries (the monthly dataset during the period of January, 1960 to May, 2011, Source: Pink data, World Bank), the stickiness of prices have been measured categorically for the food and non-food sectors following the *Indirect Estimation of Price Duration under Frequency Approach* as in Kovanen (2006) and Morandey and Tejada (2008). It is found that food price, on an average, lasts for approximately a quarter while the price of non-food item remains unchanged for more than three quarters<sup>53</sup>. Following this empirical observation and the estimate provided by Gabriel *et al.*, (2011) with reference to the formal and informal sector, values for price stickiness indices for the food and non-food sector are chosen.

The coefficients of inflation and output gap for monetary policy rule are considered as suggested by Gali (2005). However, following the findings of previous chapter, a reasonable difference in the policy rule between advanced and developing economies is portrayed by parameterization. To fulfil the condition of determinacy, active policy is allowed in the baseline model of developing economy but lack of inflation targeting has been included by keeping a difference in the size of inflation coefficient in policy rule in contrast to advanced countries. However, relative to inflation, greater priority is attached on output stabilisation for developing countries

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<sup>53</sup> See Appendix A.14 for weighted price duration of food and non-food items.

as economic growth is the prime objective for them compared to their advanced counterpart. Finally, the shock process is structured based on the work of Ireland (2004) for advanced countries and Peiris & Saxegaard, (2007), Annicchiarico, et al., (2008), Ahmad, et al., (2012) for developing economies.

#### 4.4.2 Data and Model Comparison: Matching by Second Order Moments

The proximity between data and model-generated results is examined in terms of the second order moments or *standard deviations* of the key macroeconomic aggregates at quarterly data. Given the availability of data, the sample period is chosen as the 1<sup>st</sup> quarter of 1977 to the 4<sup>th</sup> quarter of 2011.

**Table 4.4D: Second Order Moments of Target Variable – Quarterly Data & Model**

Target Variables	Advanced		Developing	
	Data	Model	Data	Model
Aggregate Output Gap	0.0118	0.013	0.0225	0.0195
Food Sector Output Gap	0.0084	0.0373	0.0031	0.0231
Non-food Sector Output Gap	0.0282	0.0011	0.0045	0.0033
Aggregate Inflation	0.0087	0.0067	0.0283	0.0274
Food Sector Inflation	0.0096	0.0089	0.0318	0.0305
Non-food Sector Inflation	0.0095	0.0057	0.0298	0.0219

For the aggregate output gap, quarterly data on GDP volume index is taken for advanced and developing economy from the IFS database and output gap is obtained using Christiano-Fitzgerald (2003) asymmetric type band pass filter on the logarithmic transformation of raw data with the periodicity of six to thirty-two quarters. For the food and non-food sector output gap, data are collected from the database of the Food and Agricultural Organization. As the data on production indices of food and non-food are available only in annual frequency, it is necessary

to adjust the periodicity from two to eight years. Again, Christiano-Fitzgerald (2003) asymmetric type band pass filter is applied on the logarithmic transformation of the raw data to obtain the output gap of each sector. On this occasion, the obtained results on standard deviations are interpolated from annual to quarterly frequency.

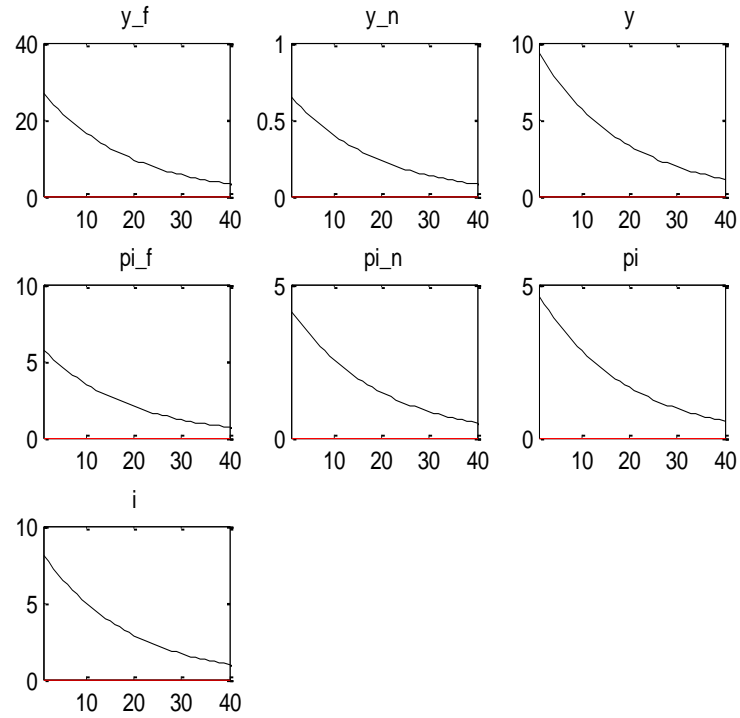
Data concerning the output is available at the group level. However, in case of aggregate inflation and its decomposition between food and non-food inflation, a sample of advanced and developing economies are considered as the group level data are absent. These samples of the two groups are same as was taken in Chapter Two for the Time domain analysis of inflation volatility. The CPI data and the data on CPI for food are collected from the database of the International Labour Organization. Annual frequency data are chosen and subsequently aggregate inflation and food inflation are calculated as the logarithmic difference of price level between two consecutive periods. Given the share of expenditure on food in the general CPI basket of advanced and developing economies, the non-food inflation is computed from aggregate and food sector inflation. Finally, the results of standard deviations of inflation are interpolated to quarterly frequency. In Table: 4.4D, results are shown for data and model generated values of the relevant macroeconomic aggregates. While the results show close proximity of the model with the data for most of the target variables, it fails to capture the data feature for the food and non-food output gap. The model overestimates the output gap of food sector and underestimates the same for the non-food sector.

#### 4.4.3 Impulse Response Analysis

Given the parameterization of model, the effects of shocks on seven major macroeconomic variables are analysed. The variables are:  $\tilde{y}_t$ ,  $\tilde{y}_{F,t}$ ,  $\tilde{y}_{N,t}$ ,  $\pi_t$ ,  $\pi_{F,t}$ ,  $\pi_{N,t}$ ,  $i_t$ . To see these effects, the impulse response functions are plotted in Figure 4.3 for advanced and developing economies respectively. A positive preference shock on consumption raises aggregate demand via increasing the demand for food and non-food consumption. Such a rising demand will be anticipated by the intermediate goods producing firms and, in order to meet the excess demand, production in each sector will rise. This will induce real marginal cost of food and non-food production to surpass their steady state level. Following the positive deviation of real marginal cost from steady state, the output gap for both sectors and aggregate level will rise and lead to rising inflation across the economy. Given the upsurge of inflation, the nominal interest rate will be raised by the central bank to keep the real rate unaffected. In the case of a positive monetary policy shock through the nominal interest rate hike, current consumption will become costly and aggregate demand will be depressed due to dynamic IS relation. This will reduce the output gap and inflation across the sectors and at the aggregate level. Again, if there appears a positive productivity shock, the natural level of output will go up for each sector and therefore, real natural rate of interest will decrease. Following the decline of the real natural rate of interest both for food and non-food, the real interest rate gap will rise which will trim down the output gap. A decline in the output gap will subsequently be followed by a decline in inflation and a fall of nominal interest rate.

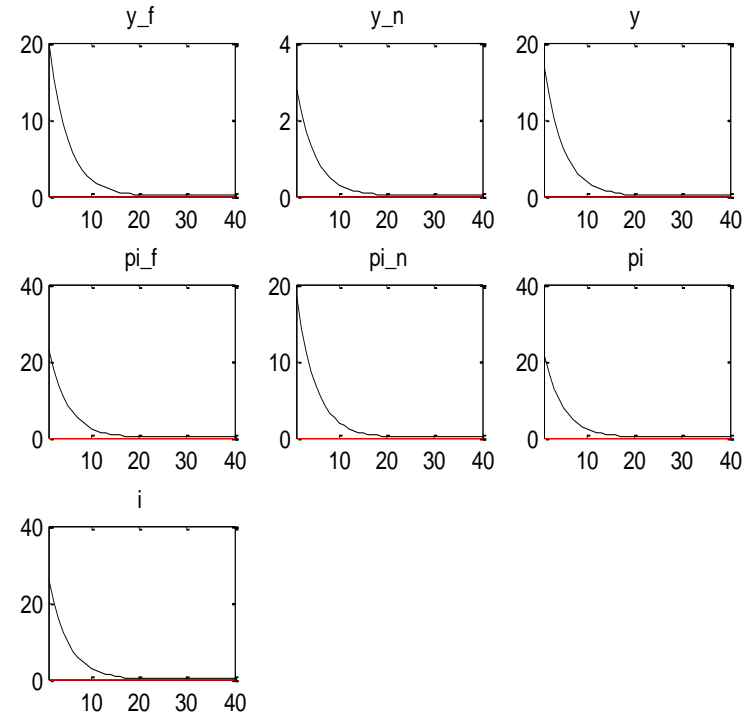
**Figure 4.3: Plots of Impulse Response**

**Impulse responses to Preference Shock: Advanced Economy**



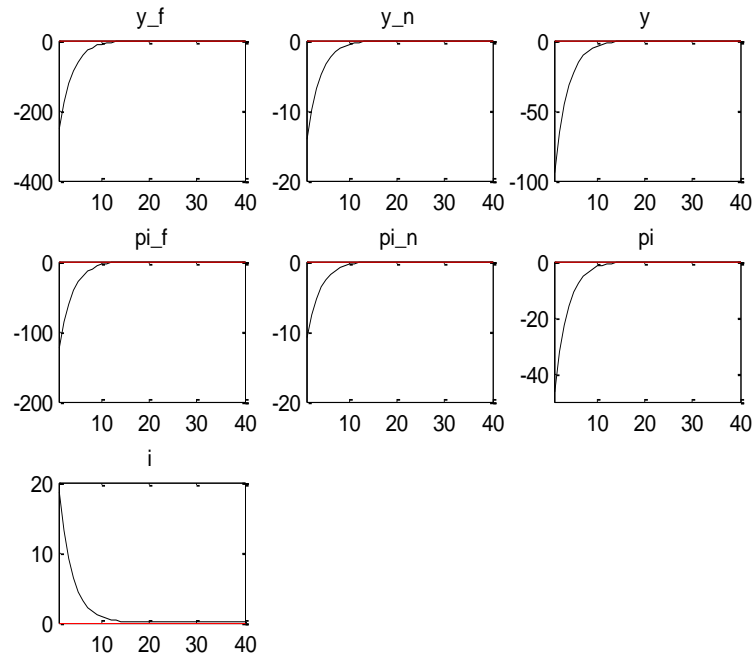
In percent of standard error of an orthogonalised shock to  $\epsilon_{p,t}$

**Impulse responses to Preference Shock: Developing Economy**



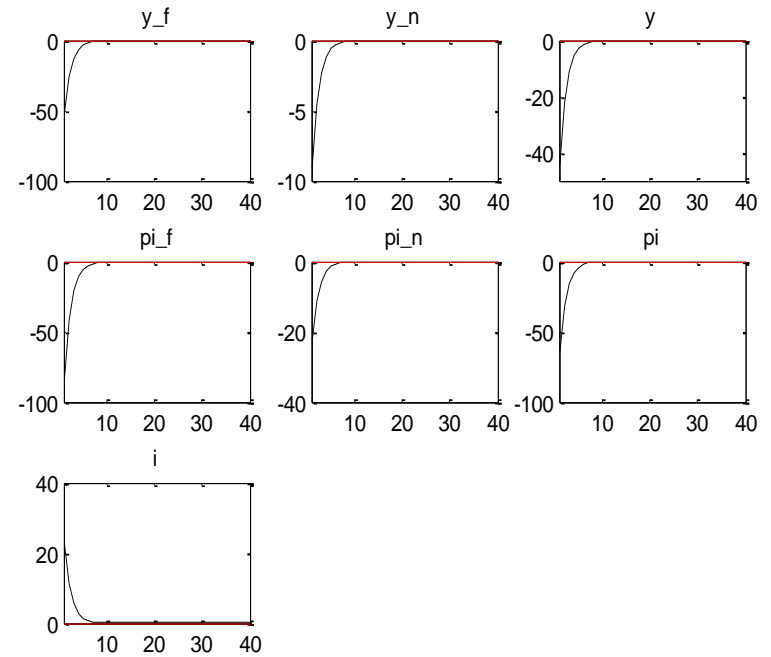
In percent of standard error of an orthogonalised shock to  $\epsilon_{p,t}$

**Impulse responses to Policy Shock: Advanced Economy**



In percent of standard error of an orthogonalised shock to  $\epsilon_{m,t}$

**Impulse responses to Policy Shock: Developing Economy**

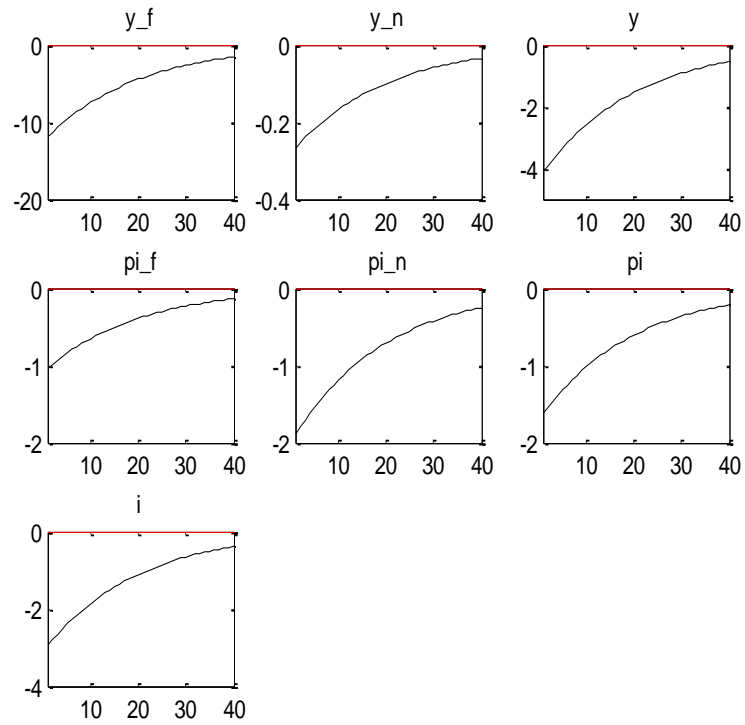


In percent of standard error of an orthogonalised shock to  $\epsilon_{m,t}$



**Impulse responses to Food Sector Productivity Shock:**

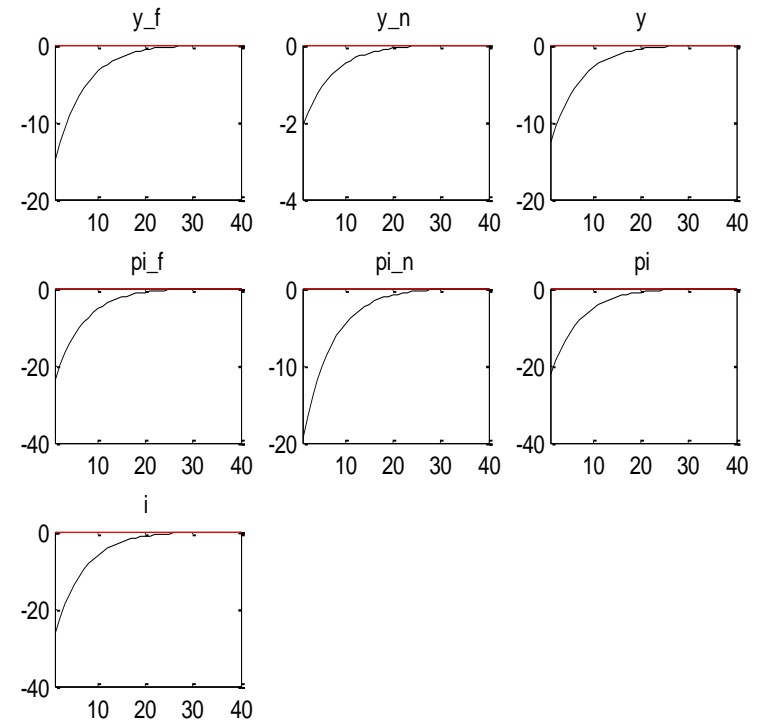
**Advanced Economy**



In percent of standard error of an orthogonalised shock to  $\epsilon_{f,t}$

**Impulse responses to Food Sector Productivity Shock:**

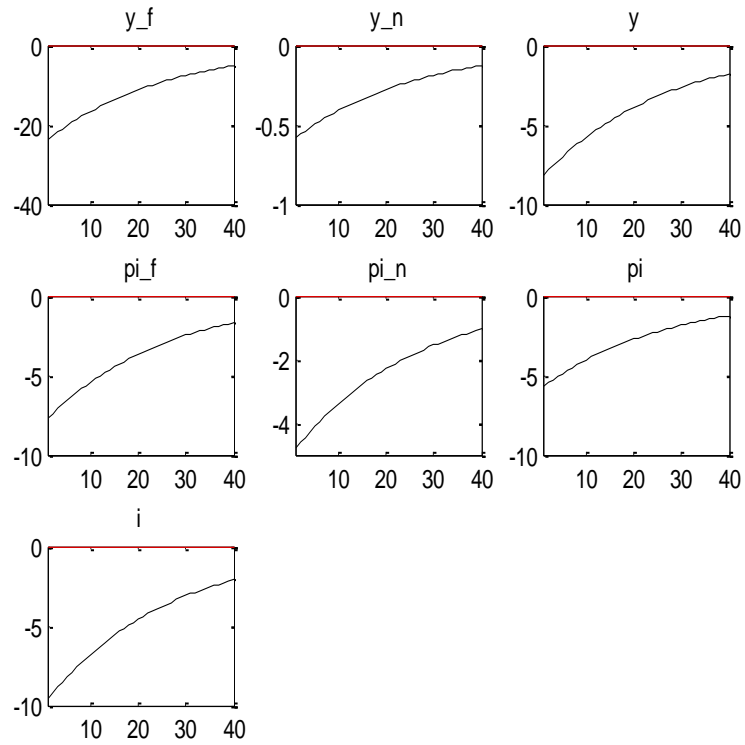
**Developing Economy**



In percent of standard error of an orthogonalised shock to  $\epsilon_{f,t}$

**Impulse responses to Non-Food Sector Productivity Shock:**

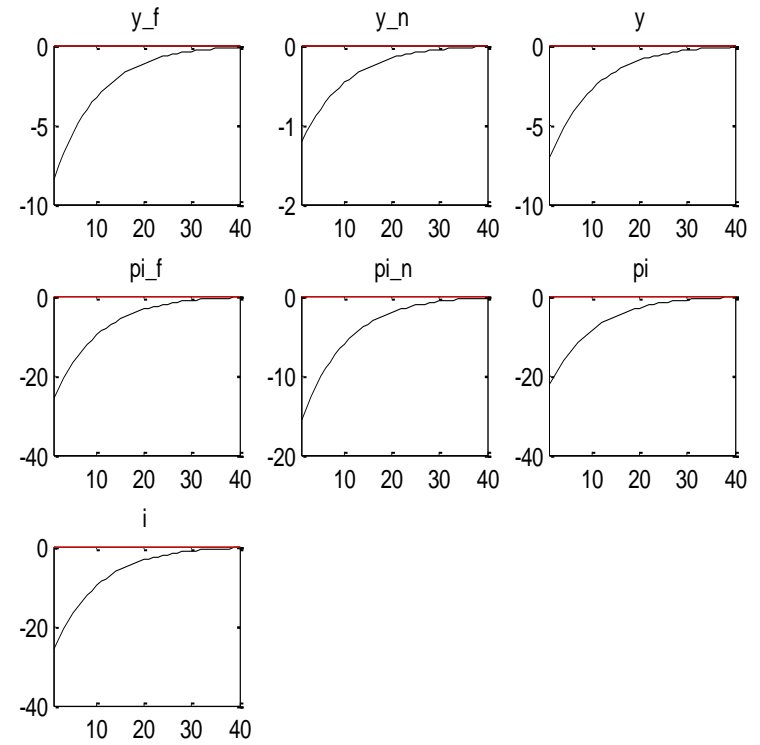
**Advanced Economy**



In percent of standard error of an orthogonalised shock to  $\epsilon_{n,t}$

**Impulse responses to Non-Food Sector Productivity Shock:**

**Developing Economy**



In percent of standard error of an orthogonalised shock to  $\epsilon_{n,t}$

The basic mechanism of shocks remains similar for both economies but the magnitude of impact effects of the shocks are different. In Figure 4.3, plots of impulse response are presented.

#### 4.4.4 Variance Decomposition

From Table 4.5 of variance decomposition, it can be observed that aggregate inflation variability is largely driven by preference shock on consumption for both economies. While it explains 76% of the variation for advanced economies, for developing economy it explains relatively less, i.e. 65%. For developing economies, next to preference shock, monetary policy shock explains the variation (12%).

**Table 4.5: Variance Decomposition**

<i>Advanced Economies</i>				
	Productivity Shock in Food	Productivity Shock in Non-food	Monetary Shock	Preference shock
Aggregate Inflation	1.18	14.08	9.06	75.68
Food Sector Inflation	0.23	12.41	31.51	55.84
Non-food Sector Inflation	2.21	13.74	0.68	83.37
<i>Developing Economies</i>				
	Productivity Shock in Food	Productivity Shock in Non-food	Monetary Shock	Preference shock
Aggregate Inflation	11.38	11.23	12.32	65.06
Food Sector Inflation	10.35	11.99	17.34	60.32
Non-food Sector Inflation	13.80	8.64	2.42	75.15

Considering preference and monetary shock together, it can be seen that according to the model, the demand side disturbances is the main cause for higher inflation variability in developing economies. Nevertheless, role of productivity shocks remain considerable for these economies. Further, looking into the individual sector's inflation volatility, role of preference shock is stronger for non-food inflation than for food inflation. It can be noted that policy shock takes a moderate

role behind food inflation along with productivity shocks. In sum, the model identifies demand shocks as the fundamental source of inflation volatility.

#### **4.4.5 Sensitivity Analysis of Inflation Volatility**

From the variance decomposition, it is found that the volatile behaviour of inflation is predominantly demand driven. This enables us to identify the exogenous process that causes volatility of inflation. However, the question still remains of what factors can explain the difference in inflation volatility between advanced and developing countries. Using simulation exercise, it is possible to conduct a comparative static analysis and recognise the structural and policy factors which would escalate the volatility in developing countries. The comparative static analysis is based on the baseline parametric configuration of developing economy. Table: 4.6 (A to C) shows the results of the sensitivity analysis. From simulation, it is observed that nominal rigidity, labour share for food sector, and inter-sector elasticity of substitution for labour as the structural attributes and inflation stabilising coefficient as the policy parameter, are the major factors to determine the magnitude of inflation variability.

Simulation shows that the difference between advanced and developing economy in terms of such factors can be extremely important for explaining the striking difference of inflation volatility between the two economies. Apart from this, the sensitivity analysis also provides a robustness check for greater volatility of food inflation than the non-food inflation in the composition of aggregate inflation variability as it is observed in data.

Heterogeneous nominal rigidity in both sectors has strong implication on the volatility of inflation. There is an inverse relation between stickiness index and volatility. In Table 4.6A, the effect of lower price stickiness in food and non-food sector on volatility is shown. It can be seen that the continuing decline in the price stickiness index raises volatility of inflation across the economy. Over the exogenous shocks, if price adjustment takes place more frequently than its usual level, i.e. if the sectors become less sticky, the resultant inflation will become more variable in nature as impact of shocks can pass through in a greater extent via the channel of real marginal cost.

Another critical structural aspect is the distribution of labour supply between food and non-food. This one is also directly related to volatility. If labour share for food sector decreases, inflation volatility will decrease. The reason is as follows. The responsiveness of inflation to real marginal cost is strictly decreasing to the index of price stickiness, measure of decreasing returns and elasticity of demand.

**Table 4.6: Comparative Statics for Developing Economies**

Table 4.6A: Price Stickiness and Inter-sector Elasticity of Substitution in Consumption

Parameter	Inflation volatility			Parameter	Inflation volatility		
$\theta_F$	food	non-food	aggregate	$\theta_N$	food	non-food	aggregate
0.25	0.0304	0.0219	0.0274	0.7	0.0265	0.0168	0.0231
0.35	0.0303	0.0221	0.0274	0.65	0.0305	0.0219	0.0274
0.45	0.0301	0.0224	0.0274	0.6	0.0347	0.0271	0.0320
0.55	0.0297	0.0229	0.0273	0.55	0.0389	0.0324	0.0366
0.65	0.0291	0.0239	0.0273	0.5	0.0430	0.0375	0.0410

Table 4.6B: Labour share for food sector and Inter-sector Elasticity of Labour Substitution

Parameter	Inflation volatility			Parameter	Inflation volatility		
	food	non-food	aggregate		food	non-food	aggregate
$\nu$				$\gamma$			
0.43	0.0366	0.0271	0.0332	0.15	0.0305	0.0219	0.0274
0.42	0.0339	0.0248	0.0307	0.2	0.0304	0.0202	0.0268
0.41	0.0320	0.0232	0.0288	0.25	0.0302	0.0186	0.0261
0.40	0.0305	0.0219	0.0274	0.3	0.0299	0.0171	0.0254
0.39	0.0294	0.0209	0.0263	0.35	0.0297	0.0157	0.0248

Table 4.6C: Policy Parameter of Inflation in Taylor Rule

Parameter	Inflation volatility		
	food	non-food	Aggregate
$\phi_\pi$			
1.1	0.0305	0.0219	0.0274
1.15	0.0286	0.0204	0.0257
1.2	0.0270	0.0192	0.0242
1.25	0.0256	0.0182	0.0229
1.3	0.0243	0.0172	0.0217

Given the parameterization of the model, price stickiness, measure of decreasing returns and intra-sector demand elasticity are lower in the food sector than in the non-food sector. Therefore, the responsiveness of food price inflation to the deviation of real marginal cost from its steady state is relatively higher than non-food sector. Any exogenous shock, impinging on the economy, can be transmitted through the food sector relatively faster than the non-food sector. Thus, if share of labour moves from the impulsive sector like food to a comparatively stable non-food sector, then transmission of the volatility of shocks reduces and is reflected in the inflation of each sector as well as at an aggregate level. From Table 4.4B, it can be observed that gradual shift of labour share from food to non-food sector brings down the entire economy in a lower regime of inflation volatility. In addition to distribution parameter of labour, the role of inter-sector elasticity of labour substitution needs to be emphasised. Highly inelastic nature of labour substitution between the sectors indicates that on the face of shocks labour is nearly immobile

from one sector to another. This implies perturbation in inflation, emerging from variance of shocks through the channels of output gaps, can increase and persist. On the contrary, if the developing economy features more substitutability in labour allocation between the food and non-food sectors, it experiences low level of inflationary fluctuations. From Table 4.6B, it can be observed that as labour substitution becomes less inelastic, the volatility of inflation comes down.

Along with the structural parameters, once again, the role of the inflation coefficient in the Taylor rule is examined in order to determine the inflation volatility. Though empirical evidence found in previous chapter contradicts with this, the baseline value of inflation stabilising coefficient of Taylor rule is taken as 1.1 to satisfy the determinacy condition of the model. Simulating the parameter of inflation of monetary policy rule, clear evidence is obtained on the inverse relation between policy activism and inflation stabilisation. From Table 4.6C, it can be noticed that as inflation is targeted increasingly, the volatility of inflation in each sector and in aggregate level drops. Given the fact that inflation volatility is driven by demand side disturbances, strict inflation targeting by activist monetary policy can perform well as a demand management tool.

#### **4.5 Conclusion**

This chapter replicates the key stylised fact that inflation volatility is higher for developing economies than their advanced counterpart and attempts to find out the reasons behind this fact using a two-sector New Keynesian model. It has been possible to identify the main source and critical factors of the greater volatility of inflation in developing economies. It is observed that demand side shocks are the

fundamental forces for inflation volatility. Volatility crucially hinges upon the structural attributes of nominal rigidity, distribution of labour between the sector and inter-sector elasticity of substitution in labour supply. As the policy factor, it appears that lack of inflation targeting of monetary authority is a potential reason for inflation volatility. The baseline model for advanced and developing economy fits into the empirical regularities of inflation process moderately. It projects volatility of inflation fairly well. To improve the fit of the model with data, the next course of research can be extended to bring in elements like wage rigidity, endogenous capital accumulation, adjustment cost of capital and investment. These ingredients can generate sluggish adjustment, persistence of fluctuations and thereby improvise the model to meet the features of data more accurately.



## Chapter Five

### Concluding Remarks

Variability or volatility is one of the fundamental constituents of the time series process of any macroeconomic variable, and inflation is not an exception. The dynamic behaviour of inflation critically pivots around its second order moment. The existing literature recognises the unpleasant results of inflation volatility, but has not explored its major regularities across different economies. Noting this gap in the literature, the present thesis places inflation volatility at its core. It pursues research in order to illuminate the empirical facts and features of volatility across the inflation experiences of advanced and developing countries and probes into the sources and determinants of volatility. The main results are summarised as follows.

Visual inspection indicates a clear demarcation between the time series processes of inflation in advanced versus developing countries. It is observed that distinctive feature of volatility makes the pattern of inflation substantially different between the two groups. Following this observation, an in-depth analysis is carried out using monthly and quarterly CPI inflation data over the period 1968 to 2011. I find that:

- i) Instantaneous volatility, embedded in the underlying data generating process of inflation, is quite predominant for developing economies over the medium term cycle and across its different frequency bands.
- ii) Time-varying volatility of inflation strongly prevails in developing economies and affects them to a greater extent than advanced economies.

- iii) Persistence of volatility, derived from conditional variability, is more or less similar in nature across the economies.
- iv) The magnitude of the long run volatility is remarkably higher for developing economies, approximately by thirteen-fourteen times, than the advanced economies. This difference is largely driven by the country specific shocks which are also significantly diverse among the developing economies.

Summing up all, the thesis elucidates the robustness of the stylised fact that inflation is highly volatile in developing countries compared to advanced countries. Furthermore, the welfare consequence of the stylised fact is evaluated. It is found that volatile inflation is more costly for developing countries (approximately by more than double) than that of advanced countries. This observation motivates the research to study the factors which would cause such a differential in inflation volatility. Based on New Keynesian precepts, differences in policy reaction of monetary authorities and structural attributes between advanced and developing economies were examined.

Following the conventional argument of New Keynesian literature on the relation between active monetary policy and dynamic stability of inflation, empirical investigation was conducted using Taylor type interest rate rule to examine the role of monetary authority. A simple three equation New Keynesian model is proposed and an analytical solution of inflation volatility is derived which substantiates the link between coefficient of inflation in the monetary policy rule and inflation variability. By simulation, the inverse relation between the policy parameter of inflation and inflation volatility was shown.

Based on this theoretical ground, different variants of Taylor rule were estimated over the sample period of balanced panel for developed countries from the 2<sup>nd</sup> Quarter of 1991 to the 2<sup>nd</sup> Quarter of 2011. The sample period of balanced panel for developing countries included data from the 1<sup>st</sup> Quarter of 1997 to the 1<sup>st</sup> Quarter of 2011. At the outset, the Panel GMM estimation technique was applied and, thereafter, the Arellano and Bover (1995) method of dynamic panel estimation was used to estimate the policy parameters. The central empirical finding is that inflation is actively targeted by the monetary authority of the advanced countries but not so by those in the developing economies. The difference is so prominent that the inflation stabilising coefficient turns out substantially greater than one (1.8 to 2.2) for the advanced group and remains much below than one (0.2 to 0.6) for the developing economies. This striking difference in the policy regimes between the two groups can be one of the reasons for the difference in inflation volatility.

While considering the policy aspect, this research also considers the structural differences between the two groups of economies. Using New Keynesian building blocks, a structural model was developed to capture the asymmetry in the consumption pattern and labour allocation to address aggregate inflation dynamics by the components of food and non-food inflation. The transitional dynamics of consumption between food and non-food that emerge from Engle's Law are preserved in the model by incorporating non-homotheticity in the preference function. Given imperfection in the goods market and Calvo-type price setting behaviour of the firms, this micro founded structural model yielded a generalized DIS and NKPCs for food, non-food and aggregate economy and is closed by a Taylor type policy rule. Considering two different sets of parameterization of the log

linearized version of structural model, two different scenarios of prototype advanced and developing economies were produced that fits with the data. The calibration exercise shows that:

- i) The two sector structural model fits well with the data for inflation, both at aggregate level and for individual sector, and aggregate output gap. However, it struggles to fit with the sector-wise output gap.
- ii) Preference shock is the prime demand side disturbances, which fuels volatility of inflation.

Three key insights were obtained from the sensitivity analysis on the baseline parameterization of the developing countries. First, the nominal friction, particularly for the non-food sector, controls the transmission of exogenous shocks via elasticity of inflation to real marginal cost. Second, higher share of labour towards relatively volatile sector, i.e. food, can exacerbate the aggregate volatility by determining the extent of impact of shocks across the economy. Finally, the inelastic nature of labour substitution due to physical constraint regulates the propagation mechanism of shocks to variability of inflation through inter-sector adjustment. Along with the structural parameters, simulation on inflation coefficient of the Taylor rule re-emphasises that an active and aggressive inflation targeting is essential for the developing countries to tackle the volatile behaviour of inflation.

The study, undertaken in this thesis, opens up several dimensions for future research. The stylised fact of inflation volatility raised in the thesis is essentially quantitative in nature. It pins down the difference in the magnitude of volatility between advanced and developing economies but it does not characterise the qualitative

nature of volatility. One can analyse such qualitative features using various improvised volatility models, such as, component or asymmetric component GARCH model in order to examine the pattern of volatility and characteristics of shocks across various economies. Besides, empirical research can be directed to isolate the welfare loss due to volatility from the welfare loss stemming up from the level or persistent behaviour of inflation. Furthermore, following Cochrane's criticism on Taylor rule, the explanation provided in terms of policy activism, is contentious on the ground of determinacy and identification issues. These problems may be dealt with by a richer structural framework and possibly by incorporating *learning* into the system. The conclusion on the difference of active and passive monetary policy between advanced and developing economies respectively can also motivate researchers to investigate the reasons behind the passive policy response of the central banks of developing countries. Finally, the structural model developed in this thesis can be extended and improvised by inserting nominal frictions in the labour markets, habit formation in the non-food consumption, capital accumulation and adjustment costs in order to obtain more insights about the dynamics of inflation.

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# Appendix

## A.1 Estimating Inflation Volatility by Spectral Density

Traditional time domain and relatively challenging frequency domain or spectral analyses are just two ways of looking at the same phenomenon. Since frequency domain methods are more non-parametric, they are particularly useful in model specification (Engle, 1976). Frequency domain or Spectral analysis characterizes a time series process as a combination of numerous sine and cosine waves with different frequencies and random amplitudes. In course of characterizing the time series of interest, spectral analysis enables to understand the contributions made by various periodic components in the series. It plots the squared amplitude of each component against the frequency of that component. It is continuous and always greater than zero as long as there are no deterministic elements (i.e., no exactly repeating components or components that can be predicted exactly based on the past). This is a very general way to describe a stochastic process. According to Harvey (1993), theoretically, spectral density of a covariance stationary stochastic process is presented as:

$$f(\lambda) = (2\pi)^{-1}[\gamma(0) + 2 \sum_{\tau=1}^{\infty} \gamma(\tau) \cos(\lambda\tau)] \dots\dots\dots (A.1.1)$$

Where,  $\lambda$  is the frequency in radians can take any value in the range of  $[-\pi, \pi]$ . Since  $f(\lambda)$  is symmetric about zero, the information in the power spectrum is contained in the range of  $[0, \pi]$ . However, for the purpose of estimation, the theoretical auto-covariances, given by (A.1.1) is replaced by the sample auto-covariance as:

$$I(\lambda) = (2\pi)^{-1}[c(0) + 2 \sum_{\tau=1}^{T-1} c(\tau) \cos(\lambda\tau)] \dots\dots\dots (A.1.2)$$

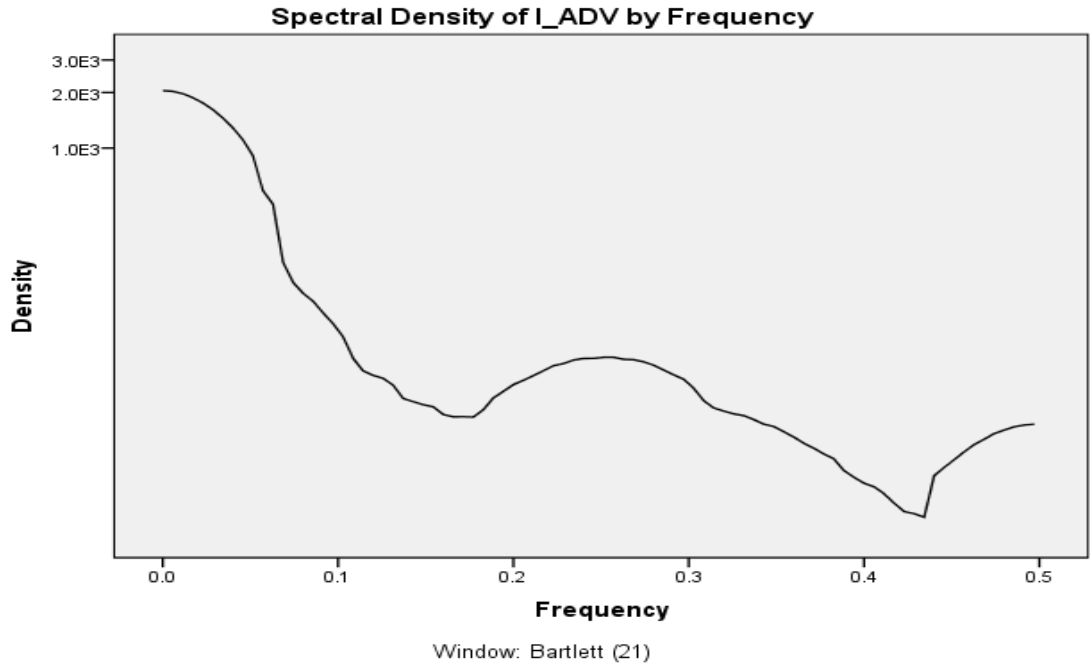
Where,  $T$  is finite and therefore, the summation is also finite. Auto-covariances can only be estimated up to a lag of  $(T-1)$ , with  $c(T-1)$  being a function of a single pair of observations, the first and last. The expression of (A.1.2) defines *Sample Spectral Density*.

Here, it is imperative to note the key properties of  $I(\lambda)$ . For a given frequency of  $\lambda$ , say  $\lambda_j$ , the sample spectral density  $I(\lambda)$  is an unbiased estimator of  $f(\lambda)$ . However, as its variance does not depend on  $T$ , it does not give a consistent estimator of the power spectrum at a given frequency. The ordinates of  $I(\lambda)$  at different frequencies are asymptotically independent. To overcome this problem, literature suggests smoothing  $I(\lambda_j)$  by averaging over adjacent frequencies. Choice of the number of adjacent frequencies for averaging is termed as ‘window’. There are several windows proposed for spectral estimation in the literature, e.g., rectangular window, Bartlett window, Blackman-Tukey window, Pazen window.

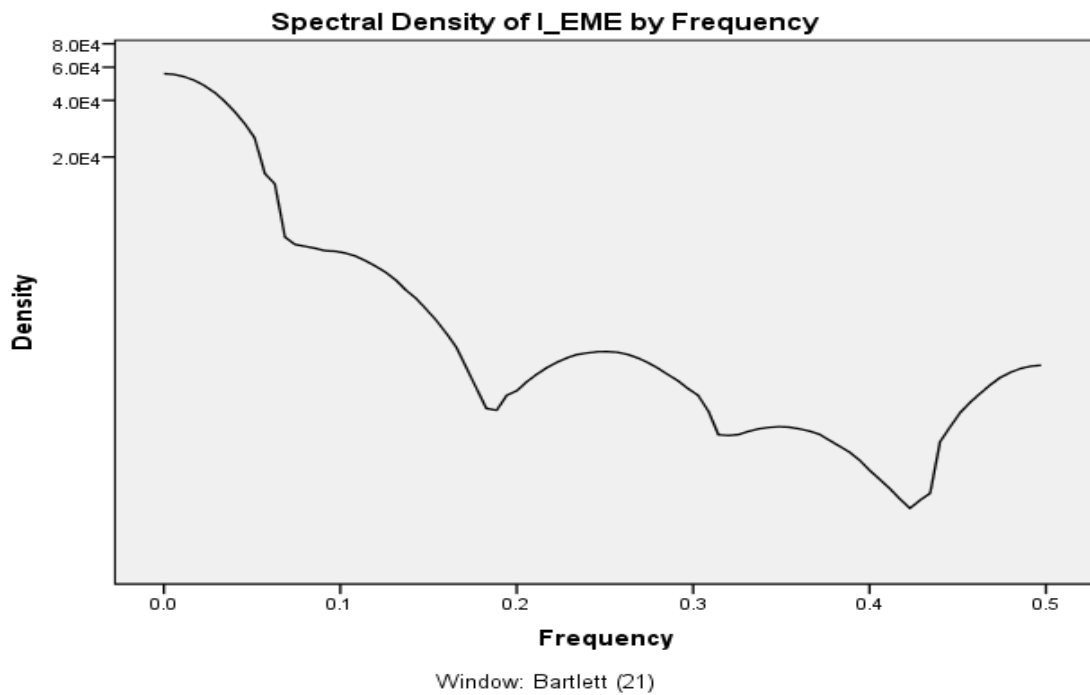
The technique of spectral analysis can be deployed to estimate the volatility of inflation. Using Bartlett window with a time span of five years, spectral density function is estimated and plotted for the inflation data of advanced and developing economies, both at the group level and for the individual countries included in the sample. From the following plots, one can explore the volatility of underlying data generating process at various frequencies. In Figure A.1, the group level result for the advanced and developing economies are plotted. In Figure A.2, inflation data of the individual sample countries are plotted. Due to missing values and in cases of short time span of the data, not all thirty sample countries have been plotted.

**Figure A.1: Spectral Analysis of Inflation Volatility (Group Level Data)**

**Inflation of Advanced Economies (Q1, 1968 to Q2, 2011)**



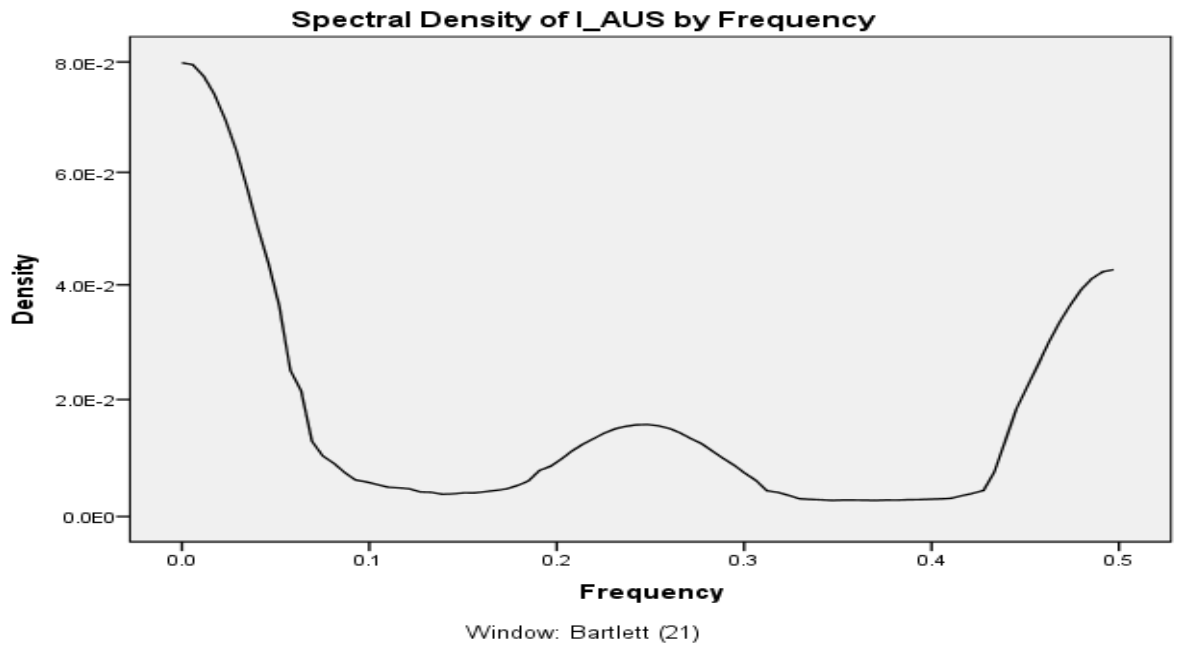
**Inflation of Emerging Economies**



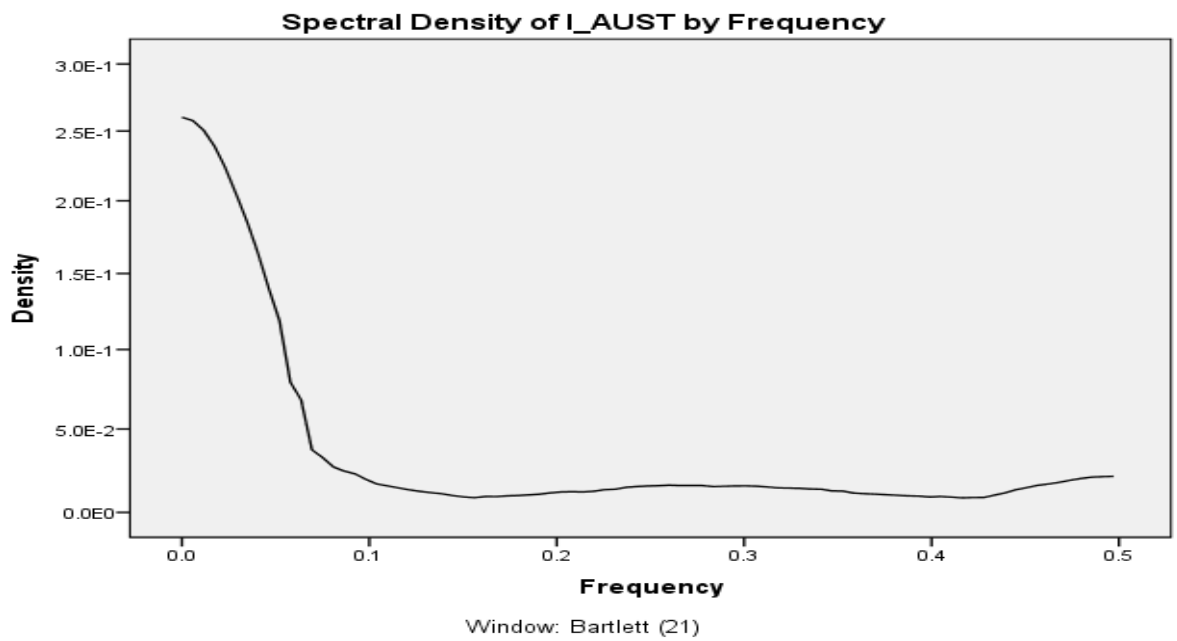
**Figure A.2: Spectral Analysis of Inflation Volatility (Country-wise Data)**

**Sample of Advanced Economies (Q1, 1968 to Q2, 2011)**

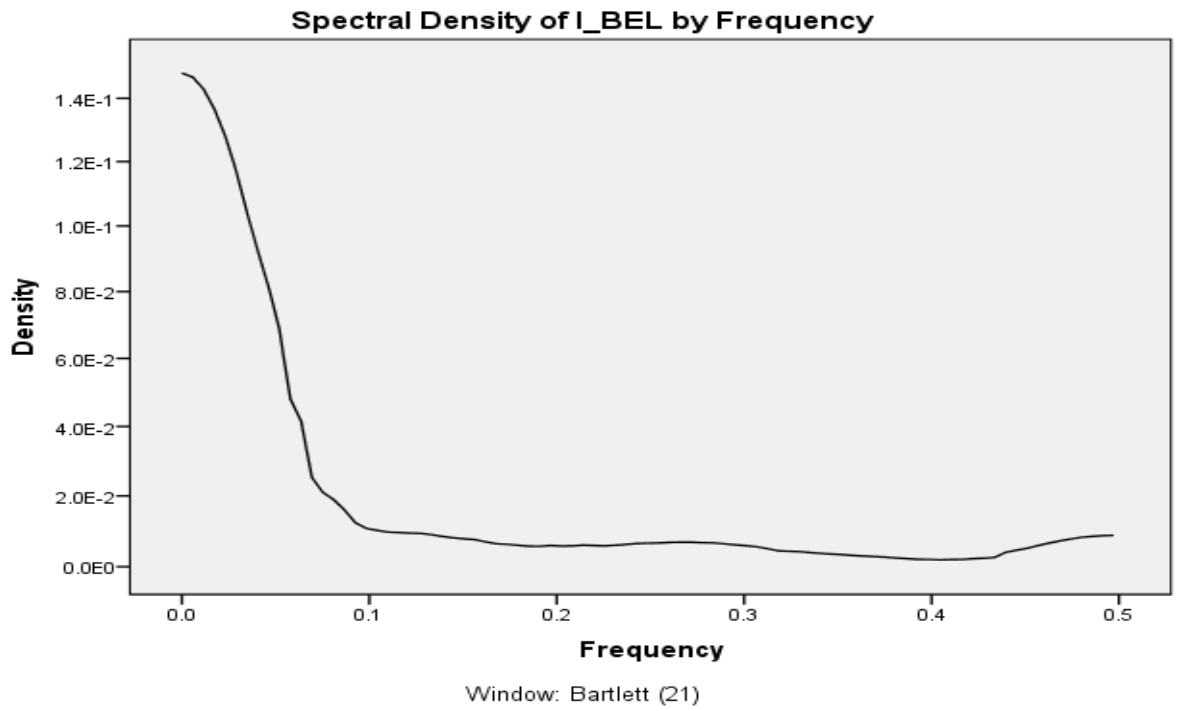
**Australia**



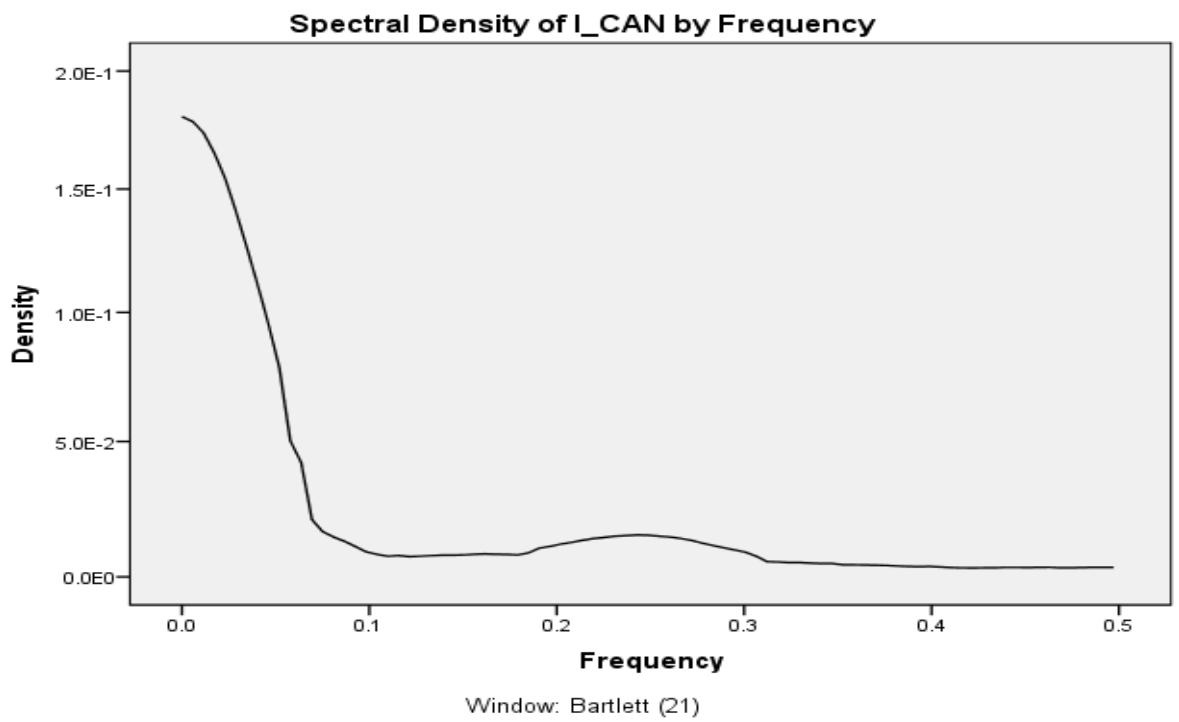
**Austria**



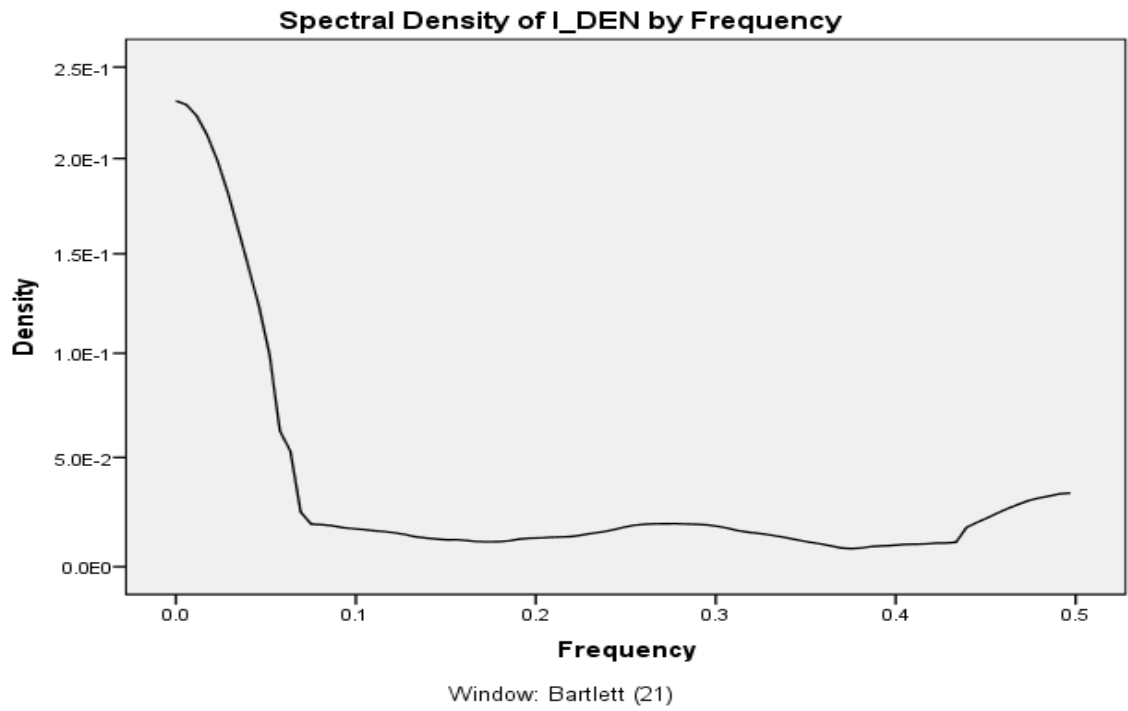
## Belgium



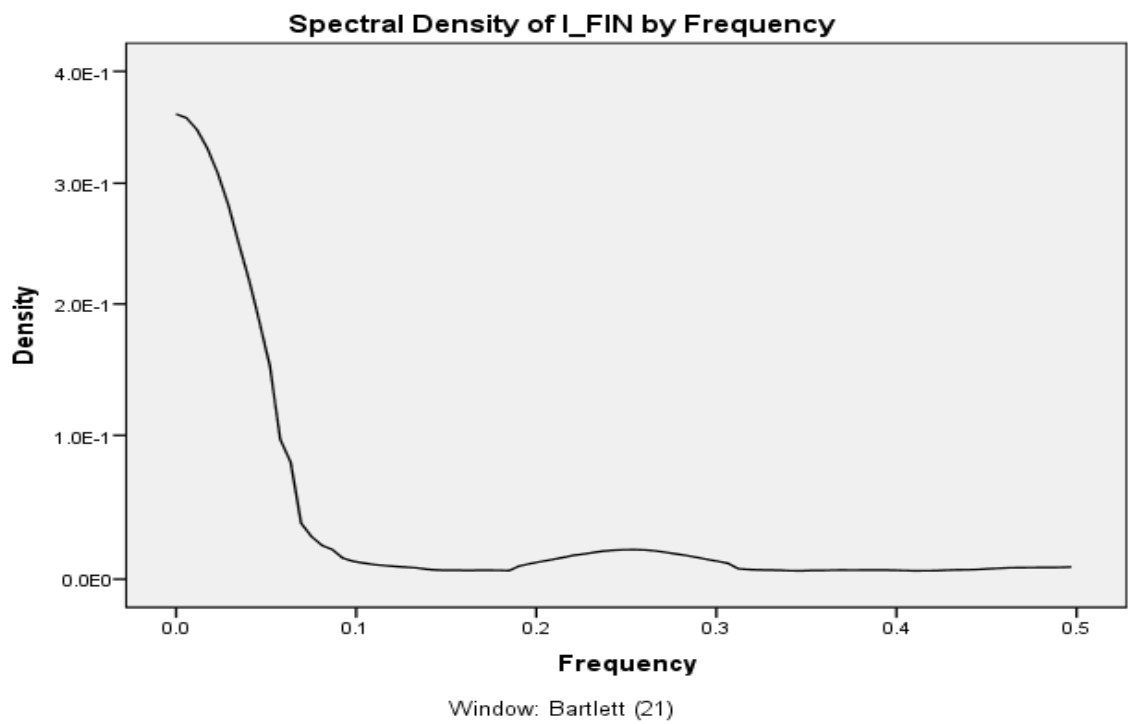
## Canada



## Denmark

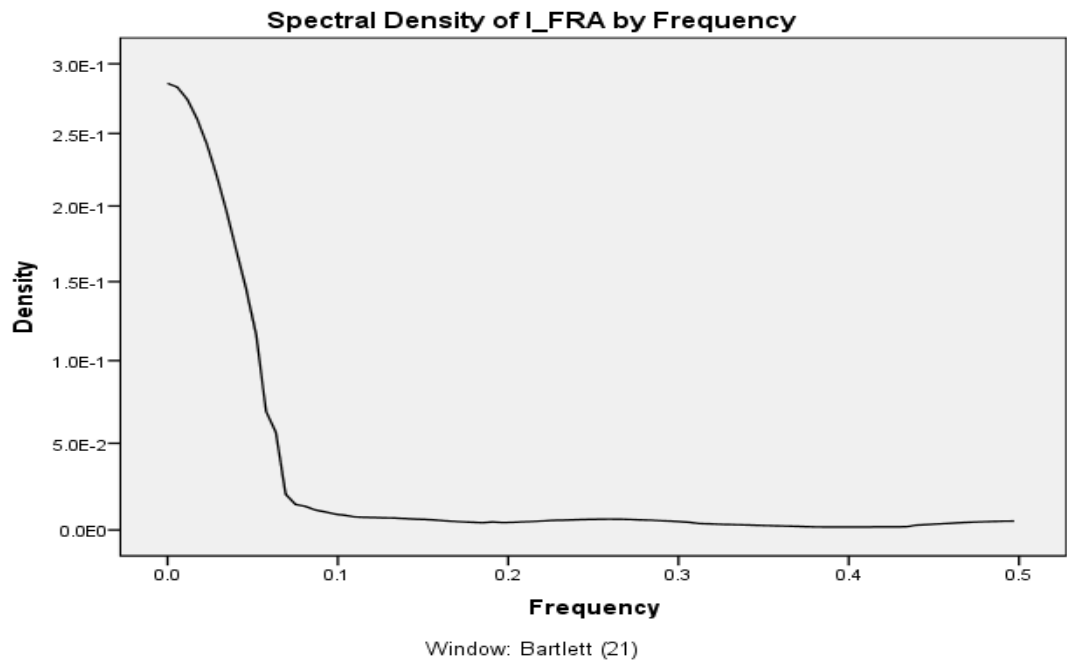


## Finland

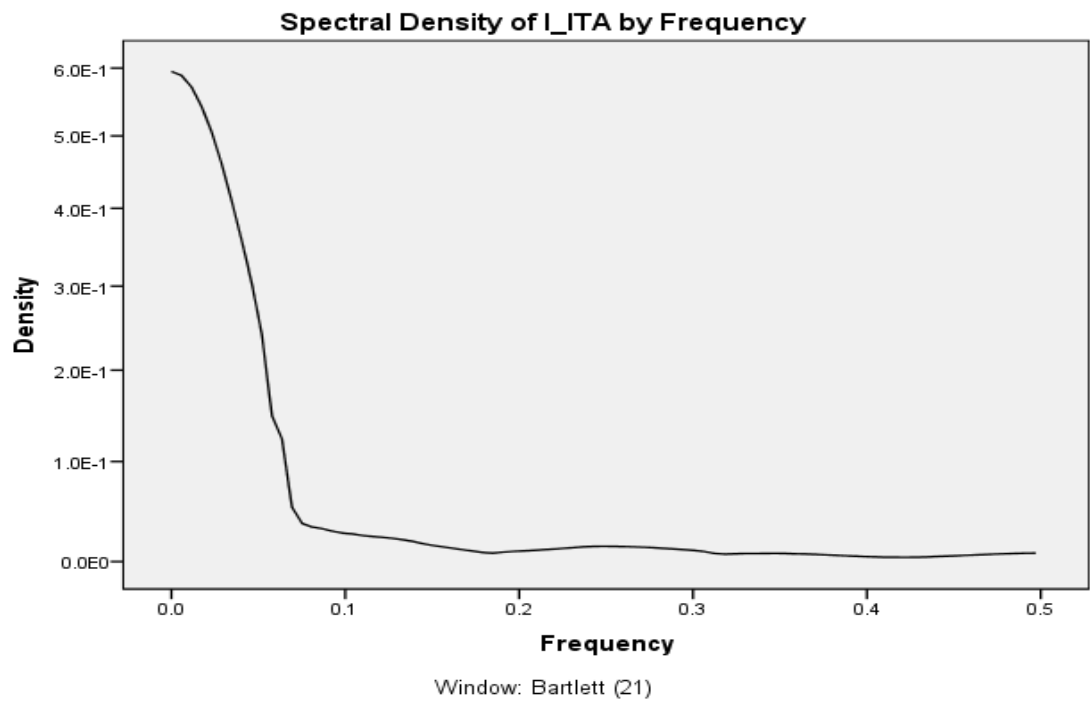




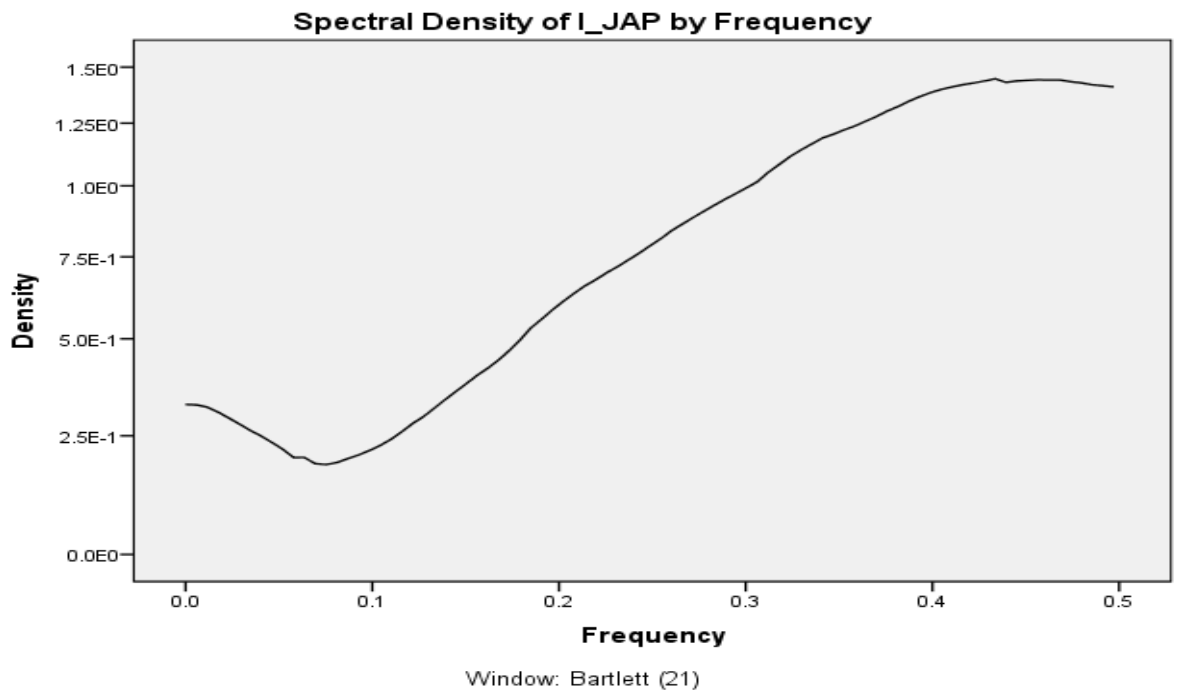
## France



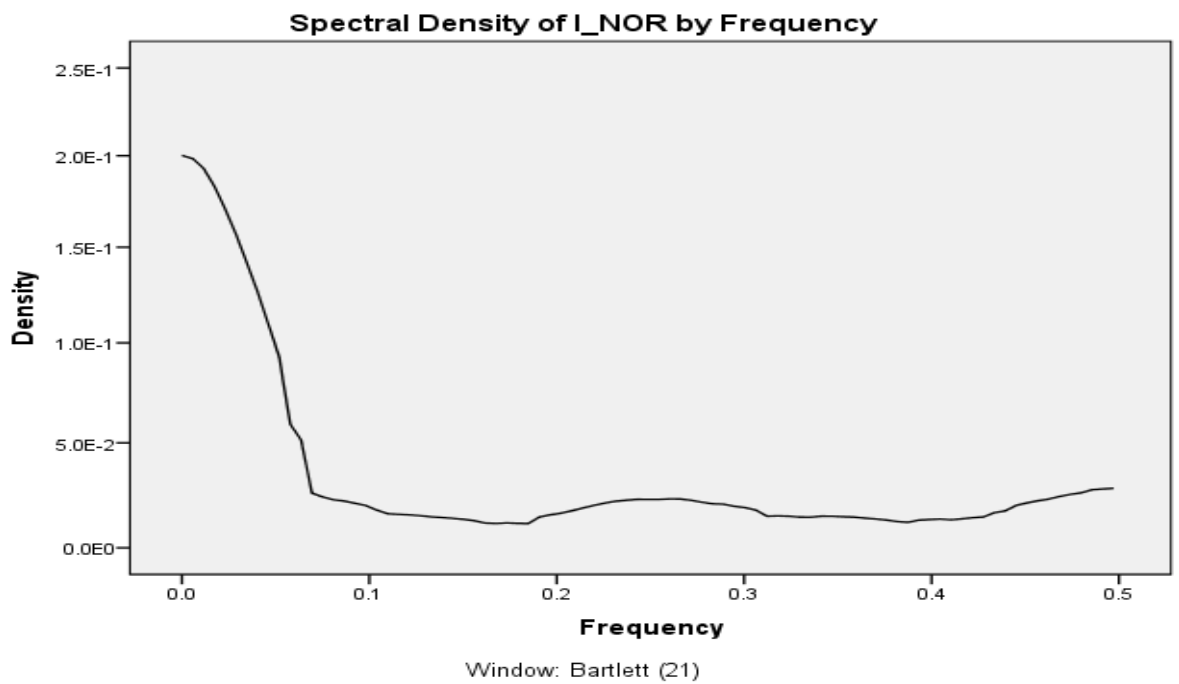
## Italy



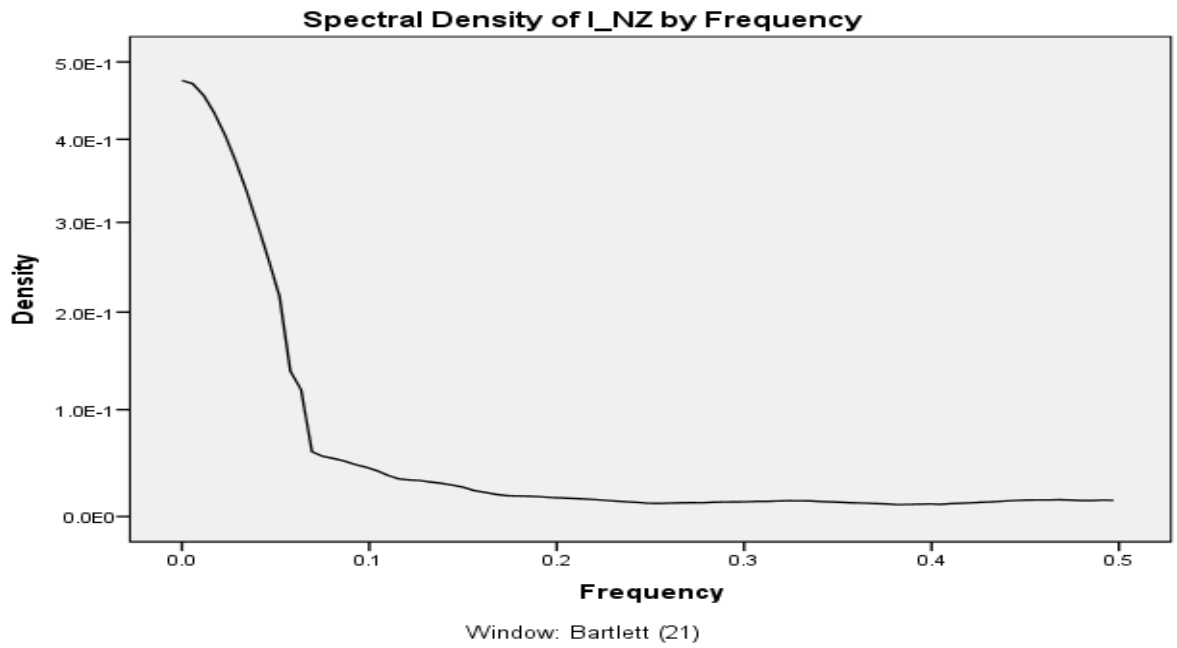
## Japan



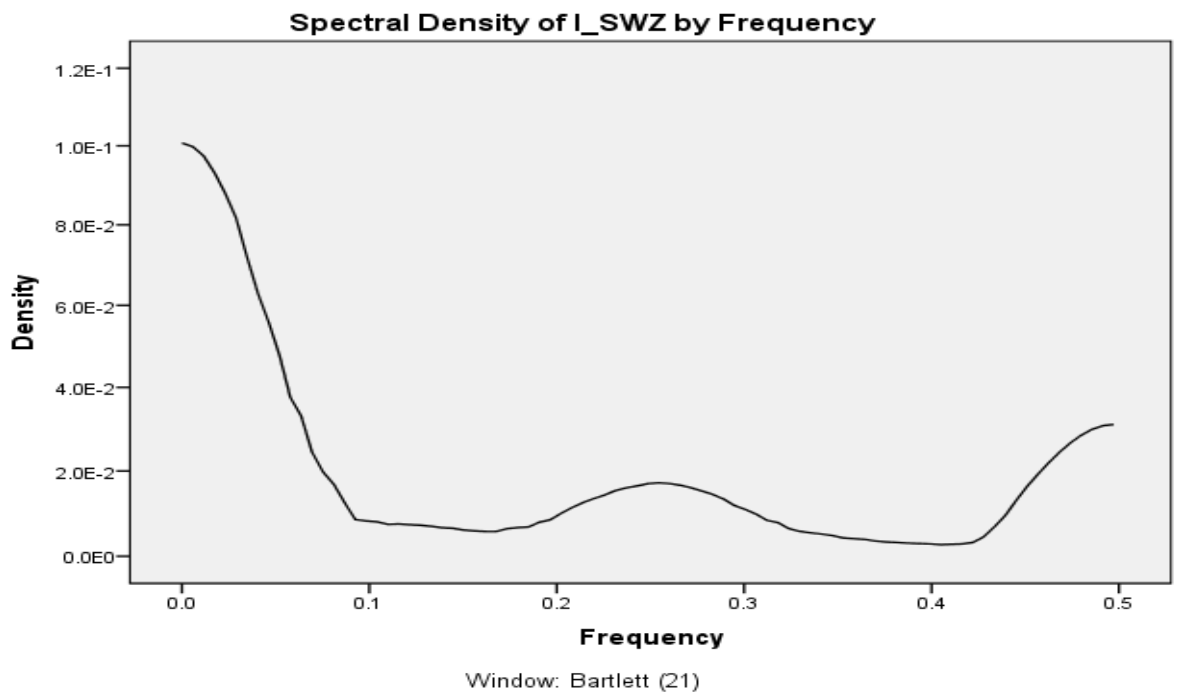
## Norway



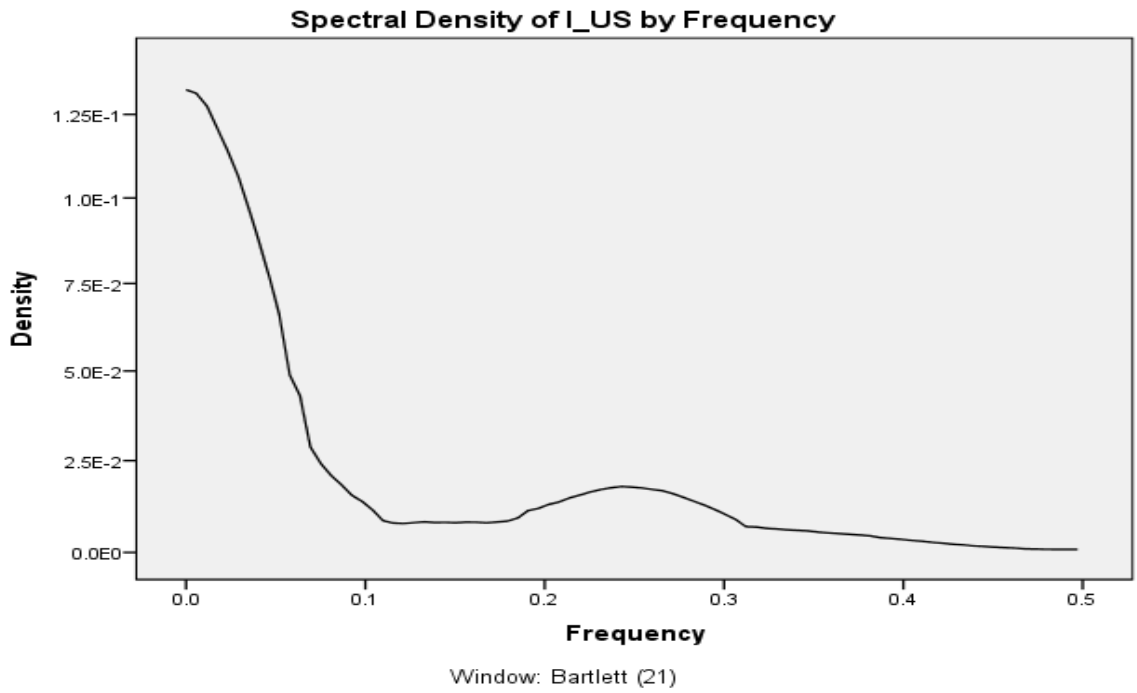
## New Zealand



## Switzerland

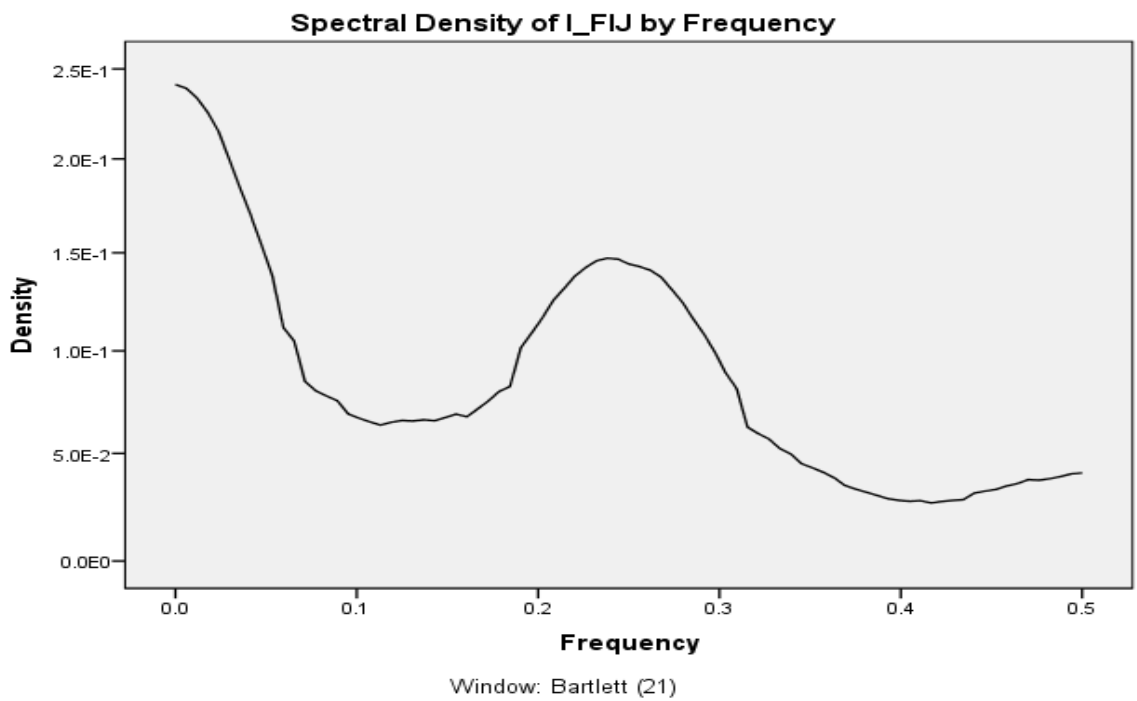


US

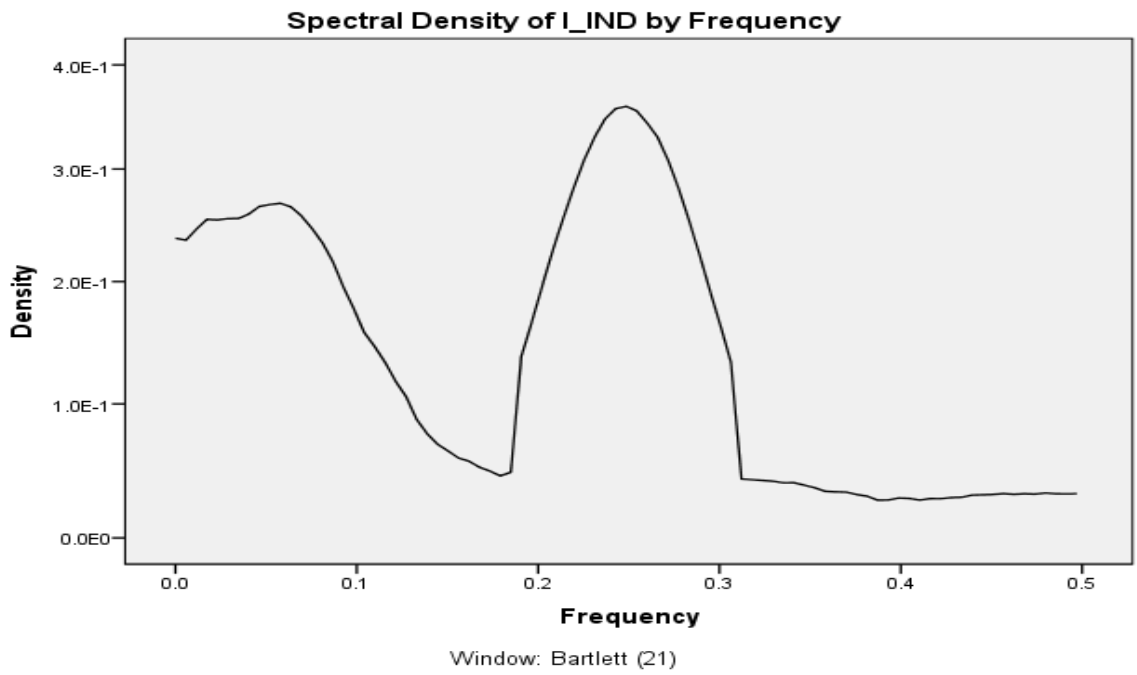


**Sample of Developing Economies(Q1, 1968 to Q2, 2011)**

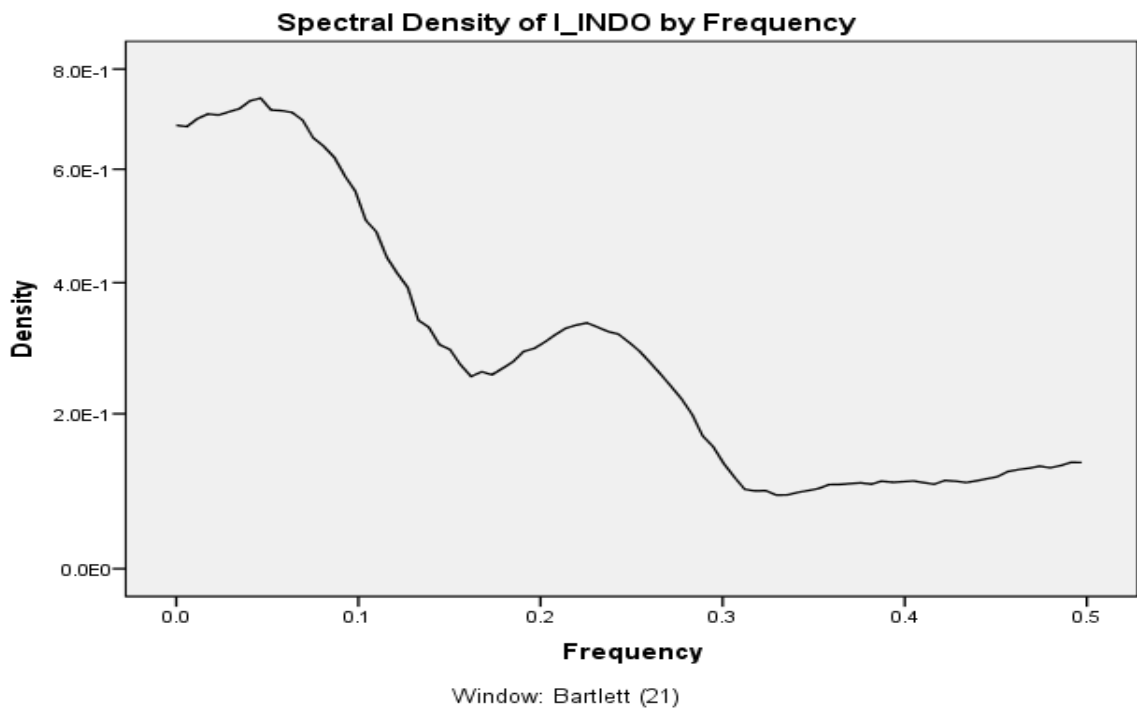
Fiji



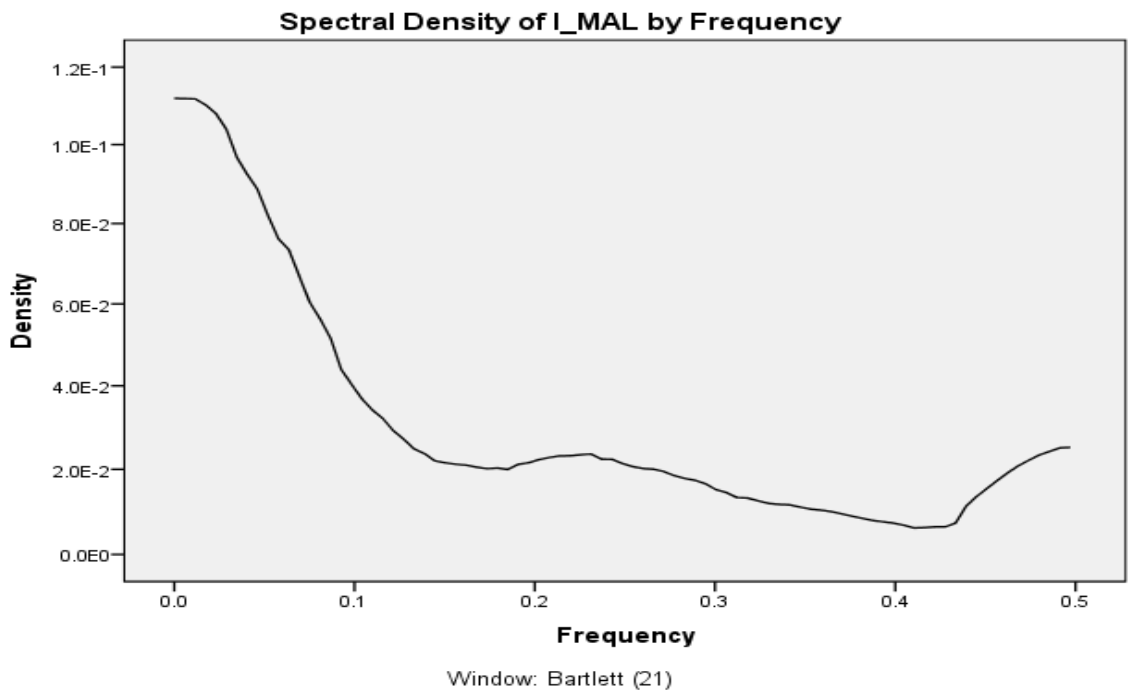
## India



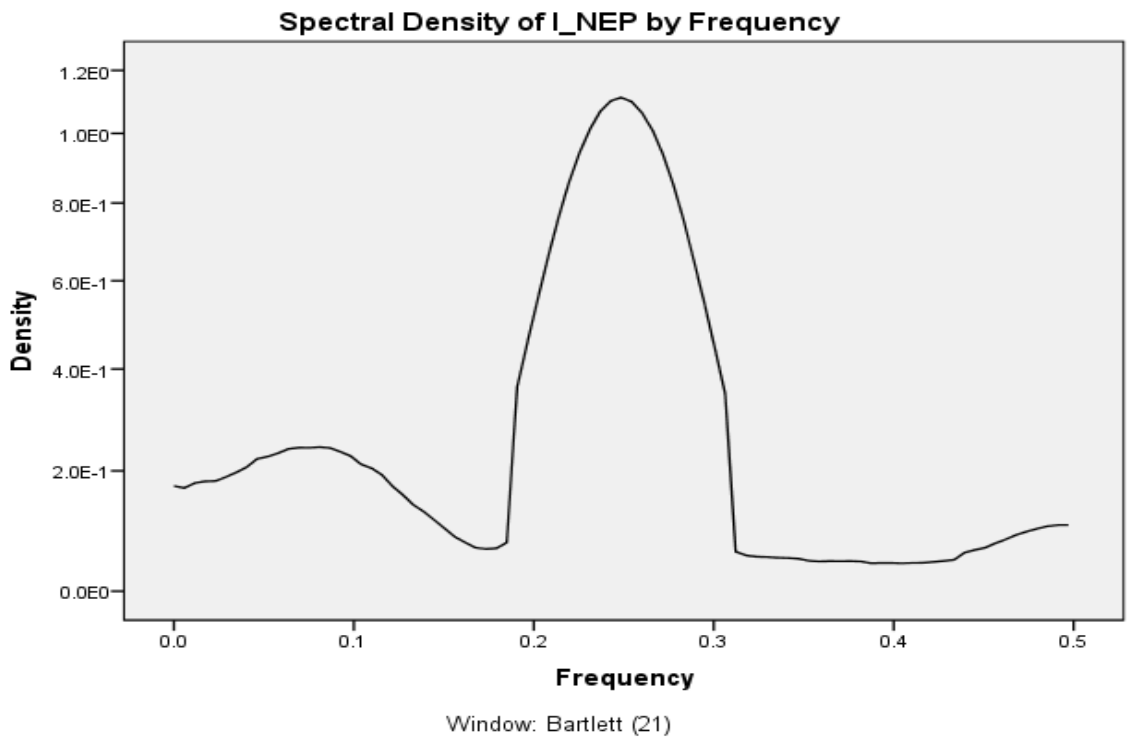
## Indonesia



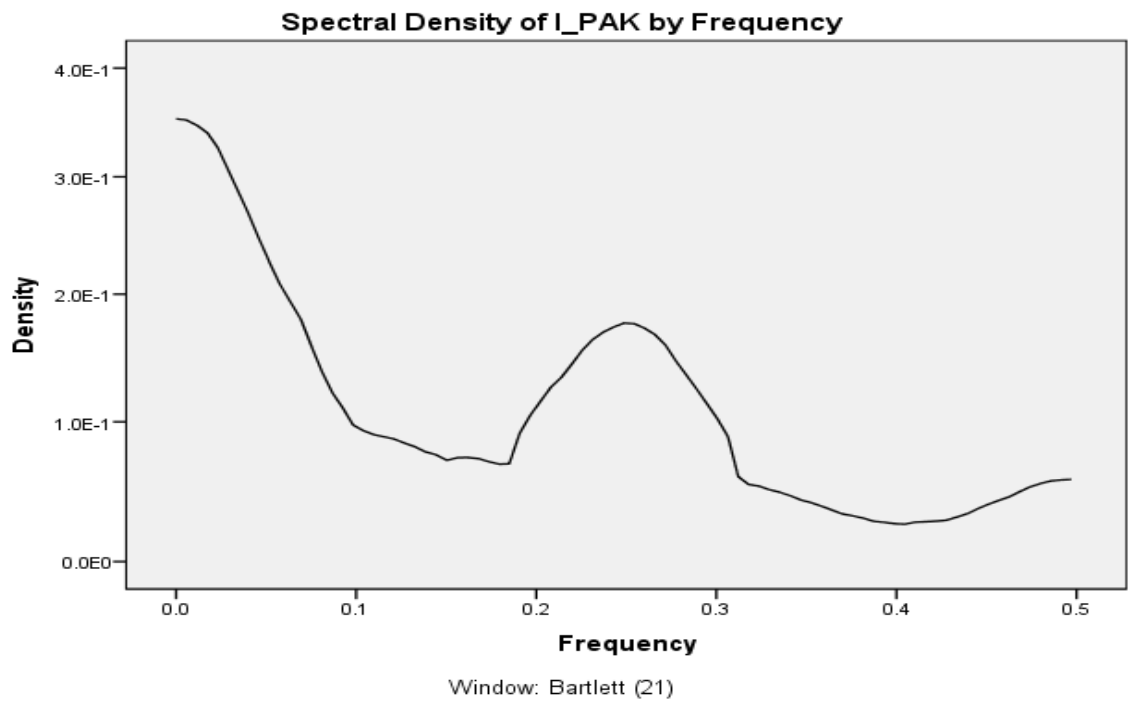
## Malaysia



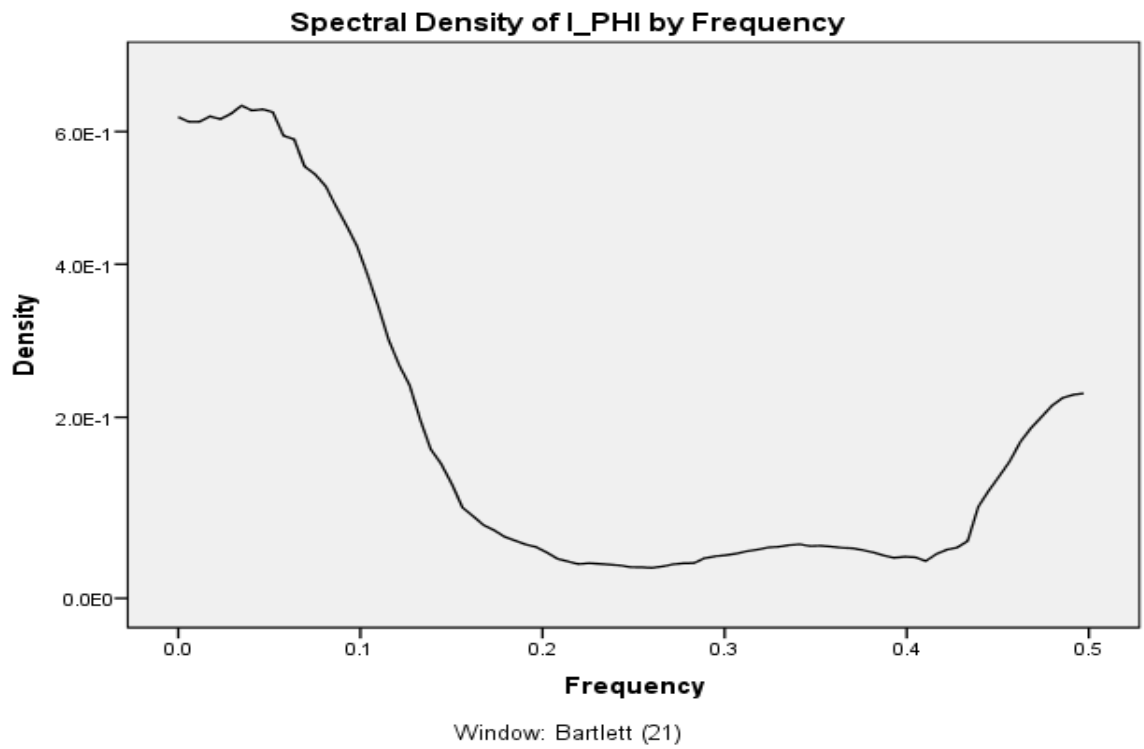
## Nepal



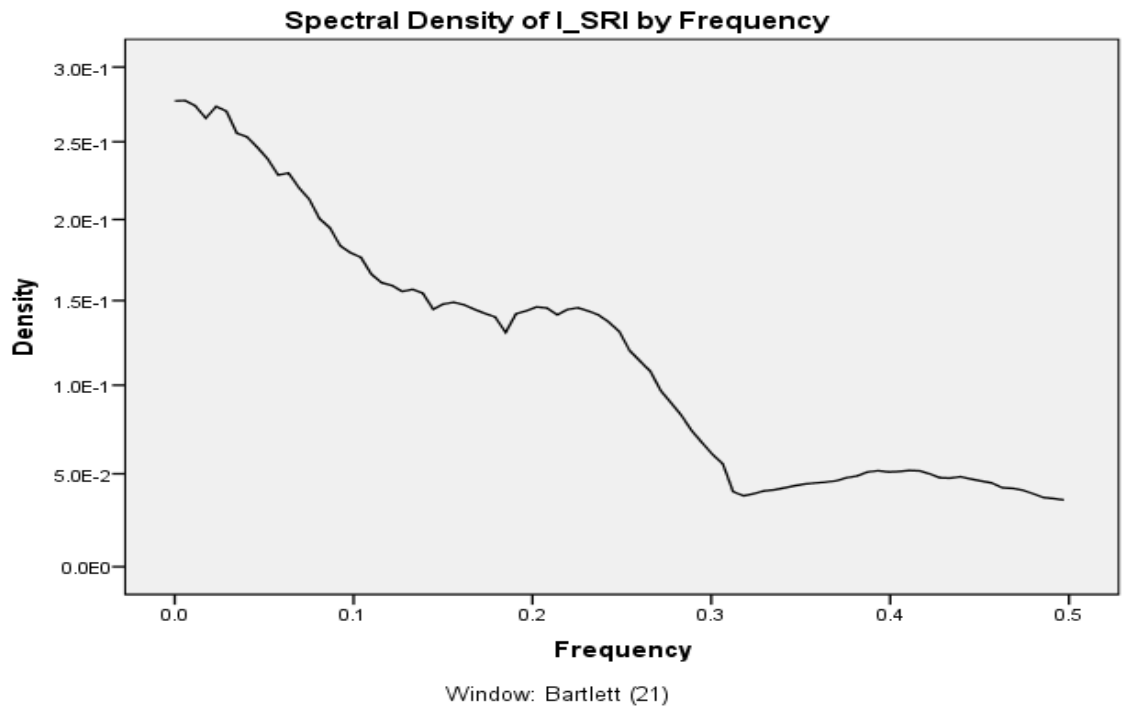
## Pakistan



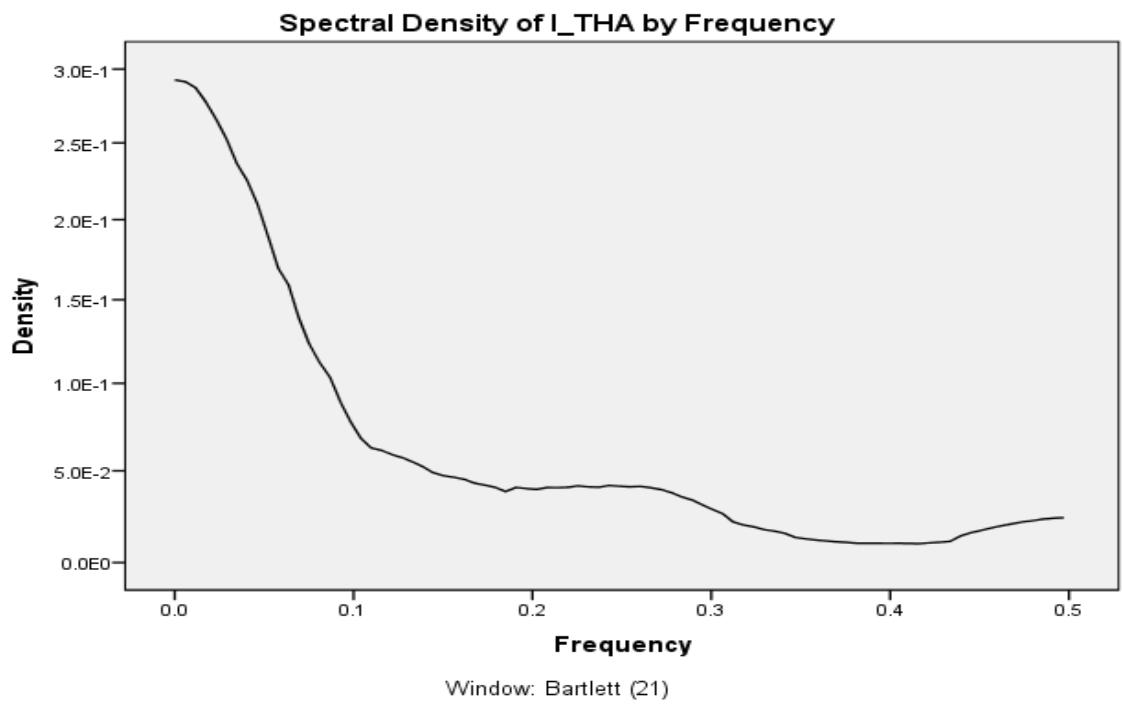
## Philippines



## Srilanka



## Thailand





Comparing the spectral density plots of the group level data in Figure A.1, higher volatility of inflation is clear from the difference of scale (given in the vertical axis) of the two diagrams. It is noticeable that for each frequency, autocovariances of the inflation series of developing countries are approximately ten times higher than the advanced countries. However, it is not much clear from the spectral plots of the sample countries in Figure A.2, whether autocovariance of inflation is strictly greater for the developing economies compared to the advanced ones. Thus, country-wise spectral analysis does not help to pin down the difference of inflation volatility. Nevertheless, the density plots for individual countries convey the message that at different bands of the frequencies, e.g. 0 to 0.1 or 0.2 to 0.3, autocovariances are different between the two groups. Alternatively, it can be stated that depending on different range of periodicities, volatility of inflation can differ between these economies. It implies that to compare the inflation volatility, one has to set different frequency bands (e.g. low frequency or high frequency) or regular cycles (like business cycle or medium run) in terms of well-defined periodicities and then using the band pass filter, inflation variance can be obtained for respective frequency bands. Hence, country level spectral estimation rationalizes the approach followed for the Frequency domain analysis in Chapter 2.

### **A Brief Note on Christiano-Fitzgerald (2003) Band Pass Filter**

In this section, a brief note is produced regarding the methodology of Christiano-Fitzgerald (2003) Band Pass Filter following Rua and Nunes (2005). Band pass filters allow to retain the elements of a specified frequency band while eliminate all other unwanted frequencies. An ideal filter enables to isolate the fluctuations with

the periodicity of  $\left(\frac{2\pi}{\omega_U}\right)$  and  $\left(\frac{2\pi}{\omega_L}\right)$  in for any generic series  $y_t$ . Such series can be represented as:

$$y_t^{F^*} = B^*(L)y_t$$

Where,  $B^*(L)$  is the ideal BP filter:  $B^*(L) = \sum_{j=-\infty}^{\infty} b_j^* L^j$  with the following weights of:

$$b_0^* = \frac{\omega_U - \omega_L}{\pi} ; \text{ and } b_j^* = \frac{\sin(j\omega_U) - \sin(j\omega_L)}{\pi j} \quad \text{for } j \neq 0$$

Since, the ideal BP filter can only be applicable for the infinite time series, some approximation needs to be taken to deal with a finite sample of  $T$  observations. Christiano and Fitzgerald (2003) have proposed a procedure to estimate  $y_t^{F^*}$  by  $y_t^F$  which is a linear function of the data under consideration. According to them;

$$y_t^F = B^{p,f}(L)y_t$$

Where,  $B^{p,f}(L) = \sum_{j=-f}^p b_j^{p,f} L^j$  with  $f = T - t$  and  $p = t - 1$

Selecting the filter weights  $b_j^{p,f}$  by:

$$\min_{b_j^{p,f}, j=-f, \dots, p} \int_{-\pi}^{\pi} |B^*(e^{-i\omega}) - B^{p,f}(e^{-i\omega})|^2 f_y(\omega) d\omega$$

Where,  $f_y(\omega)$  is the spectrum of  $y_t$  at frequency  $\omega$  which measures the contribution of each frequency component to the overall variance of  $y_t$ . Now, if stationarity and symmetry are imposed on the true data generating process, then it implies:  $p = f = \text{constant}$ ; and an equal weight is assigned to all frequencies, i.e.  $f_y(\omega) = 1$ . In course of estimating the cyclical component at different frequency bands, this chapter considers stationarity and symmetry of the filters. Imposing stationarity has

econometric advantages and symmetry ensures no phase shifting between projected cyclical components and the original series. However, these benefits are obtained only at the cost of small amount of data lose.

## A.2 Analytical Expression of Inflation Variance in Relation to Inflation Coefficient of Taylor Rule

Consider a standard three equation New Keynesian framework as given below:

$$x_t = E_t\{x_{t+1}\} - \sigma[r_t - E_t\{\pi_{t+1}\} - \delta] + g_t \dots\dots\dots (3.1)$$

$$\pi_t = \beta E_t\{\pi_{t+1}\} + \kappa x_t + u_t \dots\dots\dots (3.2)$$

$$r_t = \delta + \phi_\pi \pi_t + \phi_x x_t + v_t \dots\dots\dots (3.3)$$

In this system of equations, Equation (3.1) represents Dynamic IS curve, (3.2) stands for New Keynesian Phillips Curve and (3.3) implies the Taylor rule. Using method of Undetermined Coefficients, one can solve  $\pi_t$  analytically. This helps further to obtain the expression of inflation variance in terms of variance of exogenous shocks.

First, (3.2) is expressed as:

$$E_t\{\pi_{t+1}\} = \left(\frac{1}{\beta}\right) \pi_t + \left(\frac{\kappa}{\beta}\right) x_t + \left(\frac{1}{\beta}\right) u_t \dots\dots\dots (A.2.1)$$

Secondly, substitute (3.3) and (A.2.1) in (3.1), we obtain:

$$x_t = A^{-1}E_t\{x_{t+1}\} - \left\{\sigma\left(\phi_\pi - \frac{1}{\beta}\right)A^{-1}\right\}\pi_t - \sigma A^{-1}v_t - \left(\frac{\sigma}{\beta}\right)A^{-1}u_t - A^{-1}g_t \dots\dots\dots (A.2.2)$$

Where,  $A = \left\{1 + \sigma\left(\phi_x - \frac{\kappa}{\beta}\right)\right\}$

Third, the guessed solutions for  $x_t$  and  $\pi_t$  are proposed in the following way:

$$x_t = \gamma_0 g_t + \gamma_1 u_t + \gamma_2 v_t \dots\dots\dots (A.2.3)$$

$$\pi_t = \theta_0 g_t + \theta_1 u_t + \theta_2 v_t \dots\dots\dots (A.2.4)$$

Assuming the law of motion of structural shocks,  $g_t$ ,  $u_t$ , and  $v_t$  as the AR(1) process and we specify:

$$h_t = \rho_h h_{t-1} + \epsilon_{h,t} \dots\dots\dots (A.2.5); \text{ where, } 0 < \rho_h < 1, \epsilon_{h,t} \sim N(0, \sigma_h^2), \text{ and}$$

$$h = g, u, v$$

Now, substituting (A.2.3) and (A.2.4) in (A.2.1) and (A.2.2), we obtain:

$$x_t = \left[ \rho_g A^{-1} \gamma_0 - \left\{ \sigma \left( \phi_\pi - \frac{1}{\beta} \right) A^{-1} \right\} \theta_0 + A^{-1} \right] g_t + \left[ \rho_u A^{-1} \gamma_1 - \left\{ \sigma \left( \phi_\pi - \frac{1}{\beta} \right) A^{-1} \right\} \theta_1 - \left( \frac{\sigma}{\beta} \right) A^{-1} \right] u_t + \left[ \rho_v A^{-1} \gamma_2 - \left\{ \sigma \left( \phi_\pi - \frac{1}{\beta} \right) A^{-1} \right\} \theta_2 - \sigma A^{-1} \right] v_t \dots\dots\dots (A.2.6)$$

$$\pi_t = (\rho_g \theta_0 + \kappa \gamma_0) g_t + (\rho_u \theta_1 + \kappa \gamma_1 + 1) u_t + (\rho_v \theta_2 + \kappa \gamma_2) v_t \dots\dots\dots (A.2.7)$$

Comparing (A.2.7) with the guessed solution of (A.2.4) and using fixed point argument; one can obtain the solution of:

$$\theta_0 = \left[ \left\{ \frac{(A - \rho_g)(1 - \rho_g)}{\kappa} \right\} + \sigma \left( \phi_\pi - \frac{1}{\beta} \right) \right]^{-1}$$

$$\theta_1 = \left[ \left( \frac{A - \rho_u}{\kappa} \right) - \left( \frac{\sigma}{\beta} \right) \right] \left[ \left\{ \frac{(A - \rho_u)(1 - \rho_u)}{\kappa} \right\} + \sigma \left( \phi_\pi - \frac{1}{\beta} \right) \right]^{-1}$$

$$\theta_2 = -\sigma \left[ \left\{ \frac{(A - \rho_v)(1 - \rho_v)}{\kappa} \right\} + \sigma \left( \phi_\pi - \frac{1}{\beta} \right) \right]^{-1}$$

Hence, an analytical closed form solution can be found for inflation by inserting the above expressions of  $\theta$ 's in (A.2.4). Note that, each expression of  $\theta$  contains ' $\phi_\pi$ ' in its definition.

Further, for any generic AR (1) process,  $h_t$ , referred in (A.2.5), the variance of the series will be:

$$var(h_t) = \left( \frac{\sigma_h^2}{1-\rho_h^2} \right) \quad \forall h = g, u, v$$

Therefore, given the values of:  $\theta_0$ ,  $\theta_1$ , and  $\theta_2$ , the expression for inflation variance can be obtained as:

$$var(\pi_t) = \left( \frac{\theta_0^2}{1-\rho_g^2} \right) \sigma_g^2 + \left( \frac{\theta_1^2}{1-\rho_u^2} \right) \sigma_u^2 + \left( \frac{\theta_2^2}{1-\rho_v^2} \right) \sigma_v^2$$

$$\Rightarrow var(\pi_t) = \psi_1 \sigma_g^2 + \psi_2 \sigma_u^2 + \psi_3 \sigma_v^2 \quad ; \quad \text{where, } \psi_i = f_i(\phi_\pi) \quad \forall i = 1, 2, \& 3$$

..... (A.2.8)

### A.3 Derivation of Optimal Demand for firm-j in Food and Non-food sector:

Consider the following consumption aggregator which consists of both food and

$$\text{non-food consumption: } C_t = \left[ \alpha^{\frac{1}{\varepsilon}} (C_{F,t} - \Lambda)^{\frac{\varepsilon-1}{\varepsilon}} + (1 - \alpha)^{\frac{1}{\varepsilon}} C_{N,t}^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}} ;$$

$$\text{where, } C_{F,t} = \left[ \left\{ \int_0^1 C_{F,t}^{\frac{\varepsilon_F-1}{\varepsilon_F}} (i) di \right\}^{\frac{\varepsilon_F}{\varepsilon_F-1}} \right] \text{ and } C_{N,t} = \left[ \left\{ \int_0^1 C_{N,t}^{\frac{\varepsilon_N-1}{\varepsilon_N}} (i) di \right\}^{\frac{\varepsilon_N}{\varepsilon_N-1}} \right]$$

Now, from the aggregate expenditure minimizing exercise of consumer, optimal consumption bundle of food and non-food items, price indices of both food and non-food sector ( $P_{F,t}$  &  $P_{N,t}$ ) and finally the aggregate price index ( $P_t$ ).

Aggregate Expenditure ( $Z_t$ ) is equal to:

$$Z_t = Z_{F,t} + Z_{N,t}$$

$$Z_t = P_{F,t}C_{F,t} + P_{N,t}C_{N,t}$$

$$Z_t = \int_0^1 P_{F,t}(i)C_{F,t}(i)di + \int_0^1 P_{N,t}(i)C_{N,t}(i)di$$

Lagrangian Expression:

$$L = P_{F,t}C_{F,t} + P_{N,t}C_{N,t} + \lambda \left[ 1 - \left\{ \alpha^{\frac{1}{\varepsilon}}(C_{F,t} - \Lambda)^{\frac{\varepsilon-1}{\varepsilon}} + (1 - \alpha)^{\frac{1}{\varepsilon}} C_{N,t}^{\frac{\varepsilon-1}{\varepsilon}} \right\}^{\frac{\varepsilon}{\varepsilon-1}} \right]$$

Substituting  $C_{F,t}$  and  $C_{N,t}$ , we obtain:

$$L = \int_0^1 P_{F,t}(i)C_{F,t}(i)di + \int_0^1 P_{N,t}(i)C_{N,t}(i)di + \lambda \left[ 1 - \left[ \alpha^{\frac{1}{\varepsilon}} \left\{ \int_0^1 C_{F,t}^{\frac{\varepsilon_F-1}{\varepsilon_F}}(i) di - \Lambda \right\}^{\frac{\varepsilon-1}{\varepsilon}} + (1 - \alpha)^{\frac{1}{\varepsilon}} \left\{ \int_0^1 C_{N,t}^{\frac{\varepsilon_N-1}{\varepsilon_N}}(i) di \right\}^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}} \right]$$

From the F.O.C's we get:

$$\frac{\partial L}{\partial C_{F,t}(i)} = 0; \frac{\partial L}{\partial C_{N,t}(i)} = 0; \frac{\partial L}{\partial C_{F,t}(j)} = 0; \frac{\partial L}{\partial C_{N,t}(j)} = 0; \frac{\partial L}{\partial C_{F,t}} = 0; \frac{\partial L}{\partial C_{N,t}} = 0; \frac{\partial L}{\partial \lambda} = 0$$

$$\frac{\partial L}{\partial C_{F,t}(i)} = 0 \Rightarrow$$

$$P_{F,t}(i) - \lambda \left( \frac{\varepsilon}{\varepsilon-1} \right) \left[ \alpha^{\frac{1}{\varepsilon}}(C_{F,t} - \Lambda)^{\frac{\varepsilon-1}{\varepsilon}} + (1 - \alpha)^{\frac{1}{\varepsilon}} C_{N,t}^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{1}{\varepsilon-1}} \left( \frac{\varepsilon-1}{\varepsilon} \right) \alpha^{\frac{1}{\varepsilon}}(C_{F,t} - \Lambda)^{\frac{\varepsilon-2}{\varepsilon}} - \lambda \left( \frac{\varepsilon_F}{\varepsilon_F-1} \right) \left\{ \int_0^1 C_{F,t}^{\frac{\varepsilon_F-1}{\varepsilon_F}}(i) di \right\}^{\frac{1}{\varepsilon_F-1}} \left( \frac{\varepsilon_F-1}{\varepsilon_F} \right) C_{F,t}^{\frac{1}{\varepsilon_F}}(i) = 0$$

$$\begin{aligned} \Rightarrow P_{F,t}(i) &= \lambda \left[ \left\{ \alpha^{\frac{1}{\varepsilon}} (C_{F,t} - \Lambda)^{\frac{\varepsilon-1}{\varepsilon}} + (1-\alpha)^{\frac{1}{\varepsilon}} C_{N,t}^{\frac{\varepsilon-1}{\varepsilon}} \right\}^{\frac{\varepsilon}{\varepsilon-1}} \right]^{\frac{1}{\varepsilon}} \alpha^{\frac{1}{\varepsilon}} (C_{F,t} \\ &\quad - \Lambda)^{-\frac{1}{\varepsilon}} \left[ \int_0^1 C_{F,t}^{\frac{\varepsilon_F-1}{\varepsilon_F}}(i) di \right]^{\frac{\varepsilon_F}{\varepsilon_F-1}} C_{F,t}^{-\frac{1}{\varepsilon_F}}(i) \end{aligned}$$

$$\Rightarrow P_{F,t}(i) = \lambda \alpha^{\frac{1}{\varepsilon}} C_t^{\frac{1}{\varepsilon}} (C_{F,t} - \Lambda)^{-\frac{1}{\varepsilon}} C_{F,t}^{-\frac{1}{\varepsilon_F}} C_{F,t}^{-\frac{1}{\varepsilon_F}}(i)$$

Similarly, from  $\frac{\partial L}{\partial C_{F,t}(j)} = 0$ , we get:

$$P_{F,t}(j) = \lambda \alpha^{\frac{1}{\varepsilon}} C_t^{\frac{1}{\varepsilon}} (C_{F,t} - \Lambda)^{-\frac{1}{\varepsilon}} C_{F,t}^{-\frac{1}{\varepsilon_F}} C_{F,t}^{-\frac{1}{\varepsilon_F}}(j)$$

From  $\frac{\partial L}{\partial C_{N,t}(i)} = 0$ , we get:

$$\Rightarrow P_{N,t}(i) = \lambda \alpha^{\frac{1}{\varepsilon}} C_t^{\frac{1}{\varepsilon}} C_{N,t}^{-\frac{1}{\varepsilon}} C_{N,t}^{-\frac{1}{\varepsilon_N}} C_{N,t}^{-\frac{1}{\varepsilon_N}}(i)$$

From  $\frac{\partial L}{\partial C_{N,t}(j)} = 0$ , we get:

$$\Rightarrow P_{N,t}(j) = \lambda \alpha^{\frac{1}{\varepsilon}} C_t^{\frac{1}{\varepsilon}} C_{N,t}^{-\frac{1}{\varepsilon}} C_{N,t}^{-\frac{1}{\varepsilon_N}} C_{N,t}^{-\frac{1}{\varepsilon_N}}(j)$$

$$\text{Now, } \frac{\partial L}{\partial C_{F,t}} = 0 \Rightarrow P_{F,t} = \lambda \alpha^{\frac{1}{\varepsilon}} \left[ C_t^{\frac{1}{\varepsilon}} (C_{F,t} - \Lambda)^{-\frac{1}{\varepsilon}} \right]$$

$$\text{Similarly, from } \frac{\partial L}{\partial C_{N,t}} = 0 \Rightarrow P_{N,t} = \lambda (1-\alpha)^{\frac{1}{\varepsilon}} \left[ C_t^{\frac{1}{\varepsilon}} C_{N,t}^{\left(-\frac{1}{\varepsilon}\right)} \right]$$

Combining  $P_{F,t}(i)$  and  $P_{F,t}(j)$ , we have:

$$\left( \frac{P_{F,t}(i)}{P_{F,t}(j)} \right) = \left[ \frac{\lambda \alpha^{\frac{1}{\varepsilon}} C_t^{\frac{1}{\varepsilon}} (C_{F,t} - \Lambda)^{-\frac{1}{\varepsilon}} C_{F,t}^{-\frac{1}{\varepsilon_F}} C_{F,t}^{-\frac{1}{\varepsilon_F}}(i)}{\lambda \alpha^{\frac{1}{\varepsilon}} C_t^{\frac{1}{\varepsilon}} (C_{F,t} - \Lambda)^{-\frac{1}{\varepsilon}} C_{F,t}^{-\frac{1}{\varepsilon_F}} C_{F,t}^{-\frac{1}{\varepsilon_F}}(j)} \right]$$

$$\Rightarrow \left( \frac{P_{F,t}(i)}{P_{F,t}(j)} \right) = C_{F,t}^{-\frac{1}{\varepsilon_F}}(i) C_{F,t}^{\frac{1}{\varepsilon_F}}(j)$$

$$\Rightarrow C_{F,t}(i) = \left( \frac{P_{F,t}(i)}{P_{F,t}(j)} \right)^{-\varepsilon_F} C_{F,t}(j) \dots\dots\dots (A.3.1)$$

In the same way, we can obtain:

$$C_{N,t}(i) = \left( \frac{P_{N,t}(i)}{P_{N,t}(j)} \right)^{-\varepsilon_N} C_{N,t}(j) \dots\dots\dots (A.3.2)$$

Let us now consider the aggregate expenditure for food consumption which is as follows:

$$Z_{F,t} = P_{F,t} C_{F,t}$$

$$\text{Now, } P_{F,t} C_{F,t} = \int_0^1 P_{F,t}(i) C_{F,t}(i) di$$

Substituting  $C_{F,t}(i)$  in the above expression:

$$P_{F,t} C_{F,t} = \int_0^1 P_{F,t}(i) \left( \frac{P_{F,t}(i)}{P_{F,t}(j)} \right)^{-\varepsilon_F} C_{F,t}(j) di$$

$$\Rightarrow P_{F,t} C_{F,t} = C_{F,t}(j) P_{F,t}^{\varepsilon_F}(j) \int_0^1 P_{F,t}^{1-\varepsilon_F}(i) di$$

$$C_{F,t}(j) = \left[ \frac{P_{F,t} C_{F,t}}{P_{F,t}^{\varepsilon_F}(j) \int_0^1 P_{F,t}^{1-\varepsilon_F}(i) di} \right] \dots\dots\dots (A.3.3)$$

$$C_{F,t}^{-\frac{1}{\varepsilon_F}}(j) = \left[ \frac{P_{F,t} C_{F,t}}{P_{F,t}^{\varepsilon_F}(j) \int_0^1 P_{F,t}^{1-\varepsilon_F}(i) di} \right]^{-\frac{1}{\varepsilon_F}}$$

So, we can write:

$$C_{F,t}(j) C_{F,t}^{-\frac{1}{\varepsilon_F}}(j) = C_{F,t}(j) \left[ \frac{P_{F,t} C_{F,t}}{P_{F,t}^{\varepsilon_F}(j) \int_0^1 P_{F,t}^{1-\varepsilon_F}(i) di} \right]^{-\frac{1}{\varepsilon_F}}$$



$$C_{F,t}^{1-\frac{1}{\varepsilon_F}}(j) = \{P_{F,t}(j)C_{F,t}(j)\}\{P_{F,t}C_{F,t}\}^{-\frac{1}{\varepsilon_F}} \left\{ \int_0^1 P_{F,t}^{1-\varepsilon_F}(i)di \right\}^{\frac{1}{\varepsilon_F}} \int_0^1 C_{F,t}^{\frac{\varepsilon_F-1}{\varepsilon_F}}(j)dj =$$

$$\left[ \int_0^1 P_{F,t}(j)C_{F,t}(j)dj \right] Z_{F,t}^{-\frac{1}{\varepsilon_F}}$$

$$\left\{ \int_0^1 P_{F,t}^{1-\varepsilon_F}(i)di \right\}^{\frac{1}{\varepsilon_F}} \left[ \int_0^1 C_{F,t}^{\frac{\varepsilon_F-1}{\varepsilon_F}}(j)dj \right]^{\frac{\varepsilon_F}{\varepsilon_F-1}} = \left\{ Z_{F,t} Z_{F,t}^{-\frac{1}{\varepsilon_F}} \right\}^{\frac{\varepsilon_F}{\varepsilon_F-1}} \left\{ \int_0^1 P_{F,t}^{1-\varepsilon_F}(i)di \right\}^{\frac{1}{\varepsilon_F-1}}$$

$$\Rightarrow C_{F,t} = Z_{F,t} \left\{ \int_0^1 P_{F,t}^{1-\varepsilon_F}(i)di \right\}^{-\left(\frac{1}{1-\varepsilon_F}\right)}$$

$$\Rightarrow C_{F,t} = P_{F,t} C_{F,t} \left\{ \int_0^1 P_{F,t}^{1-\varepsilon_F}(i)di \right\}^{-\left(\frac{1}{1-\varepsilon_F}\right)}$$

$$P_{F,t} = \left\{ \int_0^1 P_{F,t}^{1-\varepsilon_F}(i)di \right\}^{\frac{1}{1-\varepsilon_F}} \dots\dots\dots (A.3.4) \Rightarrow \text{Price Index of Food sector}$$

Similarly, we will get:

$$P_{N,t} = \left\{ \int_0^1 P_{N,t}^{1-\varepsilon_N}(i)di \right\}^{\frac{1}{1-\varepsilon_N}} \dots\dots\dots (A.3.5) \Rightarrow \text{Price Index of Non-food sector}$$

Again, from (A.3.3), using (A.3.4), we get:

$$C_{F,t}(j) = \left[ \frac{P_{F,t}C_{F,t}}{P_{F,t}^{\varepsilon_F}(j) \int_0^1 P_{F,t}^{1-\varepsilon_F}(i)di} \right]$$

$$C_{F,t}(j) = \left[ \frac{P_{F,t}C_{F,t}}{P_{F,t}^{\varepsilon_F}(j)P_{F,t}^{1-\varepsilon_F}} \right]$$

$$C_{F,t}(j) = \left( \frac{P_{F,t}(j)}{P_{F,t}} \right)^{-\varepsilon_F} C_{F,t} \dots\dots\dots (A.3.6)$$

Similarly, for non-food sector

$$C_{N,t}(j) = \left( \frac{P_{N,t}(j)}{P_{N,t}} \right)^{-\varepsilon_N} C_{N,t} \dots\dots\dots (A.3.7)$$

#### A.4 Derivation of Price Aggregator and Aggregate Inflation

Minimize the aggregate expenditure  $(P_{F,t}C_{F,t} + P_{N,t}C_{N,t})$  subject to one unit of aggregate consumption  $C_t$ . So, the expression of Lagrangian function will be:

$$L = P_{F,t}C_{F,t} + P_{N,t}C_{N,t} + \lambda_t \left[ 1 - \left\{ \alpha^{\frac{1}{\varepsilon}} (C_{F,t} - \Lambda)^{\frac{\varepsilon-1}{\varepsilon}} + (1 - \alpha)^{\frac{1}{\varepsilon}} C_{N,t}^{\frac{\varepsilon-1}{\varepsilon}} \right\}^{\frac{\varepsilon}{\varepsilon-1}} \right]$$

From first order conditions of optimisation:

$$\frac{\partial L}{\partial C_{F,t}} = 0 \Rightarrow P_{F,t} = \lambda_t \left( \frac{\varepsilon}{\varepsilon-1} \right) C_t^{\frac{1}{\varepsilon}} \alpha^{\frac{1}{\varepsilon}} \left( \frac{\varepsilon-1}{\varepsilon} \right) (C_{F,t} - \Lambda)^{-\frac{1}{\varepsilon}} \dots \dots \dots (A.4.1)$$

$$\frac{\partial L}{\partial C_{N,t}} = 0 \Rightarrow P_{N,t} = \lambda_t \left( \frac{\varepsilon}{\varepsilon-1} \right) C_t^{\frac{1}{\varepsilon}} (1 - \alpha)^{\frac{1}{\varepsilon}} \left( \frac{\varepsilon-1}{\varepsilon} \right) C_{N,t}^{-\frac{1}{\varepsilon}} \dots \dots \dots (A.4.2)$$

$$\frac{\partial L}{\partial \lambda_t} = 0 \Rightarrow \left[ \alpha^{\frac{1}{\varepsilon}} (C_{F,t} - \Lambda)^{\frac{\varepsilon-1}{\varepsilon}} + (1 - \alpha)^{\frac{1}{\varepsilon}} C_{N,t}^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}} = 1 \dots \dots \dots (A.4.3)$$

Dividing (i) by (ii), we get:

$$\frac{P_{F,t}}{P_{N,t}} = \left( \frac{\alpha}{1 - \alpha} \right)^{\frac{1}{\varepsilon}} \left\{ \frac{(C_{F,t} - \Lambda)}{C_{N,t}} \right\}^{-\frac{1}{\varepsilon}}$$

$$\Rightarrow \left\{ \frac{(C_{F,t} - \Lambda)}{C_{N,t}} \right\}^{-\frac{1}{\varepsilon}} = \frac{P_{F,t}}{P_{N,t}} \left( \frac{1 - \alpha}{\alpha} \right)^{\frac{1}{\varepsilon}}$$

$$\Rightarrow \left\{ \frac{C_{N,t}}{(C_{F,t} - \Lambda)} \right\} = \left( \frac{1 - \alpha}{\alpha} \right) \left( \frac{P_{F,t}}{P_{N,t}} \right)^{\varepsilon}$$

$$\Rightarrow (C_{F,t} - \Lambda) = \left( \frac{\alpha}{1 - \alpha} \right) \left( \frac{P_{N,t}}{P_{F,t}} \right)^{\varepsilon} C_{N,t} \dots \dots \dots (A.4.4)$$

Now, substituting the value of  $(C_{F,t} - \Lambda)$  into (A.4.3), we obtain:

$$\left[ \alpha^{\frac{1}{\varepsilon}} (C_{F,t} - \Lambda)^{\frac{\varepsilon-1}{\varepsilon}} + (1-\alpha)^{\frac{1}{\varepsilon}} C_{N,t}^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}} = 1$$

$$\Rightarrow \alpha^{\frac{1}{\varepsilon}} (C_{F,t} - \Lambda)^{\frac{\varepsilon-1}{\varepsilon}} + (1-\alpha)^{\frac{1}{\varepsilon}} C_{N,t}^{\frac{\varepsilon-1}{\varepsilon}} = 1$$

$$\Rightarrow \alpha^{\frac{1}{\varepsilon}} \left\{ \left( \frac{\alpha}{1-\alpha} \right) \left( \frac{P_{N,t}}{P_{F,t}} \right)^{\varepsilon} C_{N,t} \right\}^{\frac{\varepsilon-1}{\varepsilon}} + (1-\alpha)^{\frac{1}{\varepsilon}} C_{N,t}^{\frac{\varepsilon-1}{\varepsilon}} = 1$$

$$\Rightarrow \left[ \alpha^{\frac{1}{\varepsilon}} \left\{ \left( \frac{\alpha}{1-\alpha} \right) \left( \frac{P_{N,t}}{P_{F,t}} \right)^{\varepsilon} \right\}^{\frac{\varepsilon-1}{\varepsilon}} + (1-\alpha)^{\frac{1}{\varepsilon}} \right] C_{N,t}^{\frac{\varepsilon-1}{\varepsilon}} = 1$$

$$\Rightarrow \left[ \alpha (1-\alpha)^{\frac{1-\varepsilon}{\varepsilon}} \left( \frac{P_{N,t}}{P_{F,t}} \right)^{\varepsilon-1} + (1-\alpha)^{\frac{1}{\varepsilon}} \right] = C_{N,t}^{\frac{1-\varepsilon}{\varepsilon}}$$

$$\Rightarrow \left[ \alpha (1-\alpha)^{\frac{1-\varepsilon}{\varepsilon}} \left( \frac{P_{F,t}}{P_{N,t}} \right)^{1-\varepsilon} + (1-\alpha)^{\frac{1}{\varepsilon}} \right] = C_{N,t}^{\frac{1-\varepsilon}{\varepsilon}}$$

$$\Rightarrow \left[ \alpha (1-\alpha)^{\frac{1-\varepsilon}{\varepsilon}} \left( \frac{P_{F,t}}{P_{N,t}} \right)^{1-\varepsilon} + (1-\alpha)^{\frac{1}{\varepsilon}} \right]^{\frac{\varepsilon}{1-\varepsilon}} = C_{N,t}$$

Consider (A.4.4) once again:

$$\Rightarrow (C_{F,t} - \Lambda) = \left( \frac{\alpha}{1-\alpha} \right) \left( \frac{P_{N,t}}{P_{F,t}} \right)^{\varepsilon} C_{N,t}$$

$$\Rightarrow (C_{F,t} - \Lambda) = \left( \frac{\alpha}{1-\alpha} \right) \left( \frac{P_{F,t}}{P_{N,t}} \right)^{-\varepsilon} \left[ \alpha (1-\alpha)^{\frac{1-\varepsilon}{\varepsilon}} \left( \frac{P_{F,t}}{P_{N,t}} \right)^{1-\varepsilon} + (1-\alpha)^{\frac{1}{\varepsilon}} \right]^{\frac{\varepsilon}{1-\varepsilon}}$$

$$\Rightarrow (C_{F,t} - \Lambda) = \left( \frac{\alpha}{1-\alpha} \right) \left( \frac{P_{F,t}}{P_{N,t}} \right)^{-\varepsilon} \left[ \alpha (1-\alpha)^{\frac{1-\varepsilon}{\varepsilon}} \left( \frac{P_{F,t}}{P_{N,t}} \right)^{1-\varepsilon} + (1-\alpha)^{\frac{1}{\varepsilon}} \right]^{\frac{\varepsilon}{1-\varepsilon}}$$

$$\Rightarrow C_{F,t} = \Lambda + \left( \frac{\alpha}{1-\alpha} \right) \left( \frac{P_{F,t}}{P_{N,t}} \right)^{-\varepsilon} \left[ \alpha (1-\alpha)^{\frac{1-\varepsilon}{\varepsilon}} \left( \frac{P_{F,t}}{P_{N,t}} \right)^{1-\varepsilon} + (1-\alpha)^{\frac{1}{\varepsilon}} \right]^{\frac{\varepsilon}{1-\varepsilon}}$$

Now, the aggregate expenditure for one unit of consumption is given by:

$$Z_t = P_{F,t}C_{F,t} + P_{N,t}C_{N,t}$$

$$\Rightarrow Z_t = P_{F,t} \left[ \Lambda + \left( \frac{\alpha}{1-\alpha} \right) \left( \frac{P_{F,t}}{P_{N,t}} \right)^{-\varepsilon} \left\{ \alpha (1-\alpha)^{\frac{1-\varepsilon}{\varepsilon}} \left( \frac{P_{F,t}}{P_{N,t}} \right)^{1-\varepsilon} + (1-\alpha)^{\frac{1}{\varepsilon}} \right\}^{\frac{\varepsilon}{1-\varepsilon}} \right] \\ + P_{N,t} \left[ \left\{ \alpha (1-\alpha)^{\frac{1-\varepsilon}{\varepsilon}} \left( \frac{P_{F,t}}{P_{N,t}} \right)^{1-\varepsilon} + (1-\alpha)^{\frac{1}{\varepsilon}} \right\}^{\frac{\varepsilon}{1-\varepsilon}} \right]$$

$$\Rightarrow Z_t = P_{F,t} \left[ \Lambda + \left( \frac{\alpha}{1-\alpha} \right) \left( \frac{P_{F,t}}{P_{N,t}} \right)^{-\varepsilon} \left\{ \alpha \left\{ \frac{1}{(1-\alpha)^{\frac{\varepsilon-1}{\varepsilon}}} \right\} \left( \frac{P_{F,t}}{P_{N,t}} \right)^{1-\varepsilon} + (1-\alpha)^{\frac{1}{\varepsilon}} \right\}^{\frac{\varepsilon}{1-\varepsilon}} \right] \\ + P_{N,t} \left[ \left\{ \alpha \left\{ \frac{1}{(1-\alpha)^{\frac{\varepsilon-1}{\varepsilon}}} \right\} \left( \frac{P_{F,t}}{P_{N,t}} \right)^{1-\varepsilon} + (1-\alpha)^{\frac{1}{\varepsilon}} \right\}^{\frac{\varepsilon}{1-\varepsilon}} \right]$$

$$\Rightarrow Z_t =$$

$$\Lambda P_{F,t} + P_{F,t} \left[ \left( \frac{\alpha}{1-\alpha} \right) \left( \frac{P_{F,t}}{P_{N,t}} \right)^{-\varepsilon} \left\{ \frac{\alpha P_{F,t}^{1-\varepsilon} + (1-\alpha) P_{N,t}^{1-\varepsilon}}{(1-\alpha)^{\frac{\varepsilon-1}{\varepsilon}} P_{N,t}^{1-\varepsilon}} \right\}^{\frac{\varepsilon}{1-\varepsilon}} \right] + P_{N,t} \left[ \left\{ \frac{\alpha P_{F,t}^{1-\varepsilon} + (1-\alpha) P_{N,t}^{1-\varepsilon}}{(1-\alpha)^{\frac{\varepsilon-1}{\varepsilon}} P_{N,t}^{1-\varepsilon}} \right\}^{\frac{\varepsilon}{1-\varepsilon}} \right]$$

$$\Rightarrow Z_t = \Lambda P_{F,t} + P_{F,t} \left[ \left( \frac{\alpha}{1-\alpha} \right) \left( \frac{P_{F,t}}{P_{N,t}} \right)^{-\varepsilon} (1-\alpha) P_{N,t}^{-\varepsilon} \left\{ \alpha P_{F,t}^{1-\varepsilon} + (1-\alpha) P_{N,t}^{1-\varepsilon} \right\}^{\frac{\varepsilon}{1-\varepsilon}} \right] \\ + P_{N,t} \left[ (1-\alpha) P_{N,t}^{-\varepsilon} \left\{ \alpha P_{F,t}^{1-\varepsilon} + (1-\alpha) P_{N,t}^{1-\varepsilon} \right\}^{\frac{\varepsilon}{1-\varepsilon}} \right]$$

$$\Rightarrow Z_t = \Lambda P_{F,t} + \alpha P_{F,t}^{1-\varepsilon} \left\{ \alpha P_{F,t}^{1-\varepsilon} + (1-\alpha) P_{N,t}^{1-\varepsilon} \right\}^{\frac{\varepsilon}{1-\varepsilon}} \\ + (1-\alpha) P_{N,t}^{1-\varepsilon} \left\{ \alpha P_{F,t}^{1-\varepsilon} + (1-\alpha) P_{N,t}^{1-\varepsilon} \right\}^{\frac{\varepsilon}{1-\varepsilon}}$$

$$\Rightarrow Z_t = \Lambda P_{F,t} + \left\{ \alpha P_{F,t}^{1-\varepsilon} + (1-\alpha) P_{N,t}^{1-\varepsilon} \right\} \left\{ \alpha P_{F,t}^{1-\varepsilon} + (1-\alpha) P_{N,t}^{1-\varepsilon} \right\}^{\frac{\varepsilon}{1-\varepsilon}}$$

$$\therefore P_t = \Lambda P_{F,t} + \left\{ \alpha P_{F,t}^{1-\varepsilon} + (1-\alpha) P_{N,t}^{1-\varepsilon} \right\}^{\frac{1}{1-\varepsilon}} \dots \dots \dots (A.4.5) \Rightarrow \text{Price Aggregator}$$

Now, log-linearizing the above expression around the steady state of:  $P_t = P_{N,t} = 1$

(by assumption) and  $P_{F,t} = P_F = \left(\frac{\alpha}{\alpha+\Lambda}\right)$  (by construction); one can obtain:

$$p_t = \left[ \Lambda P_F + \alpha P_F^{1-\varepsilon} \{ \alpha P_F^{1-\varepsilon} + (1-\alpha) \}^{\frac{\varepsilon}{1-\varepsilon}} \right] p_{F,t} + \left[ (1-\alpha) \{ \alpha P_F^{1-\varepsilon} + (1-\alpha) \}^{\frac{\varepsilon}{1-\varepsilon}} \right] p_{N,t} \dots \dots \dots \text{(A.4.6)}$$

The expression of (A.4.6) can be used to derive a relation for internal terms of trade between the sectors by normalizing with respect to ‘ $p_{N,t}$ ’.

$$(p_t - p_{N,t}) = \left[ \Lambda P_F + \alpha P_F^{1-\varepsilon} \{ \alpha P_F^{1-\varepsilon} + (1-\alpha) \}^{\frac{\varepsilon}{1-\varepsilon}} \right] (p_{F,t} - p_{N,t}) \dots \dots \dots \text{(A.4.7)}$$

Finally, taking the difference between two consecutive periods for (A.4.6), the expression of aggregate inflation can be obtained. It is as follows:

$$\pi_t = d_f \pi_{F,t} + (1 - d_f) \pi_{N,t} \dots \dots \dots \text{(A.4.8)} \Rightarrow \text{Inflation Aggregator}$$

$$\text{Where, } d_f = \left[ \Lambda P_F + \alpha P_F^{1-\varepsilon} \{ \alpha P_F^{1-\varepsilon} + (1-\alpha) \}^{\frac{\varepsilon}{1-\varepsilon}} \right]$$

### A.5 First Order Conditions of Dynamic Optimisation for Representative Household

$$L = \sum_{t=0}^{\infty} \beta^t \left[ \rho_{p,t} \left( \frac{C_t^{1-\sigma}}{1-\sigma} \right) - \frac{N_t^{1+\varphi}}{1+\varphi} \right] - \sum_{t=0}^{\infty} \lambda_t [P_t C_t + Q_t B_t - W_t N_t - B_{t-1} - T_t]$$

$$\text{F.O.Cs: } \frac{\partial L}{\partial C_{F,t}} = 0, \frac{\partial L}{\partial C_{N,t}} = 0, \frac{\partial L}{\partial N_{F,t}} = 0, \frac{\partial L}{\partial N_{N,t}} = 0, \frac{\partial L}{\partial B_t} = 0, \frac{\partial L}{\partial C_t} = 0, \frac{\partial L}{\partial C_{t+1}} = 0,$$

$$\frac{\partial L}{\partial \lambda} = 0$$

$$\frac{\partial L}{\partial C_{F,t}} = 0 \Rightarrow \beta^t \rho_{p,t} \alpha^{\frac{1}{\varepsilon}} C_t^{\frac{1}{\varepsilon} - \sigma} (C_{F,t} - \Lambda)^{-\frac{1}{\varepsilon}} = \lambda_t P_{F,t}$$

$$\frac{\partial L}{\partial C_{N,t}} = 0 \Rightarrow \beta^t \rho_{p,t} (1 - \alpha)^{\frac{1}{\varepsilon}} C_t^{\frac{1}{\varepsilon} - \sigma} C_{N,t}^{-\frac{1}{\varepsilon}} = \lambda_t P_{N,t}$$

$$\frac{\partial L}{\partial N_{F,t}} = 0 \Rightarrow \beta^t v^{\frac{1}{\gamma}} N_t^{\varphi + \frac{1}{\gamma}} N_{F,t}^{-\frac{1}{\gamma}} = \lambda_t W_{F,t}$$

$$\frac{\partial L}{\partial N_{N,t}} = 0 \Rightarrow \beta^t (1 - v)^{\frac{1}{\gamma}} N_t^{\varphi + \frac{1}{\gamma}} N_{N,t}^{-\frac{1}{\gamma}} = \lambda_t W_{N,t}$$

$$\frac{\partial L}{\partial B_t} = 0 \Rightarrow \lambda_t Q_t = \lambda_{t+1}$$

$$\frac{\partial L}{\partial C_t} = 0 \Rightarrow \beta^t \rho_{p,t} C_t^{-\sigma} = \lambda_t P_t$$

$$\frac{\partial L}{\partial C_{t+1}} = 0 \Rightarrow \beta^{t+1} \rho_{p,t+1} C_{t+1}^{-\sigma} = \lambda_{t+1} P_{t+1}$$

$$\frac{\partial L}{\partial \lambda} = 0 \Rightarrow P_t C_t + Q_t B_t - W_t N_t - B_{t-1} - T_t = 0$$

## A.6 Derivation of the Aggregate Consumption Euler Equation

Following the inter-temporal optimisation for the aggregate consumption, the Euler equation can be derived.

Consider:

$$\frac{\left(\frac{\partial L}{\partial C_{t+1}}\right)}{\left(\frac{\partial L}{\partial C_t}\right)} = 0 \Rightarrow \frac{\beta^{t+1} \rho_{p,t+1} C_{t+1}^{-\sigma}}{\beta^t \rho_{p,t} C_t^{-\sigma}} = \frac{\lambda_{t+1} P_{t+1}}{\lambda_t P_t}$$

$$\Rightarrow \beta \left(\frac{\rho_{p,t+1}}{\rho_{p,t}}\right) \left(\frac{C_{t+1}}{C_t}\right)^{-\sigma} = \left(\frac{\lambda_{t+1}}{\lambda_t}\right) \left(\frac{P_{t+1}}{P_t}\right)$$

Taking logarithm in both sides:

$$\Rightarrow \ln \beta + (\ln \rho_{p,t+1} - \ln \rho_{p,t}) - \sigma (c_{t+1} - c_t) = \ln Q_t + \pi_{t+1}$$

Here, it is assumed that:  $\delta = -\ln\beta$  and  $i_t = -\ln Q_t$

Thus the aggregate consumption Euler equation for the whole economy is:

$$\Rightarrow c_t = c_{t+1} - \frac{1}{\sigma} (i_t - \pi_{t+1} - \delta) - \frac{1}{\sigma} (\ln\rho_{p,t+1} - \ln\rho_{p,t})$$

Taking the log deviation from the steady state value for preference shock term, and then expectation operator at date 't', we obtain:

$$\Rightarrow c_t = E_t\{c_{t+1}\} - \frac{1}{\sigma} [i_t - E_t\{\pi_{t+1}\} - \delta] + \left(\frac{1-\rho_p}{\sigma}\right) \ln\rho_{p,t} \dots\dots\dots (A.6.1)$$

The above equation represents the consumption Euler equation for the whole economy.

### A.7 Derivation of Dynamic IS Equations for the Aggregate Economy

Using the market clearing conditions of :  $c_t = y_t$ ; we obtain the dynamic IS equation for Food Sector from (A.6.1).

$$\Rightarrow y_t = E_t\{y_{t+1}\} - \frac{1}{\sigma} [i_t - E_t\{\pi_{t+1}\} - \delta] + \left(\frac{1-\rho_p}{\sigma}\right) \ln\rho_{p,t} \dots\dots\dots (A.7.1)$$

The log-deviation from steady state of a variable ( $x_t$ ) can be expressed as the sum of two deviations, i.e. the gap between actual and natural equilibrium level ( $\tilde{x}_t$ ) and the gap between natural equilibrium and steady state level ( $x_t^n$ ). In notations:

$$x_t \equiv \tilde{x}_t + x_t^n \dots\dots\dots (A.7.2)$$

Using (A.7.2) in (A.7.1), one can obtain:

$$\tilde{y}_t = E_t\{\tilde{y}_{t+1}\} - \frac{1}{\sigma} [i_t - E_t\{\pi_{t+1}\} - r_t^n] + \left(\frac{1-\rho_p}{\sigma}\right) \ln\rho_{p,t} \dots\dots\dots (A.7.3)$$

Where,

$$\pi_{t+1} = d_f \pi_{F,t+1} + (1 - d_f) \pi_{N,t+1}$$

$$r_t^n = \delta + \sigma E_t \{ \Delta y_{t+1}^n \}$$

$$y_t^n = \zeta_f y_{F,t}^n + \zeta_n y_{N,t}^n$$

Therefore, (A.7.3) represents the dynamic IS equation for the economy as a whole.

### A.8 Relation between Sectoral Employment, Output and Productivity Shocks:

Consider the production function of representative intermediate goods producing firm.

$$Y_{F,t}(i) = A_{F,t} N_{F,t}^{1-\alpha_F}(i)$$

$$\Rightarrow \frac{Y_{F,t}(i)}{A_{F,t}} = N_{F,t}^{1-\alpha_F}(i)$$

$$\Rightarrow N_{F,t}(i) = \left[ \frac{Y_{F,t}(i)}{A_{F,t}} \right]^{\frac{1}{1-\alpha_F}}$$

Given the optimal demand functions for food and non-food items, using market clearing conditions for each sector, it can be written:

$$C_{F,t}(i) = \left( \frac{P_{F,t}(i)}{P_{F,t}} \right)^{-\varepsilon_F} C_{F,t} \Rightarrow Y_{F,t}(i) = \left( \frac{P_{F,t}(i)}{P_{F,t}} \right)^{-\varepsilon_F} Y_{F,t}$$

$$C_{N,t}(i) = \left( \frac{P_{N,t}(i)}{P_{N,t}} \right)^{-\varepsilon_N} C_{N,t} \Rightarrow Y_{N,t}(i) = \left( \frac{P_{N,t}(i)}{P_{N,t}} \right)^{-\varepsilon_N} Y_{N,t}$$

Therefore, applying these relations in the production function of food sector:

$$N_{F,t}(i) = \left[ \frac{\left( \frac{P_{F,t}(i)}{P_{F,t}} \right)^{-\varepsilon_F} Y_{F,t}}{A_{F,t}} \right]^{\frac{1}{1-\alpha_F}}$$



Now, consider the aggregate labour index for food sector:

$$N_{F,t} = \int_0^1 N_{F,t}(i) di$$

$$N_{F,t} = \left(\frac{Y_{F,t}}{A_{F,t}}\right)^{\frac{1}{1-\alpha_F}} \int_0^1 \left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\left(\frac{\varepsilon_F}{1-\alpha_F}\right)} di$$

Taking logarithm both sides, we get:

$$n_{F,t} = \left(\frac{1}{1-\alpha_F}\right) (y_{F,t} - a_{F,t}) + d_{F,i}$$

where,  $d_{F,i} = \ln \int_0^1 \left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\left(\frac{\varepsilon_F}{1-\alpha_F}\right)} di \approx 0$  (since, dispersion of price across the firms is zero due to zero variance of steady state inflation.)

Then, we obtain:

$$n_{F,t} = \left(\frac{1}{1-\alpha_F}\right) (y_{F,t} - a_{F,t}) \dots\dots\dots (A.8.1)$$

Similarly, we can obtain labour and output relation for non-food sector:

$$n_{N,t} = \left(\frac{1}{1-\alpha_N}\right) (y_{N,t} - a_{N,t}) \dots\dots\dots (A.8.2)$$

Using (A.8.1) and (A.8.2), in the natural equilibrium:

$$n_{F,t}^n = \left(\frac{1}{1-\alpha_F}\right) (y_{F,t}^n - a_{F,t}) \dots\dots\dots (A.8.3)$$

$$n_{N,t}^n = \left(\frac{1}{1-\alpha_N}\right) (y_{N,t}^n - a_{N,t}) \dots\dots\dots (A.8.4)$$

Therefore, the expression for deviation from the natural equilibrium level will be:

Food Sector:

$$\tilde{n}_{F,t} = \left( \frac{1}{1-\alpha_F} \right) \tilde{y}_{F,t} \dots\dots\dots (A.8.5)$$

Non-food Sector:

$$\tilde{n}_{N,t} = \left( \frac{1}{1-\alpha_N} \right) \tilde{y}_{N,t} \dots\dots\dots (A.8.6)$$

Let us consider the aggregate labour index:

$$N_t = \left[ u^{\frac{1}{\gamma}} N_{F,t}^{\frac{\gamma-1}{\gamma}} + (1-u)^{\frac{1}{\gamma}} N_{N,t}^{\frac{\gamma-1}{\gamma}} \right]^{\frac{\gamma}{\gamma-1}}$$

$$\Rightarrow N_t^{\frac{\gamma-1}{\gamma}} = \left[ u^{\frac{1}{\gamma}} N_{F,t}^{\frac{\gamma-1}{\gamma}} + (1-u)^{\frac{1}{\gamma}} N_{N,t}^{\frac{\gamma-1}{\gamma}} \right]$$

Log-linearizing both sides around the steady state values of:  $N_t = N$  ,  $N_{F,t} = N_F$  and

$N_{N,t} = N_N$  , we get:

$$\Rightarrow n_t = \eta_{n,F} n_{F,t} + \eta_{n,N} n_{N,t} \dots\dots\dots (A.8.7)$$

Where,  $\eta_{n,F} = u^{\frac{1}{\gamma}} \left( \frac{N_F}{N} \right)^{\frac{\gamma-1}{\gamma}}$  and  $\eta_{n,N} = (1-u)^{\frac{1}{\gamma}} \left( \frac{N_N}{N} \right)^{\frac{\gamma-1}{\gamma}}$  ;  $(\eta_{n,F} + \eta_{n,N}) = 1$

Thus, using (A.8.5) and (A.8.6) in (A.8.7), we can write:

$$\Rightarrow \tilde{n}_t = \left( \frac{\eta_{n,F}}{1-\alpha_F} \right) \tilde{y}_{F,t} + \left( \frac{\eta_{n,N}}{1-\alpha_N} \right) \tilde{y}_{N,t} \dots\dots\dots (A.8.8)$$

Moreover, note that the log-linearized version of the average marginal productivity of labour in the economy can be found from the production functions. Consider the  $i$ th firm's production function:

$$Y_{F,t}(i) = A_{F,t} N_{F,t}^{1-\alpha_F}(i)$$

$$\left\{ \frac{\partial Y_{F,t}(i)}{\partial N_{F,t}(i)} \right\} = A_{F,t} (1-\alpha_F) N_{F,t}^{-\alpha_F}(i)$$

Since the production functions are identical across all firms of the food sector, the expression of average marginal productivity of labour of a generic  $i$ -th firm will hold same form of the above expression for the aggregate level in the food sector of the economy. Taking logarithms in both sides, we obtain:

$$mpn_{F,t} = a_{F,t} + \ln(1 - \alpha_F) - \alpha_F n_{F,t} \dots\dots\dots (A.8.9)$$

Similarly, for non-food sector we will get:

$$mpn_{N,t} = a_{N,t} + \ln(1 - \alpha_N) - \alpha_N n_{N,t} \dots\dots\dots (A.8.10)$$

Using these expressions of (A.8.9) and (A.8.10), the relation between real marginal cost and output and natural level of outputs can be obtained.

### A.9 Optimal Consumption/Savings and Labour Supply Decision by Household

Marginal Rate of Substitution between food consumption and labour supply to the food sector can be obtained as:

$$\left( \frac{\frac{\partial L}{\partial N_{F,t}}}{\frac{\partial L}{\partial C_{F,t}}} \right) = 0 \Rightarrow \frac{v^\gamma N_t^{\varphi + \frac{1}{\gamma}} N_{F,t}^{-\frac{1}{\gamma}}}{\rho_{p,t} \alpha^\varepsilon C_t^{\frac{1}{\varepsilon} - \sigma} (C_{F,t}')^{-\frac{1}{\varepsilon}}} = \frac{W_{F,t}}{P_{F,t}} ; \text{ where, } C_{F,t}' = (C_{F,t} - \Lambda)$$

Taking log-deviation from the steady states in both sides:

$$\Rightarrow (w_{F,t} - p_{F,t}) = \left( \varphi + \frac{1}{\gamma} \right) n_t + \left( \sigma - \frac{1}{\varepsilon} \right) c_t + \left( \frac{1}{\gamma} \ln v - \frac{1}{\varepsilon} \ln \alpha \right) - \left( \frac{1}{\gamma} n_{F,t} - \frac{1}{\varepsilon} c'_{F,t} \right) - \ln \rho_{P,t} \dots\dots\dots (A.9.1)$$

Similarly, Marginal Rate of Substitution for non-food sector:

$$\frac{\frac{\partial L}{\partial N_{N,t}}}{\frac{\partial L}{\partial C_{N,t}}} = 0 \Rightarrow \frac{(1-v)^\gamma N_t^{\varphi + \frac{1}{\gamma}} N_{N,t}^{-\frac{1}{\gamma}}}{\rho_{p,t} (1-\alpha)^\varepsilon C_t^{\frac{1}{\varepsilon} - \sigma} C_{N,t}^{-\frac{1}{\varepsilon}}} = \frac{W_{N,t}}{P_{N,t}}$$

Taking log-deviation from the steady states in both sides:

$$\begin{aligned} (w_{N,t} - p_{N,t}) &= \left(\varphi + \frac{1}{\gamma}\right) n_t + \left(\sigma - \frac{1}{\varepsilon}\right) c_t + \left(\frac{1}{\gamma} \ln(1-v) - \frac{1}{\varepsilon} \ln(1-\alpha)\right) - \\ \left(\frac{1}{\gamma} n_{N,t} - \frac{1}{\varepsilon} c_{N,t}\right) - \ln \rho_{P,t} & \dots\dots\dots (A.9.2) \end{aligned}$$

In this context, it can be noted that there exists a real wage gap between food and non-food sector. From the conditions of MRS for food and non-food sectors, we can obtain the real wage gap between the sectors, i.e.

$$\bar{\omega}_t = \left[ \frac{1}{\gamma} \ln\left(\frac{1-v}{v}\right) - \frac{1}{\varepsilon} \ln\left(\frac{1-\alpha}{\alpha}\right) \right] + \frac{1}{\varepsilon} c_t^d - \frac{1}{\gamma} n_t^s$$

- where,  $c_t^d \Rightarrow$  relative demand for non-food items over food items,  $n_t^s \Rightarrow$  relative supply of labour to non-food sector over food sector,  $\bar{\omega}_t \Rightarrow$  real wage gap.

The above relation shows that real wage gap is directly and indirectly related to  $c_t^d$  and  $n_t^s$  respectively. Even when,  $c_t^d$  and  $n_t^s$  are zero, there exists:  $\bar{\omega}_t > 0$  which would explain wage premium to work in non-food sector.

**A.10 Relation between Inflation and Real Marginal Cost**

The dynamics of aggregate price for each sector food and non-food, specified by equations:

$$P_{j,t} = \left[ \theta_j (P_{j,t-1})^{1-\varepsilon_j} + (1 - \theta_j) (P_{j,t}^*)^{1-\varepsilon_j} \right]^{\frac{1}{1-\varepsilon_j}} \dots\dots\dots (A.10.1); \text{ where, } j = F, N$$

The above two equations can be log-linearized around zero inflation steady state for each sector and give rise to basic inflation equation subject to index of respective price stickiness. These are as follows:

$$\pi_{j,t} = (1 - \theta_j)(p_{j,t}^* - p_{t-1}) \dots\dots\dots (A.10.2)$$

At this stage, firms of the  $j$ 'th sector, who are willing to reschedule their price, will choose  $p_{j,t}^*$  optimally to maximize the discounted value of their profit. For this, the representative firm of the  $j$ 'th sector will solve the problem of:

$$\text{Max}_{p_{j,t}^*} \sum_{k=0}^{\infty} \theta_j^k E_t [Q_{t,t+k} \{P_{j,t}^* Y_{j,t+k|t} - \Psi_{j,t+k}(Y_{j,t+k|t})\}]$$

Subject to:  $Y_{j,t+k|t} = \left(\frac{P_{j,t}^*}{P_{j,t+k}}\right)^{-\varepsilon_j} Y_{j,t+k}$  ; where,  $\Psi_{j,t+k}(\cdot)$  is the cost function of food sector and  $Q_{t,t+k}$  is the stochastic discount factor.

$$\dots\dots\dots (A.10.3)$$

From the first order condition, we get:

$$\sum_{k=0}^{\infty} \theta_j^k E_t \left[ Q_{t,t+k} \left\{ Y_{j,t+k|t} \left\{ \left(\frac{P_{j,t}^*}{P_{j,t-1}}\right) - \left(\frac{\varepsilon_j}{\varepsilon_j - 1}\right) \left(\frac{\Psi'_{j,t+k}(Y_{j,t+k|t})}{P_{j,t+k}}\right) \left(\frac{P_{j,t+k}}{P_{j,t-1}}\right) \right\} \right\} \right] = 0$$

$$\dots\dots\dots (A.10.4)$$

Note that, the term:  $\left(\frac{\Psi'_{j,t+k}(Y_{j,t+k|t})}{P_{j,t+k}}\right)$  represents the real marginal cost in period  $(t + k)$  for the firm that last set its price in period  $t$ .

Again, using log-linearization around the zero inflation steady state in (A.10.4), an expression for  $p_{j,t}^*$  is derived. It is:

$$p_{j,t}^* = \mu_j + (1 - \beta\theta_j) \sum_{k=0}^{\infty} (\beta\theta_j)^k E_t \{mc_{j,t+k|t} + p_{j,t+k}\} \dots\dots\dots (A.10.5)$$

Now, we consider the definition of real marginal cost forecasted for  $(t + k)$  at date  $t$ :

$$mc_{j,t+k|t} = w_{j,t+k} - p_{j,t+k} - mpn_{j,t+k|t}$$

Following the above definition, we get:

$$mc_{j,t+k|t} = mc_{j,t+k} - \left(\frac{\alpha_j \varepsilon_j}{1-\alpha_j}\right) (p_{j,t}^* - p_{j,t+k}) \dots\dots\dots (A.10.6)$$

Now, combining (A.10.6) with (A.10.5), we obtain:

$$p_{j,t}^* - p_{j,t-1} = \beta \theta_j E_t(p_{j,t+1}^* - p_{j,t}) + (1 - \beta \theta_j) \left(\frac{1-\alpha_j}{1-\alpha_j+\alpha_j \varepsilon_j}\right) \widehat{mc}_{j,t} + \pi_{j,t} \dots\dots\dots (A.10.7)$$

Finally, using (A.10.2) with (A.10.7), the dynamics of j'th sector's 1 inflation is derived:

$$\pi_{j,t} = \beta E_t\{\pi_{j,t+1}\} + \lambda_j \widehat{mc}_{j,t} \dots\dots\dots (A.10.8)$$

Where,

$$\lambda_j = \left[\frac{(1-\theta_j)(1-\beta\theta_j)}{\theta_j}\right] \left[\frac{(1-\alpha_j)}{1-\alpha_j+\alpha_j \varepsilon_j}\right]$$

### A.11 Relation between Real Marginal Cost and Output Gap

Real marginal cost in the Food sector is defined as:

$$\begin{aligned} mc_{F,t} &= (w_{F,t} - p_{F,t}) - mpn_{F,t} \\ \Rightarrow mc_{F,t} &= \left(\varphi + \frac{1}{\gamma}\right) n_t + \left(\sigma - \frac{1}{\varepsilon}\right) c_t + \left(\frac{1}{\gamma} \ln v - \frac{1}{\varepsilon} \ln \alpha\right) - \left(\frac{1}{\gamma} n_{F,t} - \frac{1}{\varepsilon} c'_{F,t}\right) - \\ & \ln \rho_{P,t} - a_{F,t} - \ln(1 - \alpha_F) + \alpha_F n_{F,t} \end{aligned}$$

Here, using the resource constraint and market clearing conditions of  $c_t = y_t$  and

$c'_{F,t} = y'_{F,t}$ ; and rearranging the terms, we obtain:

$$\Rightarrow mc_{F,t} = \left(\varphi + \frac{1}{\gamma}\right)n_t + \left(\sigma - \frac{1}{\varepsilon}\right)y_t + \frac{1}{\varepsilon}y'_{F,t} + \left(\alpha_F - \frac{1}{\gamma}\right)n_{F,t} - \ln\rho_{P,t} - a_{F,t} + \left[\left(\frac{1}{\gamma}\ln\nu - \frac{1}{\varepsilon}\ln\alpha\right) - \ln(1 - \alpha_F)\right]$$

$$\Rightarrow mc_{F,t} = \left(\varphi + \frac{1}{\gamma}\right)n_t + \left(\sigma - \frac{1}{\varepsilon}\right)y_t + \frac{1}{\varepsilon(1-\Lambda_F)}y_{F,t} + \left(\alpha_F - \frac{1}{\gamma}\right)n_{F,t} - \ln\rho_{P,t} - a_{F,t} + \left[\left(\frac{1}{\gamma}\ln\nu - \frac{1}{\varepsilon}\ln\alpha\right) - \ln(1 - \alpha_F)\right]$$

Taking the deviation form of the above equation from the natural equilibrium level, it can be written as:

$$\Rightarrow \widehat{mc}_{F,t} = \left(\varphi + \frac{1}{\gamma}\right)\tilde{n}_t + \left(\sigma - \frac{1}{\varepsilon}\right)\tilde{y}_t + \frac{1}{\varepsilon(1-\Lambda_F)}\tilde{y}_{F,t} + \left(\alpha_F - \frac{1}{\gamma}\right)\tilde{n}_{F,t}$$

Now, substituting the relations of (A.8.8), (A.7.3), and (A.8.5) in the right hand side, we obtain:

$$\Rightarrow \widehat{mc}_{F,t} = \left[\left(\varphi + \frac{1}{\gamma}\right)\left(\frac{\eta_{n,F}}{1-\alpha_F}\right) + \left(\alpha_F - \frac{1}{\gamma}\right)\left(\frac{1}{1-\alpha_F}\right) + \left(\sigma - \frac{1}{\varepsilon}\right)\zeta_F + \left\{\frac{1}{\varepsilon(1-\Lambda_F)}\right\}\right]\tilde{y}_{F,t} + \left[\left(\varphi + \frac{1}{\gamma}\right)\left(\frac{\eta_{n,N}}{1-\alpha_N}\right) + \left(\sigma - \frac{1}{\varepsilon}\right)\zeta_N\right]\tilde{y}_{N,t}$$

Inflation equation for food sector:

Let us consider the inflation equation for food sector:

$$\pi_{F,t} = \beta E_t\{\pi_{F,t+1}\} + \lambda_F \widehat{mc}_{F,t}$$

Substituting  $\widehat{mc}_{F,t}$  in this equation, we get:

$$\pi_{F,t} = \beta E_t\{\pi_{F,t+1}\} + \vartheta_f^F \tilde{y}_{F,t} + \vartheta_n^F \tilde{y}_{N,t} \dots\dots\dots (A.11.1)$$

Where,

$$\vartheta_f^F = \lambda_F \left[\left(\varphi + \frac{1}{\gamma}\right)\left(\frac{\eta_{n,F}}{1-\alpha_F}\right) + \left(\alpha_F - \frac{1}{\gamma}\right)\left(\frac{1}{1-\alpha_F}\right) + \left(\sigma - \frac{1}{\varepsilon}\right)\zeta_F + \left\{\frac{1}{\varepsilon(1-\Lambda_F)}\right\}\right]$$

$$\vartheta_n^F = \lambda_F \left[ \left( \varphi + \frac{1}{\gamma} \right) \left( \frac{\eta_{n,N}}{1-\alpha_N} \right) + \left( \sigma - \frac{1}{\varepsilon} \right) \varsigma_N \right]$$

Again, the real marginal cost in the non-food sector is defined as:

$$mc_{N,t} = (w_{N,t} - p_{N,t}) - mpn_{N,t}$$

$$mc_{N,t} = \left( \varphi + \frac{1}{\gamma} \right) n_t + \left( \sigma - \frac{1}{\varepsilon} \right) c_t + \left( \frac{1}{\gamma} \ln(1 - \nu) - \frac{1}{\varepsilon} \ln(1 - \alpha) \right) - \left( \frac{1}{\gamma} n_{N,t} - \frac{1}{\varepsilon} c_{N,t} \right) - \ln \rho_{P,t} - a_{N,t} - \ln(1 - \alpha_N) + \alpha_N n_{N,t}$$

$$mc_{N,t} = \left( \varphi + \frac{1}{\gamma} \right) n_t + \left( \sigma - \frac{1}{\varepsilon} \right) y_t + \left( \frac{1}{\gamma} \ln(1 - \nu) - \frac{1}{\varepsilon} \ln(1 - \alpha) \right) - \left( \frac{1}{\gamma} n_{N,t} - \frac{1}{\varepsilon} y_{N,t} \right) - \ln \rho_{P,t} - a_{N,t} - \ln(1 - \alpha_N) + \alpha_N n_{N,t}$$

Therefore, the deviation from steady state will take the form of:

$$\widehat{mc}_{N,t} = \left( \varphi + \frac{1}{\gamma} \right) \tilde{n}_t + \left( \sigma - \frac{1}{\varepsilon} \right) \tilde{y}_t + \left( \alpha_N - \frac{1}{\gamma} \right) \tilde{n}_{N,t} + \frac{1}{\varepsilon} \tilde{y}_{N,t}$$

Now, substituting the relations of (A.8.8), (A.7.3), and (A.8.6) in the right hand side,

we obtain:

$$\widehat{mc}_{N,t} = \left[ \left\{ \left( \varphi + \frac{1}{\gamma} \right) \left( \frac{\eta_{n,F}}{1-\alpha_F} \right) \right\} + \left( \sigma - \frac{1}{\varepsilon} \right) \varsigma_F \right] \tilde{y}_{F,t} + \left[ \left\{ \left( \varphi + \frac{1}{\gamma} \right) \left( \frac{\eta_{n,N}}{1-\alpha_N} \right) \right\} + \left\{ \left( \alpha_N - \frac{1}{\gamma} \right) \left( \frac{1}{1-\alpha_N} \right) \right\} + \left( \sigma - \frac{1}{\varepsilon} \right) \varsigma_N + \frac{1}{\varepsilon} \right] \tilde{y}_{N,t}$$

Now, consider the inflation equation for non-food sector:

$$\pi_{N,t} = \beta E_t \{ \pi_{N,t+1} \} + \lambda_N \widehat{mc}_{N,t}$$

Replacing  $\widehat{mc}_{N,t}$  in the above equation:

$$\pi_{N,t} = \beta E_t \{ \pi_{N,t+1} \} + \vartheta_f^N \tilde{y}_{F,t} + \vartheta_n^N \tilde{y}_{N,t} \dots \dots \dots (A.11.2)$$

$$\text{Where, } \vartheta_f^N = \lambda_N \left[ \left\{ \left( \varphi + \frac{1}{\gamma} \right) \left( \frac{\eta_{n,F}}{1-\alpha_F} \right) \right\} + \left( \sigma - \frac{1}{\varepsilon} \right) \varsigma_F \right]$$



$$\vartheta_n^N = \lambda_N \left[ \left\{ \left( \varphi + \frac{1}{\gamma} \right) \left( \frac{\eta_{n,N}}{1-\alpha_N} \right) \right\} + \left\{ \left( \alpha_N - \frac{1}{\gamma} \right) \left( \frac{1}{1-\alpha_N} \right) \right\} + \left( \sigma - \frac{1}{\varepsilon} \right) \varsigma_N + \frac{1}{\varepsilon} \right]$$

### A.12 Relation between Natural Level of Output and Shocks in Food Sector:

The real marginal cost in food sector is:

$$\begin{aligned} \Rightarrow mc_{F,t} &= \left( \varphi + \frac{1}{\gamma} \right) n_t + \left( \sigma - \frac{1}{\varepsilon} \right) y_t + \left\{ \frac{1}{\varepsilon(1-\Lambda_F)} \right\} y_{F,t} + \left( \alpha_F - \frac{1}{\gamma} \right) n_{F,t} - \ln \rho_{P,t} - \\ &a_{F,t} + \left[ \left( \frac{1}{\gamma} \ln v - \frac{1}{\varepsilon} \ln \alpha \right) - \ln(1 - \alpha_F) \right] \end{aligned}$$

Using the values of natural equilibrium, the above expression can be written as:

$$\begin{aligned} \Rightarrow -\mu_F &= \left( \varphi + \frac{1}{\gamma} \right) [\eta_{n,F} n_{F,t}^n + \eta_{n,N} n_{N,t}^n] + \left( \sigma - \frac{1}{\varepsilon} \right) y_t^n + \left\{ \frac{1}{\varepsilon(1-\Lambda_F)} \right\} y_{F,t}^n + \\ &\left( \alpha_F - \frac{1}{\gamma} \right) n_{F,t}^n - \ln \rho_{P,t} - a_{F,t} + \left[ \left( \frac{1}{\gamma} \ln v - \frac{1}{\varepsilon} \ln \alpha \right) - \ln(1 - \alpha_F) \right] \end{aligned}$$

Using (A.8.3) and (A.8.4) and rearranging the terms, it can be obtained:

$$\begin{aligned} \Rightarrow &\left\{ \left( \varphi + \frac{1}{\gamma} \right) \left( \frac{\eta_{n,F}}{1-\alpha_F} \right) + \left( \alpha_F - \frac{1}{\gamma} \right) \left( \frac{1}{1-\alpha_F} \right) + \left( \sigma - \frac{1}{\varepsilon} \right) \varsigma_f + \frac{1}{\varepsilon(1-\Lambda_F)} \right\} y_{F,t}^n + \\ &\left\{ \left( \varphi + \frac{1}{\gamma} \right) \left( \frac{\eta_{n,N}}{1-\alpha_N} \right) + \left( \sigma - \frac{1}{\varepsilon} \right) \varsigma_n \right\} y_{N,t}^n = k_F + \ln \rho_{P,t} + \left[ 1 + \left( \varphi + \frac{1}{\gamma} \right) \left( \frac{\eta_{n,F}}{1-\alpha_F} \right) + \right. \\ &\left. \left( \alpha_F - \frac{1}{\gamma} \right) \left( \frac{1}{1-\alpha_F} \right) \right] a_{F,t} + \left[ \left( \varphi + \frac{1}{\gamma} \right) \left( \frac{\eta_{n,N}}{1-\alpha_N} \right) \right] a_{N,t} \end{aligned}$$

$$\text{Where, } k_F = \left[ \ln(1 - \alpha_F) - \left( \frac{1}{\gamma} \ln v - \frac{1}{\varepsilon} \ln \alpha \right) - \mu_F \right]$$

Taking ‘ $\Delta$ ’ both sides, it results:

$$\Rightarrow \Gamma_1^F \Delta y_{F,t}^n + \Gamma_2^F \Delta y_t^n = \Delta \ln \rho_{P,t} + \Gamma_3^F \Delta a_{F,t} + \Gamma_4^F \Delta a_{N,t} \dots \dots \dots \text{(A.12.1)}$$

Where,

$$\Gamma_1^F = \left[ \left( \varphi + \frac{1}{\gamma} \right) \left( \frac{\eta_{n,F}}{1-\alpha_F} \right) + \left( \alpha_F - \frac{1}{\gamma} \right) \left( \frac{1}{1-\alpha_F} \right) + \left( \sigma - \frac{1}{\varepsilon} \right) \varsigma_f + \frac{1}{\varepsilon(1-\Lambda_F)} \right]$$

$$\Gamma_2^F = \left[ \left( \varphi + \frac{1}{\gamma} \right) \left( \frac{\eta_{n,N}}{1-\alpha_N} \right) + \left( \sigma - \frac{1}{\varepsilon} \right) \zeta_n \right]$$

$$\Gamma_3^F = \left[ 1 + \left( \varphi + \frac{1}{\gamma} \right) \left( \frac{\eta_{n,F}}{1-\alpha_F} \right) + \left( \alpha_F - \frac{1}{\gamma} \right) \left( \frac{1}{1-\alpha_F} \right) \right]$$

$$\Gamma_4^F = \left[ \left( \varphi + \frac{1}{\gamma} \right) \left( \frac{\eta_{n,N}}{1-\alpha_N} \right) \right]$$

In the similar way, another equation will be obtained consisting of the natural output level for food and non-food as the function of shocks from expression of real marginal cost of non-food sector as:

$$\Rightarrow \Gamma_1^N \Delta y_{F,t}^n + \Gamma_2^N \Delta y_t^n = \Delta \ln \rho_{p,t} + \Gamma_3^N \Delta a_{F,t} + \Gamma_4^N \Delta a_{N,t} \dots \dots \dots (A.12.2)$$

Where,

$$\Gamma_1^N = \left\{ \left( \varphi + \frac{1}{\gamma} \right) \left( \frac{\eta_{n,F}}{1-\alpha_F} \right) + \left( \sigma - \frac{1}{\varepsilon} \right) \zeta_f \right\}$$

$$\Gamma_2^N = \left\{ \left( \varphi + \frac{1}{\gamma} \right) \left( \frac{\eta_{n,N}}{1-\alpha_N} \right) + \left( \alpha_N - \frac{1}{\gamma} \right) \left( \frac{1}{1-\alpha_N} \right) + \left( \sigma - \frac{1}{\varepsilon} \right) \zeta_n + \frac{1}{\varepsilon} \right\}$$

$$\Gamma_3^N = \left[ \left( \varphi + \frac{1}{\gamma} \right) \left( \frac{\eta_{n,F}}{1-\alpha_F} \right) \right]$$

$$\Gamma_4^N = \left[ 1 + \left( \varphi + \frac{1}{\gamma} \right) \left( \frac{\eta_{n,N}}{1-\alpha_N} \right) + \left( \alpha_N - \frac{1}{\gamma} \right) \left( \frac{1}{1-\alpha_N} \right) \right]$$

Now, solving (A.12.1) and (A.12.1) together, the analytical forms of the change of natural output of food and non-food sectors are derived. These will take the form of:

$$\Delta y_{F,t}^n = \psi_p^F \Delta \ln \rho_{p,t} + \psi_f^F \Delta a_{F,t} + \psi_n^F \Delta a_{N,t}$$

$$\Delta y_{N,t}^n = \psi_p^N \Delta \ln \rho_{p,t} + \psi_f^N \Delta a_{F,t} + \psi_n^N \Delta a_{N,t}$$

### A.13 List of Composite Parameters with Definition

$$P_{f,s} = \left( \frac{\alpha}{\alpha + \Lambda} \right)$$

$$d_f = \left[ \Lambda P_F + \alpha P_F^{1-\varepsilon} \{ \alpha P_F^{1-\varepsilon} + (1-\alpha) \}^{\frac{\varepsilon}{1-\varepsilon}} \right]$$

$$\zeta_f = \left[ \left[ \frac{\left\{ \Lambda P_{f,s} + \alpha P_{f,s}^{1-\varepsilon} \{ \alpha P_{f,s}^{1-\varepsilon} + (1-\alpha) \}^{\frac{\varepsilon}{1-\varepsilon}} \right\}}{\varepsilon(1-\Lambda_F)} \right] + \left\{ 1 - \frac{1}{\varepsilon(1-\Lambda_F)} \right\} P_{f,s} S_F \right]$$

$$\zeta_n = \left[ (1 - S_F) - \left[ \frac{\left\{ \Lambda P_{f,s} + \alpha P_{f,s}^{1-\varepsilon} \{ \alpha P_{f,s}^{1-\varepsilon} + (1-\alpha) \}^{\frac{\varepsilon}{1-\varepsilon}} \right\} - P_{f,s} S_F}{\varepsilon} \right] \right]$$

$$\vartheta_f^F = \lambda_F \left\{ \left( \varphi + \frac{1}{\gamma} \right) \left( \frac{\eta_{n,F}}{1-\alpha_F} \right) + \left( \alpha_F - \frac{1}{\gamma} \right) \left( \frac{1}{1-\alpha_F} \right) + \left( \sigma - \frac{1}{\varepsilon} \right) \zeta_f + \frac{1}{\varepsilon(1-\Lambda_F)} \right\}$$

$$\vartheta_n^F = \lambda_F \left\{ \left( \varphi + \frac{1}{\gamma} \right) \left( \frac{\eta_{n,N}}{1-\alpha_N} \right) + \left( \sigma - \frac{1}{\varepsilon} \right) \zeta_n \right\}$$

$$\vartheta_f^N = \lambda_N \left[ \left\{ \left( \varphi + \frac{1}{\gamma} \right) \left( \frac{\eta_{n,F}}{1-\alpha_F} \right) \right\} + \left( \sigma - \frac{1}{\varepsilon} \right) \zeta_f \right]$$

$$\vartheta_n^N = \lambda_N \left[ \left\{ \left( \varphi + \frac{1}{\gamma} \right) \left( \frac{\eta_{n,N}}{1-\alpha_N} \right) \right\} + \left\{ \left( \alpha_N - \frac{1}{\gamma} \right) \left( \frac{1}{1-\alpha_N} \right) \right\} + \left( \sigma - \frac{1}{\varepsilon} \right) \zeta_n + \frac{1}{\varepsilon} \right]$$

$$\lambda_F = \left[ \frac{(1-\theta_F)(1-\beta\theta_F)}{\theta_F} \right] \left[ \frac{(1-\alpha_F)}{1-\alpha_F + \alpha_F \varepsilon_F} \right]$$

$$\lambda_N = \left[ \frac{(1-\theta_N)(1-\beta\theta_N)}{\theta_N} \right] \left[ \frac{(1-\alpha_N)}{1-\alpha_N + \alpha_N \varepsilon_N} \right]$$

### A.14 Measure of Price Stickiness of Developing Countries

In Table A.5.1 and A.5.2 are showing the price duration of food and non-food items categorically.

**Table: A.5.1**

	Food Items	Duration	Weight	Weighted Duration
Beverages	Cocoa	0.45	0.03	0.01
	Coffee	0.26	0.04	0.01
	Tea	0.62	0.01	0.01
Vegetable Oils	Coconut Oil	0.27	0.01	0.00
	Groundnut Oil	0.27	0.00	0.00

	Palm Oil	0.33	0.05	0.02
	Soybean Oil	0.30	0.02	0.01
Cereals	Maize	0.37	0.16	0.06
	Rice	0.30	0.12	0.04
	Wheat	0.34	0.10	0.03
Other Foods	Banana	0.31	0.02	0.01
	Orange	0.56	0.01	0.01
	Beef	0.26	0.03	0.01
	Chicken	0.27	0.02	0.01
	Sugar	0.67	0.04	0.03
Average duration of Aggregate Food Price (Un-weighted)				<b>0.38</b>
Average duration of Aggregate Food Price (Weighted)				<b>0.24</b>

**Table: A.5.2**

	Non-food Items	Duration	Weight	Weighted Duration
Energy Products	Petroleum	0.84	0.42	0.35
	Coal	1.72	0.02	0.04
	Natural Gas	0.90	0.05	0.05
Agricultural Raw Materials	Tobacco	0.53	0.00	0.00
	Log	0.56	0.00	0.00
	Swan wood	0.66	0.00	0.00
	Plywood	0.23	0.00	0.00
	Wood pulp	0.33	0.00	0.00
	Cotton	0.23	0.00	0.00
	Rubber	0.16	0.00	0.00
Fertilizers	Phosphate	6.34	0.00	0.02
	Urea	1.25	0.01	0.01
	Potassium Chloride	2.23	0.00	0.01
Metals & Minerals	Aluminium	0.67	0.04	0.03
	Copper	0.24	0.06	0.01
	Iron Ore	12.65	0.03	0.38
Average duration of Aggregate Non-food Price (Un-weighted)				<b>0.85</b>
Average duration of Aggregate Non-food Price (Weighted)				<b>0.91</b>

## **A.15 Derivation of Central Bank's Welfare Loss Function from Representative Household's Utility function**

Evaluation of welfare loss, incurred due to inflation volatility, requires a quantitative criterion. The existing literature on optimal monetary policy based on the works of Rotemberg and Woodford (1997, 1999), Clarida, Gali and Gertler (1999), and Woodford (2003), has adopted a welfare based criterion that relies on a second order approximation of the utility losses experienced by the representative household as a consequence of deviations from the efficient allocation. In this approach, volatility of inflation comes because of the price dispersion due to market imperfection and nominal friction in the economy. Following this line of research, the welfare loss function of central bank has been derived below. This derivation is heavily drawn from the works of Woodford (2003) and Gali (2008).

### **Outline of the Economy:**

Let us consider an economy with infinitely lived representative household, an imperfectly competitive goods market where firms set the prices for their differentiated goods and a central bank that evaluates the welfare loss of representative household given the primitive structure of the economy.

### **Representative Household:**

The economy is populated by a continuum of households within a unit interval. The representative household enters each period  $t = 0, 1, 2 \dots \infty$  with nominal bonds. Each bond will pay one unit of money tomorrow if it is bought today. At date  $t$ , the household redeems one period bonds purchased in the previous periods, which pays

$B_{t-1}$  additional units of money. At the beginning of the period, the household also receives a lump-sum monetary transfer  $T_t$  from the central bank. During the same period, the household supplies  $N_t$  units of labour in total to the various intermediate goods-producing firms. In return, it earns the wage income of  $W_t N_t$ , where  $W_t$  denote the nominal wage. The household also consumes  $C_t$  units of the finished goods purchased at the nominal prices of  $P_t$  from the representative finished goods-producing firms. It is assumed that there exists a continuum of differentiated goods, represented by the interval of  $[0, 1]$ . The household also uses some of his money to purchase new bonds of value  $Q_t B_t$ , where  $1/Q_t$  denotes the gross nominal interest rate between  $t$  and  $(t+1)^{\text{th}}$  period. The representative household chooses the sequences of  $C_t$ ,  $N_t$ , and  $B_t$ , to maximise the present value of life time expected utility function which is given by:

$$E_t \sum_{t=0}^{\infty} \beta^t U(C_t, N_t) \dots\dots\dots (A.15.1)$$

Subject to the periodical budget constraint of:

$$\int_0^1 P_t(i) C_t(i) di + Q_t B_t \leq B_{t-1} + W_t N_t + T_t \dots\dots\dots (A.15.2)$$

Where,

- The utility function of aggregate consumption and labour supply of the household is taken as additively separable

$$U(C_t, N_t) = \left( \frac{C_t^{1-\sigma}}{1-\sigma} \right) - \left( \frac{N_t^{1+\varphi}}{1+\varphi} \right) \dots\dots\dots (A.15.3)$$

- Consumption index  $C_t$  is defined as:  $C_t = \left[ \int_0^1 C_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right]^{\frac{\varepsilon}{\varepsilon-1}}$
- Labour index  $N_t$  is defined as:  $N_t = \int_0^1 N_t(i) di$

Household's optimization exercise yields, labour supply relation, consumption Euler equations and allocation of consumption among the differentiated goods. The optimal allocation of consumption among the differentiated goods gives a set of iso-elastic demand sequence as:

$$C_t(i) = \left( \frac{P_t(i)}{P_t} \right)^{-\varepsilon} C_t \dots\dots\dots (A.15.4)$$

Where,  $P_t$  is the aggregate price index and defined as:

$$P_t = \left[ \int_0^1 P_t(i)^{1-\varepsilon} di \right]^{\frac{1}{1-\varepsilon}} \dots\dots\dots (A.15.5)$$

**Representative of Intermediate Goods Producing Firms:**

Assume, there exists a representative firm from the continuum of intermediate goods producing firms indexed by  $i \in [0, 1]$ . It produces a differentiated good using a technology identical to other firms. Production function of the firm is presented as:

$$Y_t(i) = A_t N_t^{1-\alpha}(i) \dots\dots\dots (A.15.6)$$

Where,  $A_t$  represents the level of technology, assumed to be common to all firms and to evolve exogenously over time.

The firm faces an iso-elastic demand schedule given by (A.15.4) and takes the aggregate price level  $P_t$  and  $C_t$  as given.

It is assumed that the representative firm follows Calvo (1983) type price setting behaviour and resets its price only with the probability of  $(1 - \theta)$  in any given period. This probability is independent of the time elapsed since the last price adjustment. Therefore, the dynamics of aggregate price index is given by:

$$P_t = [\theta(P_{t-1})^{1-\varepsilon} + (1-\theta)(P_t^*)^{1-\varepsilon}]^{\frac{1}{1-\varepsilon}} \dots \dots \dots (A.15.7)$$

Where,  $P_t^*$  is the re-optimized price, charged by the representative firm.

The representative firm solves the price re-optimization problem for  $P_t^*$  in the following way:

$$\text{Max}_{p_t^*} \sum_{k=0}^{\infty} \theta^k E_t [Q_{t,t+k} \{P_t^* Y_{t+k|t} - \Psi_{t+k}(Y_{t+k|t})\}]$$

Subject to:  $Y_{t+k|t} = \left(\frac{P_t^*}{P_{t+k}}\right)^{-\varepsilon} Y_{t+k}$ ; where,  $\Psi_{t+k}(\cdot)$  is the cost function of food sector and  $Q_{t,t+k}$  is the stochastic discount factor.

From the first order condition, we get:

$$\sum_{k=0}^{\infty} \theta^k E_t \left[ Q_{t,t+k} \left\{ Y_{t+k|t} \left\{ \left(\frac{P_t^*}{P_{t-1}}\right) - \left(\frac{\varepsilon}{\varepsilon-1}\right) \left(\frac{\Psi'_{t+k}(Y_{t+k|t})}{P_{t+k}}\right) \left(\frac{P_{t+k}}{P_{t-1}}\right) \right\} \right\} \right] = 0 \dots \dots \dots (A.15.8)$$

Note that, the term:  $\left(\frac{\Psi'_{t+k}(Y_{t+k|t})}{P_{t+k}}\right)$  represents the real marginal cost in period (t + k) for the firm that last set its price in period t.

From (A.15.7), the inflation equation can be obtained as:

$$\pi_t = (1-\theta)(p_t^* - p_{t-1})$$

Besides, from (A.15.8) gives log-transformed re-optimized price equation:

$$p_t^* = \mu + (1-\beta\theta) \sum_{k=0}^{\infty} (\beta\theta)^k E_t \{mc_{t+k|t} + p_{t+k}\}$$

Combining, inflation equation with re-optimized price equation:

$$\pi_t = \beta E_t \{\pi_{t+1}\} + \lambda \widehat{mc}_t, \text{ where, } \lambda = \left[ \frac{(1-\theta)(1-\beta\theta)}{\theta} \right] \left[ \frac{(1-\alpha)}{1-\alpha+\alpha\varepsilon} \right]$$



**Representative of Final Goods Producing Firms:**

Consider a representative of final goods producing firms, which simply bundles up the intermediate goods and produce the aggregate output as:

$$Y_t = \left[ \int_0^1 Y_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right]^{\frac{\varepsilon}{\varepsilon-1}}$$

**Central Bank:**

Based on the knowledge of imperfect goods market and staggered price setting behaviour of firms, central bank derives the welfare loss function using the utility function of representative household. The loss function comes as result of deviation from the efficient allocation in the economy.

Let us consider a generic stochastic variable  $Z_t$ . Using quadratic approximation around the steady state<sup>54</sup> can be written as:

$$\left( \frac{Z_t - Z}{Z} \right) = \hat{z}_t \dots\dots\dots (A.15.9)$$

$$\hat{z}_t \cong \hat{z}_t + \frac{1}{2} \hat{z}_t^2 \dots\dots\dots (A.15.10)$$

Where,  $\hat{z}_t$  represents log-deviation of the variable  $Z_t$  from its steady state  $Z$ .

Now consider the utility function of the household:

$$U_t = U(C_t, N_t)$$

The quadratic approximation of  $U_t$  can be written as:

$$(U_t - U) \cong U_c C \left( \frac{C_t - C}{C} \right) + U_N N \left( \frac{N_t - N}{N} \right) + \frac{1}{2} U_{cc} C^2 \left( \frac{C_t - C}{C} \right)^2 + \frac{1}{2} U_{NN} N^2 \left( \frac{N_t - N}{N} \right)^2$$

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<sup>54</sup> Note that all the steady state values of the variables are written without time subscript, as  $Z_t = Z$

Using (A.15.9),

$$\begin{aligned} \Rightarrow (U_t - U) &= U_c C \hat{c}_t + U_N N \hat{n}_t + \frac{1}{2} U_{cc} C^2 \hat{c}_t^2 + \frac{1}{2} U_{NN} N^2 \hat{n}_t^2 \\ \Rightarrow (U_t - U) &\cong U_c C \left[ \hat{c}_t - \frac{1}{2} \left\{ - \left( \frac{U_{cc}}{U_c} \right) C \right\} \hat{c}_t^2 \right] + U_N N \left[ \hat{n}_t + \frac{1}{2} \left\{ \left( \frac{U_{NN}}{U_N} \right) N \right\} \hat{n}_t^2 \right] \end{aligned}$$

Using (A.15.10),

$$\begin{aligned} \Rightarrow (U_t - U) &= U_c C \left[ \hat{c}_t + \frac{1}{2} \hat{c}_t^2 - \frac{1}{2} \left\{ - \left( \frac{U_{cc}}{U_c} \right) C \right\} \hat{c}_t^2 \right] + U_N N \left[ \hat{n}_t + \frac{1}{2} \hat{n}_t^2 + \right. \\ &\left. \frac{1}{2} \left\{ \left( \frac{U_{NN}}{U_N} \right) N \right\} \hat{n}_t^2 \right] \end{aligned} \tag{A.15.11}$$

Note that, coefficient of relative risk ( $\sigma$ ) aversion and elasticity of labour supply ( $\varphi$ ) are defined as follows:

$$\left\{ - \left( \frac{U_{cc}}{U_c} \right) C \right\} \equiv \sigma$$

$$\left\{ \left( \frac{U_{NN}}{U_N} \right) N \right\} \equiv \varphi$$

Using the above definitions in (A.15.11), we obtain:

$$\Rightarrow (U_t - U) = U_c C \left[ \hat{c}_t + \left( \frac{1-\sigma}{2} \right) \hat{c}_t^2 \right] + U_N N \left[ \hat{n}_t + \left( \frac{1+\varphi}{2} \right) \hat{n}_t^2 \right]$$

Inserting the market clearing condition in the above expression:  $\hat{c}_t = \hat{y}_t$

$$\Rightarrow (U_t - U) = U_c C \left[ \hat{y}_t + \left( \frac{1-\sigma}{2} \right) \hat{y}_t^2 \right] + U_N N \left[ \hat{n}_t + \left( \frac{1+\varphi}{2} \right) \hat{n}_t^2 \right] \tag{A.15.12}$$

Now, inverting (A.15.6) for  $N_t(i)$  and inserting it into the labour aggregator, we get:

$$N_t = \left( \frac{Y_t}{A_t} \right)^{\left( \frac{1}{1-\alpha} \right)} \int_0^1 \left\{ \frac{P_t(i)}{P_t} \right\}^{-\left( \frac{\varepsilon}{1-\alpha} \right)} di$$

Taking the lo-deviation from the steady state, the above expression yields:

$$\hat{n}_t = \left(\frac{1}{1-\alpha}\right) (\hat{y}_t - \hat{a}_t) + d_t$$

Where,

$$d_t = (1 - \alpha) \ln \int_0^1 \left\{ \frac{P_t(i)}{P_t} \right\}^{-\left(\frac{\varepsilon}{1-\alpha}\right)} di$$

*Lemma 1:* In the neighbourhood of symmetric steady state, and up to a second order approximation,  $d_t$  is proportional to the cross-sectional variance of relative prices,

$$\text{i.e. } d_t \cong \frac{\varepsilon}{2\Theta} \text{var}_i\{p_t(i)\}; \text{ where, } \Theta = \left(\frac{1-\alpha}{1-\alpha+\varepsilon}\right)$$

For proof of *Lemma 1*, see Galí (2008), Chapter 4 Appendix pp 87

Using *Lemma 1*, the expression of (A.15.12) can be written as:

$$(U_t - U) \cong U_c C \left[ \hat{y}_t + \left(\frac{1-\sigma}{2}\right) \hat{y}_t^2 \right] + \left(\frac{U_N N}{1-\alpha}\right) \left[ \hat{y}_t + \frac{\varepsilon}{2\Theta} \text{var}_i\{p_t(i)\} + \frac{1+\varphi}{2(1-\alpha)} (\hat{y}_t - \hat{a}_t)^2 \right] + \text{t.i.p}$$

Where, ‘t.i.p’ denotes those terms, which are independent of central bank’s policy action.

$$\Rightarrow \left(\frac{U_t - U}{U_c C}\right) = \left[ \hat{y}_t + \left(\frac{1-\sigma}{2}\right) \hat{y}_t^2 \right] + \left\{ \frac{1}{1-\alpha} \left(\frac{N}{C}\right) \left(\frac{U_N}{U_c}\right) \right\} \left[ \hat{y}_t + \frac{\varepsilon}{2\Theta} \text{var}_i\{p_t(i)\} + \right.$$

$$\left. \frac{1+\varphi}{2(1-\alpha)} (\hat{y}_t - \hat{a}_t)^2 \right] + \text{t.i.p}$$

$$\Rightarrow \left(\frac{U_t - U}{U_c C}\right) = -\frac{1}{2} \left[ \frac{\varepsilon}{\Theta} \text{var}_i\{p_t(i)\} - (1 - \sigma) \hat{y}_t^2 + \frac{1+\varphi}{1-\alpha} (\hat{y}_t - \hat{a}_t)^2 \right] + \text{t.i.p}$$

$$\Rightarrow \left(\frac{U_t - U}{U_c C}\right) = -\frac{1}{2} \left[ \frac{\varepsilon}{\Theta} \text{var}_i\{p_t(i)\} + \left(\sigma + \frac{\varphi+\alpha}{1-\alpha}\right) \hat{y}_t^2 - 2 \left(\frac{1+\varphi}{1-\alpha}\right) \hat{y}_t \hat{a}_t \right] + \text{t.i.p}$$

..... (A.15.13)

Now, consider the definition of output gap ( $\tilde{y}_t$ ) as:

$$\hat{y}_t - \hat{y}_t^n = \tilde{y}_t$$

Where, the log-deviation of the natural output from its steady state ( $\hat{y}_t^n$ ) is proportional to the log-deviation of the exogenous technology shock ( $\hat{a}_t$ ) from its steady state.

$$\hat{y}_t^n = \left[ \frac{1+\varphi}{\sigma(1-\alpha)+\alpha+\varphi} \right] \hat{a}_t \dots\dots\dots (A.15.14)$$

Using (A.15.14) in (A.15.13), we get:

$$\begin{aligned} \Rightarrow \left( \frac{U_t - U}{U_c C} \right) &= -\frac{1}{2} \left[ \frac{\varepsilon}{\theta} \text{var}_i \{ p_t(i) \} + \left( \sigma + \frac{\varphi+\alpha}{1-\alpha} \right) (\hat{y}_t^2 - 2\hat{y}_t \hat{y}_t^n) \right] + \text{t.i.p} \\ \Rightarrow \left( \frac{U_t - U}{U_c C} \right) &= -\frac{1}{2} \left[ \frac{\varepsilon}{\theta} \text{var}_i \{ p_t(i) \} + \left( \sigma + \frac{\varphi+\alpha}{1-\alpha} \right) \tilde{y}_t^2 \right] + \text{t.i.p} \dots\dots\dots (A.15.15) \end{aligned}$$

The consumer's aggregate welfare loss is defined as:

$$\mathbb{W} = E_0 \sum_{t=0}^{\infty} \beta^t \left( \frac{U_t - U}{U_c C} \right)$$

Using (A.15.15) in the above expression:

$$\mathbb{W} = -\frac{1}{2} E_0 \sum_{t=0}^{\infty} \beta^t \left[ \frac{\varepsilon}{\theta} \text{var}_i \{ p_t(i) \} + \left( \sigma + \frac{\varphi+\alpha}{1-\alpha} \right) \tilde{y}_t^2 \right]$$

*Lemma 2:* Discounted sum of relative price variance is proportional to the discounted sum of inflation variance, i.e.

$$\sum_{t=0}^{\infty} \beta^t \text{var}_i \{ p_t(i) \} = \left[ \frac{\theta}{(1-\theta)(1-\beta\theta)} \right] \sum_{t=0}^{\infty} \beta^t \pi_t^2$$

For proof, see Woodford (2003), Chapter 6, pp 400.

Using *Lemma 2*, consumer's aggregate welfare loss can be expressed as:

$$\Rightarrow \mathbb{W} = -\frac{1}{2} E_0 \sum_{t=0}^{\infty} \beta^t \left[ \left( \frac{\varepsilon}{\lambda} \right) \pi_t^2 + \left( \sigma + \frac{\varphi+\alpha}{1-\alpha} \right) \tilde{y}_t^2 \right]$$

$$\Rightarrow \mathbb{W} = -\frac{1}{2} E_0 \sum_{t=0}^{\infty} \beta^t \left[ \left( \frac{\varepsilon}{\lambda} \right) \text{var}(\pi_t) + \left( \sigma + \frac{\varphi+\alpha}{1-\alpha} \right) \text{var}(\tilde{y}_t) \right]$$

Therefore,  $t^{\text{th}}$  period welfare loss can be written as:

$$\Rightarrow \mathbb{L} = \left( \frac{\varepsilon}{\lambda} \right) \text{var}(\pi_t) + \left( \sigma + \frac{\varphi+\alpha}{1-\alpha} \right) \text{var}(\tilde{y}_t)$$

$$\Rightarrow \mathbb{L} = \omega_{\pi} \text{var}(\pi_t) + \omega_y \text{var}(\tilde{y}_t) \dots\dots\dots (\text{A.15.16})$$

Where,  $\omega_{\pi} = \left( \frac{\varepsilon}{\lambda} \right)$ ;  $\omega_y = \left( \sigma + \frac{\varphi+\alpha}{1-\alpha} \right)$

The loss function, presented by the Equation (A.15.16) is used to evaluate the welfare loss from inflation volatility in Chapter 2, Section 5.

**Output Equivalent Welfare Loss from Inflation Volatility:**

Output Equivalent Welfare Loss can be computed from the welfare loss function with normalized relative weights, as given by Equation (6.4) in Chapter 2, Section 5:

$$\mathbb{L} = \varpi_y^j \text{var}(\tilde{y}_t) + \varpi_{\pi}^j \text{var}(\pi_t) \dots\dots\dots (6.4); j = \textit{Advanced, Developing}$$

Where,  $\varpi_y^j = \left( \frac{\omega_y}{\omega_y + \omega_{\pi}} \right)$  and  $\varpi_{\pi}^j = \left( \frac{\omega_{\pi}}{\omega_y + \omega_{\pi}} \right)$

In principle, this welfare loss (6.4) is due to price dispersion which can be traced back to inflation volatility by  $\text{var}(\pi_t)$ .

Let us start from a steady state output  $Y_0$ . The corresponding steady state utility can be derived using the power utility specification of representative household, given by (A.15.3). Suppose, the initial steady state utility is  $U(Y_0)$ .

Due to inflation volatility there is a welfare loss, which means that the economy will arrive at a new steady state, say  $Y_1$ . So the corresponding utility of the household will be  $U(Y_1)$ .

Therefore, the loss of welfare for the  $j^{\text{th}}$  country is equal to:

$$U(Y_0) - U(Y_1) = \varpi_y^j \text{var}(\tilde{y}_t) + \varpi_\pi^j \text{var}(\pi_t) \dots\dots\dots (\text{A.15.17})$$

Using mean value theorem:

$$U(Y_0) - U(Y_1) \cong (Y_0 - Y_1)U'(Y_0) \dots\dots\dots (\text{A.15.18})$$

Dividing both sides by  $Y_0$  and obtain:

$$\left(\frac{Y_0 - Y_1}{Y_0}\right) \cong \frac{U(Y_0) - U(Y_1)}{Y_0 U'(Y_0)}$$

Using (A.15.17) in the above expression, we get:

$$\left(\frac{Y_0 - Y_1}{Y_0}\right) \cong \frac{\varpi_y^j \text{var}(\tilde{y}_t) + \varpi_\pi^j \text{var}(\pi_t)}{Y_0 U'(Y_0)} \dots\dots\dots (\text{A.15.19})$$

Now consider the power utility function of household:

$$U(C_t, N_t) = \left(\frac{C_t^{1-\sigma}}{1-\sigma}\right) - \left(\frac{N_t^{1+\varphi}}{1+\varphi}\right)$$

Using the market clearing condition of  $C_t = Y_t$  and inverting the production function with  $A_t = 1$  at steady state (along with the fact that identical technology for each firm), we get:

$$\Rightarrow U(C_t, N_t) = U(Y_t) = \frac{Y_t^{1-\sigma}}{1-\sigma} - \frac{Y_t^{\left(\frac{1+\varphi}{1-\alpha}\right)}}{1+\varphi}$$

$$\Rightarrow U'(Y_t) = Y_t^{-\sigma} - \frac{1}{1-\alpha} Y_t^{\left(\frac{1+\varphi}{1-\alpha}\right)-1}$$

$$\Rightarrow U'(Y_0) = Y_0^{-\sigma} - \frac{1}{1-\alpha} Y_0^{\left(\frac{\alpha+\varphi}{1-\alpha}\right)}$$

Suppose, at the steady state level,  $Y_0 = 1$ . Then,

$$\Rightarrow U'(1) = 1 - \frac{1}{1-\alpha} = -\left(\frac{\alpha}{1-\alpha}\right)$$

Therefore, we get:

$$\left(\frac{Y_0 - Y_1}{Y_0}\right) \cong -\left(\frac{1-\alpha}{\alpha}\right) \bar{\omega}_y^j \text{var}(\tilde{y}_t) + \bar{\omega}_\pi^j \text{var}(\pi_t)$$

$$\mathbb{L}_y \cong -\left(\frac{1-\alpha}{\alpha}\right) \bar{\omega}_y^j \text{var}(\tilde{y}_t) + \bar{\omega}_\pi^j \text{var}(\pi_t) \dots\dots\dots (\text{A.15.20}), \text{ where, } \mathbb{L}_y = \left(\frac{Y_0 - Y_1}{Y_0}\right)$$

The equation given by (A.15.20) shows the output loss equivalent to the welfare loss incurred due to inflation volatility. Using this formulation, output equivalent welfare loss due to inflation volatility is calculated for the advanced and developing economies and presented in Table 2.8C.