Effects of Oil Price on Monetary Policy in Major Oil-Exporting Countries

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By

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To my wife, Somayeh

and my parents, Hossein and Maryam

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ABSTRACT

This thesis investigates impacts of oil price on monetary policy in oil-exporting countries. The second chapter reviews the forward-looking new Keynesian model, to show the need for credibility and conservativeness in order to have less inflation, which are the theoretical foundations of central bank independence (CBI). Then by defining CBI in detail and reviewing indices for CBI, the thesis looks at the empirical works undertaken in countries to see whether or not theory is supported in the real world.

In the third chapter, the thesis applies central bank independence index to assess empirically the impact of an oil price shock on monetary policy in oil-exporting countries. Two legal central bank independence indices are chosen and calculated for the top nine oil-exporting countries. Using a panel data set and a fixed effects model, it is shown that a monetary authority with higher central bank independence implements a more contractionary (or less expansionary) monetary policy after an increase in oil price compared to another central bank which is more dependent.

Chapter four considers linearity and specification tests along with estimating in vector smooth transition regression (VSTR) models and tries to improve them. In the empirical section, a VAR model with time varying coefficients are proposed to analyse the relationship between inflation and monetary policy in Iran as an oil-based economy. The form of coefficients is a logistic smooth transition function and oil price is used as the transition variable. This VSTR model has two different regimes based on high and low oil price and they have different dynamic properties. The model supports the asymmetric effects of real money and oil price on inflation and shows that the central bank cares more about inflation in the regime with high levels of oil price. This chapter also shows that forecasting of inflation with the VSTR is superior to forecasting using the linear VAR.

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Declaration

Chapter 2 entitled "Central Bank Independence and Effects of Oil Price on Monetary Policy" has been accepted for presentation at the 2nd International Doctoral Meeting of Montpellier, University of Montpellier, France, May 2009.

Chapter 3 entitled "Central Bank Independence and Effects of Oil Price on Monetary Policy" has been accepted at the 3rd International PhD conference, University of Athens, Greece, May 2010.

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CHAPTER ONE

Introduction

Introduction

Central bank independence (CBI) has emerged as one of the key issues in monetary policy, and during the last two decades, many of the world's central banks have been granted more independence. Central bank independence gives power to the central bank to resist inflationary pressure caused by the government. Therefore, CBI helps to achieving long-run price stability. The next chapter of this thesis reviews the theoretical support for CBI and surveys empirical works regarding the impact of CBI on inflation and real activities of the economy. Whereas some show a negative correlation between CBI and inflation (see for example Alesina, 1988, Grilli et al., 1991, Cukierman, 1992, Cukierman et al., 1992, Gutierrez, 2003, Brumm, 2006, Jacome and Vazquez, 2008 and Carlstrom and Fuerst, 2009), others cannot find a robust correlation (see, for example, Campillo and Miron, 1997, Forder, 1998, Mangano, 1998, Oatley, 1999, Banaian and Luksetich, 2001, Crowe and Meade, 2007 and Down, 2008). Chapter 2, however, concludes that the majority of empirical works suggest that a central bank with more CBI implements more contractionary monetary policy and hence inflation would be less.

As empirical works have not considered the role of CBI in oil-exporting economies, chapter 3 aims to investigate whether this conventional idea about CBI holds in oil-exporting countries or not. In other words, it is expected that a central bank with greater independence tightens its monetary policy more after an oil shock compared to another central bank with less CBI. A panel data model and nine oil-exporting countries are chosen to assess this hypothesis. Although it is not a remedy for omitted-variable bias, the fixed effects method is exploited because it provides more relevant conditional correlations. The Hausman test also recommends using this method against the random effects one.

Chapter 4, however, considers monetary policy in an oil-based economy from another aspect. The question which is posed in this chapter, and to which answers are sought, is whether oil price and monetary policy have asymmetric effects on the economy or not. Although some papers (e.g. Thoma, 1994, Weise, 1999, Garcia, 2002, Chien and Piger, 2005 and Christopoulos and León-Ledesma, 2008) show that monetary policy has asymmetric effects in developed economies, to the best of my knowledge, no one has considered asymmetric effects for a developing and oil-based economy. Moreover, asymmetries of oil price have also not been studied to date.

To this end, a time varying vector autoregression (VAR) model is used because the linear model cannot investigate asymmetries. The asymmetric effects examined are based on the state of the economy. In other words, coefficients in the model depend on whether the economy is in expansion or recession. Hence, the model can assess whether variables have different impacts during times of recession and expansion.

The functional form of parameters is based on the smooth transition (STR) function. The STR model was originally developed by Teräsvirta and Anderson (1992), Granger and Teräsvirta (1993) and Teräsvirta (1994), but Camacho (2004) and Christopoulos and León-Ledesma (2008) have exploited it for the VAR; they call it the vector smooth transition regression (VSTR). The thesis applies the VSTR model to show asymmetries because this model is more comprehensive than other regime switching models, and the most important point is that the speed of adjustment between two regimes can be estimated, therefore the transition can also be smooth. It is clear that if there is no asymmetric effect the VSTR becomes a linear VAR. In other words, the null hypothesis of the model is a simple VAR.

Since policy makers, in an oil-based economy, usually want to know the effects of macroeconomic variables on the economy when oil price is high and when it is low, oil price is chosen as the transition variable. By doing so, the effect of each variable in the right-hand side of the model is dependent on oil price. Furthermore, choosing oil price as the transition variable has another advantage which is showing recessions and expansions. The logic behind this choice is that a high level of oil price means a high level of income for an oil-based country and it presages a boom, however, a low level of oil price indicates a recession. The model can estimate a threshold and the level of oil price compared to the level of threshold determines the position of the economy in the business cycle.

Many works have compared the forecasting power of STR models with linear ones, such as Granger et al. (1993), Filardo (1994), Hamilton and Perez-Quiros (1996), Krolzig (1997, 2000), Estrella and Mishkin (1998), Blix (1999), Warne (2000), Beine et al. (2002), Camacho and Perez-Quiros (2002), van Dijk et al. (2002), Camacho (2004), Christopoulos and León-Ledesma (2008) and Kavkler et al. (2008), and most of them have shown that the STR model is superior. The thesis also undertakes this comparison for predicting inflation.

Using a VSTR model with the quarterly data over 1970-2008 for Iran, the fourth chapter examines the effectiveness of monetary policy in an oil-based economy on inflation in the business cycle. The chapter also tests the asymmetric effects of oil price on inflation. These two issues will have considerable policy implications. Moreover, the model answers the question of whether the central bank cares more about inflation in a recession or an expansion.

Chapter 4 also makes a few contributions to the VSTR models by adding one extra linearity test for modelling the VSTR and proving the LM statistic suggested by Camacho (2004) for testing the error autocorrelation with a simpler method.

The rest of the thesis is organised as follows. Chapter 2, titled 'Central Bank Independence: A Review', surveys theoretical and empirical works of CBI. 'Central bank independence and effects of oil price on monetary policy' is the topic of the third chapter which examines the role of CBI in oil-exporting countries. The fourth chapter, titled 'Impact of oil price in a time varying VAR model for monetary policy' investigates asymmetries of monetary policy and oil price on inflation. Chapter 5 draws conclusions and gives some points for future research.

CHAPTER TWO

Central Bank Independence: A Review

2.1. Introduction

Before the 1990s, most central banks were under government control. Monetary authorities did not have enough power to pursue their economic objectives and they were also unable to apply their policy instruments. In other words, they were not free to set their policies and governments interfered by imposing certain interest rates, forcing central banks to lend money to state organisations, persuading monetary authorities to buy and sell government securities in the primary market, etc.

Although controlling inflation was one of important aims for governments and they wanted central banks to care about it, the inflation target was set alongside other aims and it was not considered a specific responsibility of central banks. Furthermore, governments followed this lesson that a rise in inflation leads to less unemployment, so monetary expansion to reduce the unemployment rate resulted in governments being unable to reach low inflation. Therefore central bank independence (CBI) has been suggested as a way to restrict monetary expansion and finally decrease inflation.

I start by reviewing the forward-looking new Keynesian model, to show the need for credibility and conservativeness in order to have less inflation, which are the theoretical foundations of central bank independence. Then by defining CBI in detail and reviewing indices for CBI, I look at the empirical works undertaken in developing and developed countries to see whether or not theory is supported in the real world. Then, the chapter considers the oil shocks in the 1970s and analyses the reactions of central banks in five countries and gives policy implications regarding conservativeness.

In the next step, I survey the relationship between CBI and the fixed exchange rate regime. I construct an index for the fixed exchange rate regime using the *de facto* classification of exchange rate regimes published by the International Monetary Fund. This index rises when the power of domestic monetary policy becomes weak. Then I calculate the correlation between this index and CBI in 70 countries.

The rest of this chapter is organised as follows. In the next section, I outline the theoretical foundations of CBI and review briefly the fiscal theory of price level which considers CBI as an irrelevant issue. The empirical papers are reviewed in section 3. The reactions of five industrial countries to the oil shocks in the 1970s are explained in section 4. Section 5 surveys the relation between CBI and the fixed exchange rate regime. Section 6 concludes.

2.2. The Theoretical Background

To see how the literature has extended the monetary policy design and find out the theoretical support for CBI, this section uses a standard forward-looking New Keynesian model and explains the policies under discretion and commitment. This model has been widely applied in the literature to analyse monetary policy theoretically, such as Bernanke and Woodford (1997), Clarida et al. (1999), Woodford (2003), Svensson and Woodford (2005).

The model has an IS curve (Equation 2.1) which is produced from an Euler equation for the optimal timing purchases and a Phillips curve (Equation 2.2) which is obtained from optimal price setting by the representative firm:[1]

$$y_t = -\tau[i_t - E_t\pi_{t+1}] + E_t y_{t+1} + \varepsilon_t \tag{2.1}$$

$$\pi_t = \theta y_t + \beta E_t \pi_{t+1} + u_t \tag{2.2}$$

where y_t is the output gap between the current output and the natural level of output, π_t is inflation at period t, i_t is the nominal interest rate which is the monetary instrument, E_t denotes subjective expectations conditioned on time t information, $\tau > 0$ is the intertemporal elasticity of substitution,$0 < \beta < 1$ is a discount factor, θ is a positive coefficient and ε_t and u_t are demand and cost push shocks, respectively. Unlike the classic IS, (2.1) illustrates that there is a positive relation between output and expected future output. Since more expected output leads to more expected future consumption, individuals are going to smooth consumption and consume more in the current period, which increases current output.

To obtain (2.2), one should apply staggered nominal price setting pioneered by Fischer (1977) and Taylor (1980) who introduce their idea in the non-microfounded context. A microfounded version can be seen in Chari et al. (2000) in which monopolistically competitive firms maximise their profits by setting nominal price subject to frequency of price adjustments. Since aggregating the decisions of firms under staggered price setting is hard, Calvo (1983) suggests a more simplified way to derive the

[1] To know derivations in detail, see, for example, Yun (1996), Woodford (2003) and Gali (2008).

Phillips curve.[2] The Calvo pricing model, by making price adjustment independent of past, assumes that for each period a firm keeps its price for a probability φ and therefore it will modify it by a probability $1-\varphi$. Hence, the Calvo model has implications of staggered price setting but simplifies the aggregation. Moreover, instead of expected current inflation $E_{t-1}\pi_t$, in a traditional augmented Phillips curve, (2.2) has expected future inflation. This allows that inflation totally depends on current and expected future outputs. This fact is illustrated by iterating (2.2):

$$\pi_t = E_t \sum_{d=0}^{\infty} \beta^d [\theta y_{t+d} + u_{t+d}] \tag{2.3}$$

Since y_{t+d} moves according to marginal costs, this equation shows that suppliers set price based on the expectations of future marginal costs.

Following the literature, I assume an AR(1) process for disturbances in (2.1) and (2.2):

$$\varepsilon_t = \vartheta \varepsilon_{t-1} + \hat{\varepsilon}_t \tag{2.4}$$

$$u_t = \rho u_{t-1} + \hat{u}_t \tag{2.5}$$

where $0 \leq \vartheta, \rho < 1$ and $\hat{\varepsilon}_t$ and $\hat{u}_t$ are iid shocks. As a result, (2.3) represents that inflation depends on current and expected future path of cost push shock. Furthermore, it is very easy to show that output gap also depends on current and expected future of demand shocks, as iterating (2.1) generates:

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[2] Another alternative to these frameworks for price setting is the state dependent model which shows that the timing of price adjustments depends on the state of the economy (e.g. Dotsey et al., 1999, Gertler and Leathy, 2006, Golosov and Lucas, 2007).

$$y_t = E_t \sum_{d=0}^{\infty} [-\tau(i_{t+d} - \pi_{t+1+d}) + \varepsilon_{t+d}]. \tag{2.6}$$

Based on these equations, I am going to characterise monetary policy and explain the necessity of CBI to run an optimal policy.

2.2.1. Discretionary Policy and Commitment

The monetary authority wants to determine interest rate in order to maximise the objective function subject to (2.1) and (2.2). Following the literature, the objective function can be written as:

$$-\frac{1}{2} E_t \sum_{d=0}^{\infty} \beta^d [\gamma y_{t+d}^2 + \pi_{t+d}^2] \tag{2.7}$$

where γ is the relative weight on the output gap. It is worth noting that as a purely forward-looking model, any set of equilibrium for inflation, output gap and interest rate for each period is independent of what these variables were prior to the current period and this set does not influence the equilibrium paths for the variables in the future. Thus, the central bank can assume that the policy chosen in the current period has no effect in the ensuing periods.

Under discretion, any promise in the past does not constrain the monetary authority to choosing the current interest rate, but under commitment, the central bank makes a rule for interest rate and commits to following it. Kydland and Prescott (1977) first explained that this commitment can decrease current inflation with less cost in terms of output because the output gap depends on expected future values of interest rate, so sending a credible signal to the private sector about future policy can enhance the monetary authority to fight more easily with inflation.

The difference between the two methods is related to how each affects private sector beliefs. Without any rules, individuals construct their expectations, given that the central bank freely maximises its objective function every period and its action is not apparent to the public. As a rule, however, the central bank follows a systematic process; individuals know this, and the rule can thus shape private sector expectations.

It should be mentioned that the literature is not trying to offer a tightly specified rule; rather it sets out some guidelines to improve monetary policy performance. In other words, comparing monetary policy under discretion and commitment leads to some lessons for the structure of the monetary authority. This issue will be explained further after discussing the implications of discretion and commitment.

There is a large body of literature on the credibility of monetary policy, a discussion which was originally raised by Kydland and Prescott (1977), Barro and Gordon (1983) and Rogoff (1985) and more recently by writers such as Woodford (2003) and Galí (2008). In order to understand the necessity of credibility, we have to obtain the equilibrium without a rule. In each period, the central bank chooses inflation and the output gap to maximise (2.7) subject to the Phillips curve; hence it maximises:

$$\mathcal{L}_t = -\frac{1}{2} E_t \sum_{d=0}^{\infty} \beta^d [\gamma y_{t+d}^2 + \pi_{t+d}^2] + c_t [\pi_t - \theta y_t - \beta E_t \pi_{t+1} - u_t] \qquad (2.8)$$

First order conditions are:

$$\frac{\partial \mathcal{L}_t}{\partial \pi_t} = -\pi_t + c_t = 0 \qquad (2.9)$$

$$\frac{\partial \mathcal{L}_t}{\partial y_t} = -\gamma y_t + c_t \theta = 0 \qquad (2.10)$$

$$\frac{\partial \mathcal{L}_t}{\partial c_t} = \pi_t - \theta y_t - \beta E_t \pi_{t+1} - u_t = 0 \qquad (2.11)$$

Equations (2.9) and (2.10) yield:

$$y_t = -\frac{\theta}{\gamma}\pi_t \qquad (2.12)$$

Substituting (2.12) in (2.11) and assuming rational expectations give the equilibrium under discretion:

$$y_t^d = -\frac{\theta u_t}{\theta^2 + \gamma(1-\beta\rho)} \qquad (2.13)$$

$$\pi_t^d = \frac{\gamma u_t}{\theta^2 + \gamma(1-\beta\rho)}\,. \qquad (2.14)$$

Inserting y_t^d into (2.1) gives the value of the nominal interest rate:

$$i_t = \psi E_t \pi_{t+1} + \frac{1}{\tau}\varepsilon_t, \qquad \psi \equiv 1 + \frac{(1-\rho)\theta}{\rho\tau\gamma}\,. \qquad (2.15)$$

However, it is very simple to show that when the target for the output gap is greater than zero, inflation is persistently higher than (2.14). This is the issue called the inflationary bias problem in the literature. Strikingly, the output gap does not change. To show it, suppose that the objective function is:

$$-\frac{1}{2}E_t\sum_{d=0}^{\infty}\beta^d\left[\gamma(y_{t+d}-k)^2+\pi_{t+d}^2\right] \quad (2.16)$$

where $k > 0$ denotes that the target for output gap is higher than zero. Like the previous case, maximising (2.16) subject to (2.2) yields:

$$y_t^k = -\frac{\theta}{\gamma}\pi_t^k + k. \quad (2.17)$$

Substituting (2.17) in (2.2) gives:

$$y_t^k = y_t^d \quad (2.18)$$

$$\pi_t^k = \pi_t^d + \frac{\gamma}{\theta}k \quad (2.19)$$

This means that without a credible rule, if the monetary authority wants to push output above the natural rate (since $k > 0$), inflation will be higher than the target (as much as $\frac{\gamma}{\theta}k$) without any advantage in output.

Clarida et al. (1999) believe that this analysis can explain hyper inflation during the 1970s through the early 1980s when the economies tried to recover from recession. However, the important policy implication is that commitment has gains for the economy. In this case, for example, if the central bank imposed itself $k = 0$, welfare would increase. It should be noticed that emphasis on rules does not mean that the central bankers do not care about the public interest; rather it implies that monetary goals can be efficiently attained not only when the central bank plays appropriately but also when the individuals expect a certain action from the monetary authority.

Another result from the analysis is that the smaller γ, the smaller the inflationary bias. In other words, even when $k > 0$, the central bank can reduce the inflationary bias by putting more weight on inflation in the loss function.

2.2.1.1. More Gains from Commitment

It can be shown that even with $k = 0$, there are gains from commitment. As illustrated, under equilibrium without a rule, it is optimal for the monetary authority to only modify y_t in response to cost push shock u_t; hence in order to have a general rule under commitment, one can consider the following rule:

$$y_t^c = -\omega u_t \tag{2.20}$$

where y_t^c shows the output gap under commitment and $\omega > 0$ is the coefficient of the feedback rule. Hence, the rule has the equilibrium under discretion as a specific issue (when $\omega = \frac{\theta}{\theta^2+\gamma(1-\beta\rho)}$).

Substituting (2.20) into (2.3) which was derived from the Phillips curve shows that inflation under commitment also depends on cost push shock:

$$\pi_t^c = E_t \sum_{d=0}^{\infty} \beta^d [\theta y_{t+d}^c + u_{t+d}] = E_t \sum_{d=0}^{\infty} \beta^d [-\theta\omega u_{t+d} + u_{t+d}] = \frac{1-\theta\omega}{1-\beta\rho} u_t. \tag{2.21}$$

Note that (2.21) can be written as:

$$\pi_t^c = \frac{\theta}{1-\beta\rho} y_t^c + \frac{1}{1-\beta\rho} u_t. \tag{2.22}$$

Thus, one unit contraction in y_t^c can reduce inflation under commitment for $\frac{\theta}{1-\beta\rho}$. This reduction is more than the fall of inflation under discretion ($\theta < \frac{\theta}{1-\beta\rho}$). In other words, as Clarida et al. (1999) state, when the central bank commits to a rule, it can get a gain from an improved trade-off between inflation and output. This gain would occur even if the monetary authority did not prefer output above the natural level, it means that $k = 0$.

To obtain the equilibrium for y_t^c and π_t^c, one has to maximise the following objective function subject to (2.22):

$$-\frac{1}{2}E_t\sum_{d=0}^{\infty}\beta^d[\gamma(y_{t+d}^c)^2 + (\pi_{t+d}^c)^2]. \qquad (2.23)$$

As under discretion, the following outcomes are obtained under commitment by maximising (2.23) subject to (2.22):

$$y_t^c = -\frac{\theta}{\gamma^c}\pi_t^c, \qquad \gamma^c \equiv \gamma(1-\beta\rho) \qquad (2.24)$$

$$y_t^c = -\frac{\theta u_t}{\theta^2 + \gamma^c(1-\beta\rho)} \qquad (2.25)$$

$$\pi_t^c = \frac{\gamma^c u_t}{\theta^2 + \gamma^c(1-\beta\rho)}. \qquad (2.26)$$

As $\gamma^c < \gamma$, (2.24) and (2.12) illustrate that it is optimal for the monetary authority, under commitment, to be more aggressive in response to inflation compared to discretion. Moreover, comparing (2.25)-(2.26) with (2.13)-(2.14) results in the outcome that, under commitment, inflation is closer and output is further to their targets. The aggressive reaction can be shown in the interest rate rule, which is derived from the IS curve:

$$i_t = \psi^c E_t \pi_{t+1} + \frac{1}{\tau} \varepsilon_t, \qquad \psi^c \equiv 1 + \frac{(1-\rho)\theta}{\rho \tau \gamma^c}. \tag{2.27}$$

As expected, $\psi^c > \psi$ which means that, under commitment, the monetary authority increases the nominal interest rate more in response to an increase in expected inflation.

2.2.1.2. Unconstrained optimal policy under commitment

This sub-section explains the unconstrained solution for the optimal policy commitment. To do this, one should choose a state-contingent sequence for inflation and the output gap in every period to maximise the objective function subject to the fact that the Phillips curve holds for each period. In this case, we do not constrain $\mathrm{y_t}$ to depend on the current shock; instead we let it depend on shocks in every period. To find a general solution, I follow Currie and Levine (1999), Clarida et al. (1999), Woodford (2003) and Galí (2008) and form the Lagrangian to maximise (2.7), subject to (2.2):

$$\mathcal{L} = -\frac{1}{2} E_t \sum_{d=0}^{\infty} \beta^d [\gamma y_{t+d}^2 + \pi_{t+d}^2 + c_{t+d}(\pi_{t+d} - \theta y_{t+d} - \beta \pi_{t+d+1} - u_{t+d})]. \tag{2.28}$$

Note that the law of expectations implies:

$$E_t(c_{t+d} \beta E_t \pi_{t+d+1}) = E_t(E_t c_{t+d} \beta \pi_{t+d+1}) = E_t(c_{t+d} \beta \pi_{t+d+1}).$$

Thus π_{t+d+1} can be substituted for $E_t \pi_{t+d+1}$ in the Phillips curve. First order conditions provide:

$$\frac{\partial \mathcal{L}}{\partial \pi_{t+d}} = \pi_{t+d} + \frac{1}{2} c_{t+i} - \frac{1}{2} c_{t+i-1} = 0 \tag{2.29}$$

$$\frac{\partial \mathcal{L}}{\partial y_{t+d}} = \gamma y_{t+d} - \frac{\theta}{2} c_{t+i} = 0. \quad (2.30)$$

To find optimality conditions, one can add (2.30) and $\frac{\partial \mathcal{L}}{\partial y_{t+d-1}}$ to (2.29) and obtain:

$$y_{t+d} - y_{t+d-1} = \frac{\theta}{\gamma} \pi_{t+d}. \quad (2.31)$$

While optimal discretionary policy requires that output adjusts in response to inflation, see (2.12), the last equation suggests that under commitment, the optimal policy modifies the change in output in response to inflation. In other words, the optimal discretionary reaction to a cost push shock is to decrease the output gap only in that period; however, the optimal response under commitment is to continue to reduce the output gap as long as inflation is higher than the target. In this regard, as inflation depends on future output gaps, a credible commitment to reduce output gaps in future, leads to a greater fall in inflation during the current period compared to discretionary policy.

If under commitment inflation is less, the question now is that how we can do institutional adjustments in order to have a central bank which is able to impose binding commitment or that at least has less γ. Rogoff (1985) suggests appointing a conservative central banker who is concerned more about inflation (less γ). This was the first theoretical step towards central bank independence. Either having a conservativeness characteristic or making a credible commitment can arise whenever central bank independence is met. Hence, it is theoretically expected that the greater central bank independence, the less inflation happens. In the next sections, I will survey the empirical works in the literature to see whether this theoretical implication occurs in the real world.

2.2.2. Criticisms of Forward-Looking Models

As discussed, in forward-looking models, policy emerges from future paths of the target variables and the intuition is that it is not optimal for policy to be related to irrelevant variables; however, if the policymaker wants to find the optimal policy, she needs to know the impact of policy on future paths. She understands this effect whenever she finds what called by Woodford (2000), "laws of motion" of target variables which are backward-looking. In other words, the optimal policy should consider the gains of predicting the policy at previous periods; hence it must be history-dependent.

Ignoring this fact that policy should be history-dependent leads to some problems, one of which is stabilisation bias (for example, see, Jonsson, 1997, Woodford, 1999 and Svensson and Woodford, 2005) which means that the reaction of policy is inefficient to shocks. It occurs because after a positive shock the tradeoffs between inflation and output could be improved whenever the private sector modifies its expectations about future inflation and output regarding this shock. However, this happens when the monetary authority changes its subsequent policy regarding the past shocks, and this is impossible in purely forward-looking approaches because each act at a certain point in time does not depend on the previous state of the economy.

Another problem caused by purely forward-looking models is indeterminacy of the equilibrium. Sargent and Wallace (1975) originally explained a large multiplicity of rational-expectations equilibria for variables, including ones in which the fluctuations in inflation and output are inappropriately large compared to changes in economic "fundamentals".

These shortcomings lead to the addition of the backward-looking component into the new Keynesian Phillips curve. Galí and Gertler (1999) used the Calvo pricing model and introduce a fraction of firms which are backward-looking in their price-setting behaviour which means that they set price regarding a backward-looking rule of thumb. As a result, they suggested a new hybrid Phillips curve like (2.32) instead of (2.2):

$$\pi_t = \theta y_t + \beta E_t \pi_{t+1} + \phi \, \pi_{t-1} + u_t \tag{2.32}$$

where $0 < \phi < 1$ captures the inflation persistence ignored in the purely forward-looking model. There are numerous theoretical and empirical works, such as those of Woodford (2003), Galí et al. (2005) and Nason and Smith (2008) and most of them have shown that the backward-looking component is significant although it is not as important as forward-looking price setting.

The most important thing for this work is that, since the forward-looking component is still in this kind of the new Keynesian Phillips curve, discretionary optimisations lead to the inflationary bias and this again sheds light on the importance of central bank independence. It should be noticed that the inflationary bias would not occur if the model was purely backward-looking.

2.2.3. Fiscal Theory of the Price Level

Proponents of CBI believe that an independent central bank can avoid the political orders of the government and attain price stability through stabilising the supply of money. In other words, they follow the idea of mainstream economics that inflation is a monetary phenomenon. The fiscal theory of price level (FTPL) has challenged this idea and insisted that fiscal dominance causes the central bank to follow the government and CBI is irrelevant in this framework. This sub-section describes the FTPL.

The FTPL believes that the price level is set by government debt rather than money. This means that the FTPL claims that fiscal policy determines the price level and its path regardless of monetary policy. In order to understand its criticism of the traditional analysis about inflation, consider the quantity theory of money:

$$M_t V_t = P_t Y_t, \quad t = 0, 1, 2, \ldots \qquad (2.33)$$

where M_t is nominal money balances at period t , V_t is the velocity of money, P_t is the price level and Y_t is real output. As Sargent and Wallace (1975) point out, the initial price level in (2.33) is indeterminate and different levels of price give different paths for subsequent inflation. Bassetto (2008) explains the simplest case that an interest rate peg sets the level of velocity and money and price do not change real output, so (2.33) determines real money balances ($\frac{M_t}{P_t}$) but cannot pin down the price level.

Woodford (1994), however, sets the price level from another equation which is the present value of fiscal budget constraint:

$$\frac{B_t}{P_t} = D_t + S_t(\pi), \quad t = 0, 1, 2, \ldots \qquad (2.34)$$

where B_t is the nominal value of government debt at period t, D_t denotes the present value of future primary fiscal surpluses and $S_t(\pi)$ is the present value of seignorage which is revenue from money creation and depends on inflation (π), $S'_t(\pi) > 0$. Total government liabilities (H_t) are the sum of money and debt ($H_t = B_t + M_t$), so assuming that initial liabilities are fixed ($\overline{H}$), a unique price level holds (2.34). Hence, the initial price level is pinned down. To see fiscal dominance, (2.34) at $t = 0$ can be written as:

$$\frac{\overline{H}}{P_0} = \frac{M_0}{P_0} + D_0 + S_0(\pi). \tag{2.35}$$

(2.35) illustrates that when the government commits to D_0 then the monetary authority chooses either M_0 or future inflation (π). Therefore, the supply of money is followed by fiscal policy and it is not exogenous. As the price level is still determined by the money supply, Carlstorm and Fuerst (2000) call fiscal dominance the weak-form FTPL; however, in the strong-form FTPL, the price level is only affected by fiscal policy and changes in monetary policy have no impact on it.

The FTPL, however, is not without controversy. I raise two points. First, Buiter (2002) explains that the price level is the inverse of the value of money; however the fiscal theory of the price level considers government debt instead of money and there is no guarantee that the nominal value of debt coincides with the value of money. Second, there are very few empirical works that test the FTPL compared to a wealth of empirical works which could show the strong relation between price trends and money movements.[3,4] Moreover, if fiscal dominance supported by the FTPL holds then the effect of CBI on inflation should be insignificant, however, as the next section illustrates the majority of empirical works support the negative relation between CBI and inflation. In other words, the FTPL is not supported by a large number of empirical works.

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[3] While Fan and Minford (2009) could show that the FTPL holds for the UK in the 1970s, Canzoneri et al. (2001) and Creal and Bihan (2006) reject the FTPL in five industrial countries.

[4] Lucas (1996) has reviewed the empirical studies about the relation between money growth and inflation. For more recent works, see for example, Shelly and Wallace (2005), Milas (2009) and Berger and Österholm (2011).

2.3. Empirical Works of Central Bank Independence

As discussed, Rogoff (1985) found a theoretical solution for the problem of the inflationary bias. He proposed that a conservative central bank has to execute monetary policy; furthermore it was proved that inflation is less under commitment. These findings were a prelude to the establishment of independent central banks. A central bank which cares about inflation more than other aggregate indices, has sufficient power to use its own instrument, and sends credible signal to individuals can implement tighter monetary policy, which results in low inflation.

2.3.1. What exactly does Central Bank Independence mean?

Central bank independence is a complex concept and each definition proposed relates to a different aspect of the concept. Hence, measurements of CBI which will be discussed later also differ from one another. Researchers, however, have tried to categorise the notions of this concept to illustrate a better understanding of CBI.

Grilli et al. (1991) suggest two components of CBI: political independence and economic independence. The former is determined by the government's ability to appoint the central bank governor and members of the board, the term in the board and the price stability as the statutory objective. Economic independence relies on the power of the government to influence the conditions in which the central bank lends money to the government and using the appropriate monetary instruments by the central bank. These instruments are specifically the interest rates and supervision of the banking system.

Debelle and Fischer (1994) define two other components of CBI: goal independence and instrument independence. Goal independence represents the ability of the monetary authority to set its targets, and the central bank is supposed to be more independent when the price stability goal is stated in the central bank's law. On the other hand, instrument independence is the freedom of the monetary authority to select tools to attain its objectives.

Loungani and Sheets (1997) propose a more comprehensive definition and consider three types of CBI: goal independence, economic independence and political independence. In other words, they highlight the price stability objective stated in Grilli et al.'s (1991) methodology.

2.3.2. Central Bank Independence Indices

The CBI indices can be divided in two major groups: legal indices and actual indices. Most measurements of CBI are established based on the central bank law. However, actual indices are proposed for economies in which either the law is not followed properly, or, as Dumiter (2009) mentions, the law is incomplete with grey areas in rights. As law enforcement is worse in developing countries compared to developed ones, actual indices are usually applied for these economies. To show actual independence, two proxies have been introduced. The first one suggested by Cukierman et al. (1992) is turnover of central bank governors and the other is the political vulnerability of the head of the central bank which is applied by Cukierman and Webb (1995). The political vulnerability index is determined by the frequency of events in which the governor is replaced due to a political transition. As can be seen, actual proxies are not comprehensive and focus on one criterion, so legal indices are superior unless there is a substantial deviation between independence introduced by law and *de facto* independence.

Bade and Parkin (1985) constructed the first legal index for CBI. They tried to find out the degree of government interference in finances and policies of the monetary authority. Financial influence is set by the effect of the government on salary for the board of the central bank, on the central bank's budget and the government's ability to determine central bank's profit. The government's ability to choose the members of the board, whether the government is on the board, and whether the central bank is the final policy maker, determine the degree of policy influence. Each category is set between one and four; where four shows the highest degree of independence.

Grilli et al. (1991) suggest 15 criteria based on their definition of political and economic independence. Each criterion is rated zero or one and hence their index lies between zero and 15.

Cukierman et al. (1992) propose an index which is based on 16 characteristics of the central bank's law. These characteristics pertain to procedure for the resolution of conflicts between authorities, the existence of the price stability objective in the central bank's law, limitations on lending to the government, procedure for the appointment of the board, and the allocation of authority over monetary policy. Cukierman et al. (1992) create a weighted index of these 16 criteria whereas Cukierman (1992) presents an unweighted version.

Eijffinger and Schaling (1993) create an index affected by the location of final responsibility for monetary authority, the presence or absence of the government on the board and the government's ability to appoint the members of the board. If the central bank is the final authority according to its law, it attains a double score. There are four criteria and each one is rated zero or one, except the final characteristic which gets zero or two. Thus, this index lies between zero and five; where five illustrates the highest level of CBI.

Although there are some characteristics used for all indices, each index has its own criteria with different weights. As Mango (1998, p. 478) states, however, nobody can criticise the principles applied in each index:

"It is impossible to discuss the appropriateness of the characteristics constituting Individual indices without being exposed to some degree of subjectivity as well: on which objective grounds would a criterion be considered as acceptable for inclusion, and what would objectively justify die exclusion of another? It could always be argued that, intuitively, a few criteria should unquestionably qualify, while some others needn't even be considered; but where should the line be drawn between these two categories? Clearly, these questions cannot be answered satisfactorily: blaming authors for having incorporated one characteristic rather than another is displaying as much subjectivity as (if not more than) they do."

Hence, researchers usually use the indices of Grilli et al. (1991) and Cukierman et al. (1992) because they are more comprehensive and include more characteristics than other indices.

Arnone et al. (2006) show that legal CBI has increased rapidly since 1990 in developed countries and 13 developing economies. This is supported by evidence in Cukierman et al. (2002) for former socialist economies and Jacom and Vazquez (2008) for

10 Latin American countries. Moreover, Cukierman (2008) presents the fact that the level of actual independence experienced an increase worldwide in the 1990s.

Cukierman (2008) addresses two global and regional factors for this trend in CBI. The global factors include an increased tendency towards price stability and good economic performance of low-inflation economies like Germany, where CBI was high, and globalisation, which has weakened controls on capital flows and increased capital markets. Since developing countries needed more international capital, Maxfield (1998) claims that globalisation has had a greater influence on increased CBI in these economies.

Some regional factors mentioned by Cukierman (2008) are: the breakdown of institutions established to safeguard nominal stability, like the European Monetary System, the acceptance of the Maastricht Treaty, and successful stabilisation of inflation in some regions which encourages policymakers to make new institutional arrangements to reduce persistent inflation.

2.3.3. Central Bank Independence and Monetary Policy

It was explained theoretically how monetary policy can be successful in fighting inflation under CBI. When an economy has CBI and the monetary authority does not follow political orders, monetary policy stability which is important for a successful monetary policy is guaranteed over time. To reach price stability, the supply of money should not be under the control of political authorities with short-term objectives. An economy needs credibility to confine the discretionary use of power to publish money by an institutional mechanism, which is provided by central bank independence. This fact is now accepted by the majority of economists, who believe that an independent central bank can keep the value of money stable over time.

Although there are a few works regarding the effect of CBI on monetary policy, such as Siklos and Johnson (1996) and Down (2008), all empirical works showing a negative relationship between CBI and inflation claim implicitly that central bank independence leads to a tighter monetary policy. CBI reinforces credibility, decreases inflationary expectations and, therefore, causes the money supply and inflation to decline. On the other hand, independence allows a central bank to reject requests for monetary funding of budget deficits leading to less supply of money. Moreover, the central bank's inflation target is less than the government's, so it is obvious that monetary policy implemented by an independent central bank is tighter compared to the conditions under which the government can influence monetary instruments.

Furthermore, Down (2008) illustrates, independent central banks choose a tighter policy during periods of disinflations than their politically dependent counterparts; hence, these economies have more aggressive disinflations which may be more costly, and have a higher sacrifice ratio as a result.

2.3.4. Central Bank Independence and Inflation

Early empirical studies found a negative relationship between inflation and central bank independence which is consistent with theory. These studies, such as Grilli et al. (1991), Cukierman (1992), Cukierman et al. (1992) and Alesina and Summers (1993), focus on industrial economies. A recent work using data for 26 industrial economies presents that two-thirds of the decrease in inflation is because of CBI (Carlstrom and

Fuerst, 2009). Since developing countries had not changed the central bank's legislation, research could not find any relation between legal CBI and inflation in the early 1990s; however, Cukierman et al. (1992) illustrate that there is a negative relationship between actual CBI and inflation in developing countries by using the turnover of central bank governors as an actual CBI index.

Further works, like that of Posen (1993), Neumann (1996), Fuhrer (1997), Campillo and Miron (1997) and Berger et al. (2001), raise doubts about this finding. These researchers address the fact that investigations about CBI and inflation depend on which indices are used, which aspect of CBI is measured in an index and how its weight is assigned. They believe that estimation results are also sensitive to the sample of countries.

More recent studies, though, such as de Haan and Kooi (1999), Gutierrez (2003), Arnone et al. (2007) and Jacome and Vazquez (2008), confirm the initial result and report that CBI is negatively significantly correlated with inflation. Temple (1998) mentions that the different results are attributed to a few outliers and the existence of some very high inflation countries in the sample. On the other hand, Brumm (2000) explains that different results emerge because of the failure to adequately take into account the imprecision of CBI indices.

Cukierman et al. (2002) use legal CBI and inflation data for former socialist countries and conclude that the negative relation does not appear during the first stages of liberalisation, but that emerges when privatisation becomes sustained. They argue that it happens because legal changes can be followed by authorities in practice when they understand that liberalisation is very useful and important for the economy, and it needs time.

Therefore, it can be concluded that these investigations show a negative relation between *de jure* CBI and inflation in developed economies. However, this relation, in developing countries, emerges between *de facto* CBI and inflation.

The next question is whether CBI and the variability of inflation are related. Chowdhury (1991) argues that the level and the variability of inflation are positively related, so once CBI reduces inflation, it will also decrease the variability. Some empirical works, such as those of de Haan and Sturm(1992) and Alesina and Summers (1993) could illustrate this relation.

Another issue regarding CBI and inflation is whether causality can result from inflation to CBI or not. Cukierman (2008) posits that causality happens in both ways, and in his work he was able to show that *de facto* CBI, which is the turnover of the governor, and inflation has two-direction causality (Cukierman, 1992).

2.3.5. Central Bank Independence and Real Effects

Although researchers have usually focused on the relation between CBI and inflation, some investigated the real effects of an autonomous central bank. There is a theoretical reason for a positive relation between CBI and the economic growth rate. An increase in CBI leads to less uncertainty about inflation because of the positive relation between the level and variability of inflation and less uncertainty about inflation results in an increase in economic growth (Eijffinger and de Haan, 1996). However, a few empirical works have been able to illustrate this relation. De Long and Summers (1992) show the positive correlation between *de jure* CBI and economic growth for 16 industrial economies but Cukierman et al. (1993) only find a significant correlation between *de facto* CBI and the growth rate.

Other empirical research, like that of Grilli et al. (1991), de Haan and Sturm (1992), Alesina and Summers (1993), Eijffinger and Schaling (1993) and Fratianni and Huang (1994), argue that CBI has no real effects. On the other hand, these papers suggest that CBI is not also correlated with output variability. Considering the influence of CBI on inflation and the fact that it does not harm the real sector of the economy, central bank independence is often described as a 'free lunch'.

2.4. The Oil Shocks and Monetary Policy in Oil-importing Countries during the 1970s

An oil shock is considered a cost push shock for oil-importing economies. Therefore, it simultaneously creates an increase in inflation and a decline in output. Gordon (1984), Rotemberg and Woodford (1984) and Barskey and Kilian (2002) illustrate that the former effect is unambiguous and a large body of literature supports the effect of oil shock on the real activity of the economy. Hamilton (1983, 1996) finds that oil shocks have a significant negative effect on GDP growth in the US. This finding has also been supported in other oil-importing countries, as Burbidge and Harrison (1984) show that oil price shocks and industrial production are negatively correlated in Canada, Germany, Japan, the UK, and the US during the 1970s. Figure 2.1 shows the real GDP growth rates for the period 1970-1985 in Germany, Japan, Switzerland, the UK and the US.[5]

[5] All data have been collected from International Financial Statistics.

However, the negative effects of oil shocks in the 1970s were not similar in economies. Burbidge and Harrison (1984) found that the effect of oil shocks on inflation was relatively small in Germany and Japan as can be seen in figure 2.2 which illustrates the inflation rates.[6] Blanchard and Galí (2007) used a VAR model and demonstrated that not only did oil price have little effect on inflation in these two countries between 1970-1983 but also its impact on Japanese output was small, although oil shocks had strong effects in other oil-importing countries. Markov (1994) analysed the oil shocks in the 1970s and showed that the oil shock between 1973 and 1974 decreased real GDP in Germany, Japan, the UK and the US but the oil shock of 1979-1980 had the impact on real GDP of these countries except Japan. Why are these effects different?

The growth rates of broad money are presented in figure 2.3. To have a general picture, it can be mentioned that countries with tighter monetary policy, like Switzerland and Germany, experienced less output growth after oil shocks. Japan implemented contractionary monetary policy during the first oil shock in the 1970s and reduced money growth sharply from above 20% before the oil shock. As a result, Japanese output growth reduced dramatically from its historical standards. Japan, however, implemented different policy during the second oil shock in the 1970s. It is true that Japan cut money growth in 1980, however, not only this reduction was not as sharp as the first one in 1973, but also Japan increased money growth in 1981. Hence, Japan did not experience any recession after the second oil shock.

[6] Figure 2.2 illustrates that Switzerland has less inflation during oil shocks too but it was not analysed by Burbidge and Harrison (1984).

These findings raised an important question about oil shocks: are the real activity reductions after the oil shock due to the oil shock, per se, or do they occur because of the monetary policy reaction? Bernanke et al. (1997) illustrate that contractionary monetary policy in the US after the oil shock causes between two thirds and three quarters of the decrease in output. Moreover, Lee et al. (2001) find that between 30 and 50 percent of the reduction in Japanese output following the oil shock is due to monetary tightening.

Figure 2.1. Annual real GDP Growth rates (%)

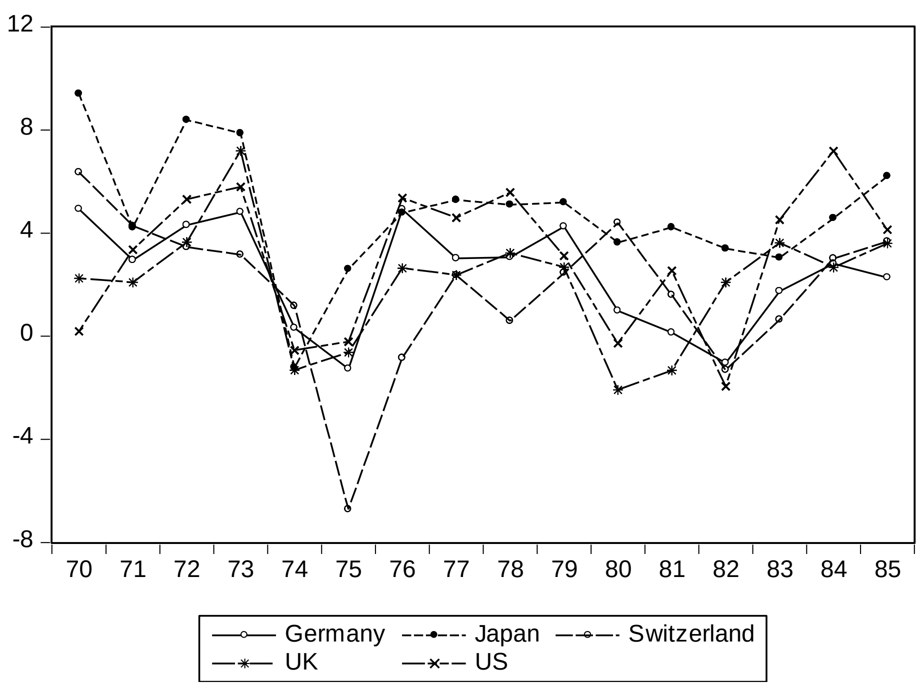


Figure 2.2. Annual CPI Inflation rates (%)

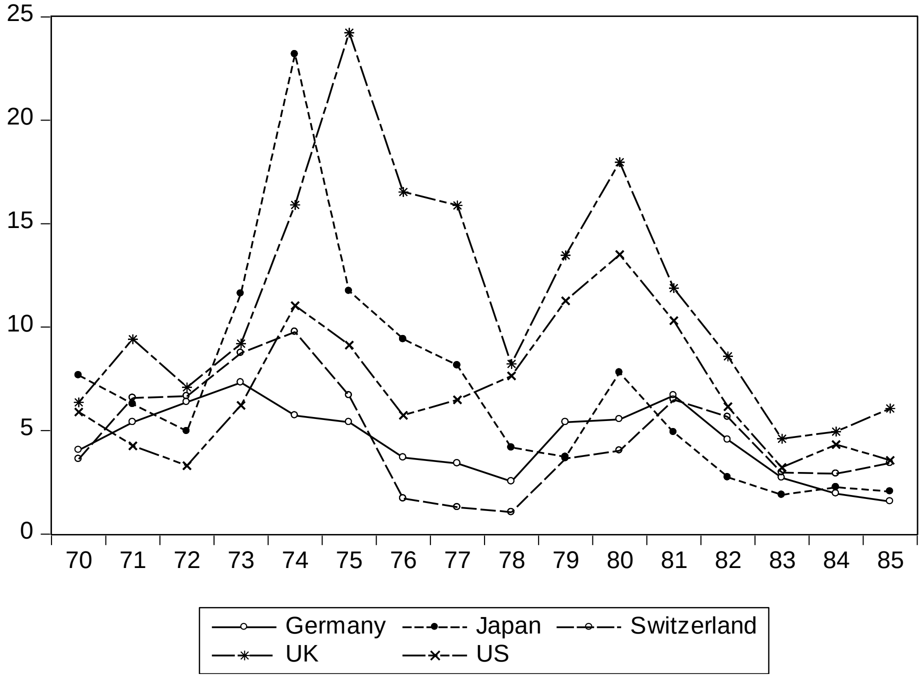
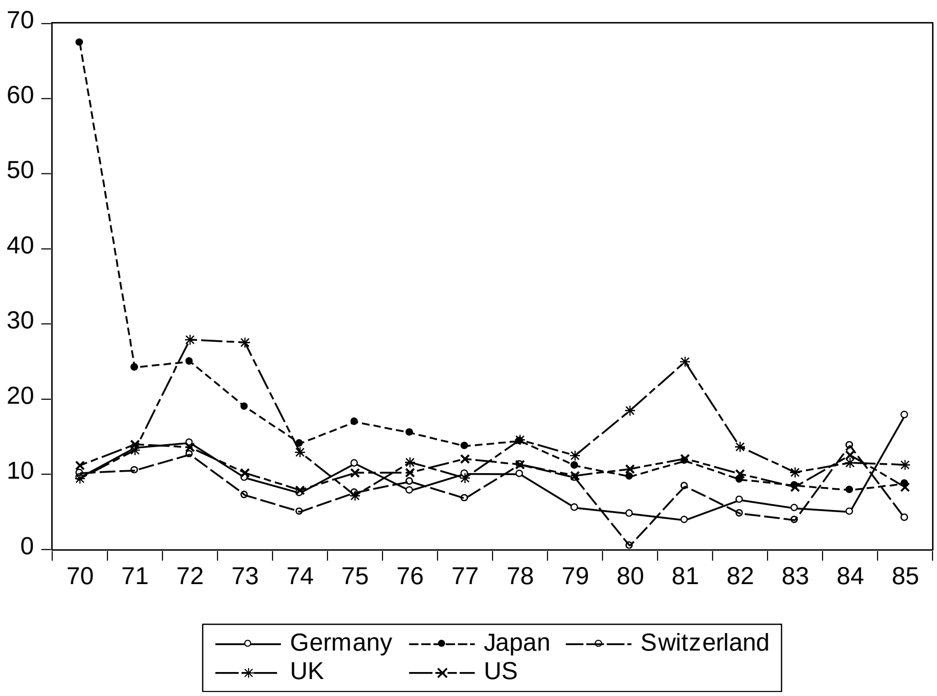


Figure 2.3. Money Growth (%)



Therefore, it should be noticed that conducting monetary policy by conservative central bankers, as suggested by CBI theories, may result in over reaction to oil shocks, so policymakers should bear in mind that their reaction to an oil shock to cut inflation may reduce output growth more than the oil shock, per se.

2.5. Central Bank Independence and the Fixed Exchange Rate Regime

There are a few works about the relation between CBI and the fixed exchange rate regime. Nevertheless, it seems that they are closely related since these two institutions are chosen to have low and stable inflation. As mentioned, a remedy for the inflationary bias suggested by theory is CBI, but another solution for this time-inconsistency problem first proposed by Rogoff (1985), Giavazzi and Pagano (1988), Alesina and Grilli (1992) and Millesi-Ferretti (1995) is conducting monetary policy by fixing the exchange rate because it results in credible commitment. The fixed exchange rate regime, like CBI, can prevent opportunistic actions to reduce unemployment in short-run which causes inflation. The proponents of the fixed exchange rate regime believe that, if domestic policy followed a less inflation-prone economy by choosing a fixed exchange rate regime, importing inflation would be less and this would result in less inflation. In this context, Bodea (2010) tries to answer this question of why when one institution is adopted by the economy to have less inflation, policymakers sometimes look for the other one. In other words, when both institutions do the same work to stabilise inflation, clarification is needed as to why economies apply different sets of institutions; as Bernhard et al. (2002) explain, 26% of countries adopted both institutions after the collapse of the Bertton Woods system and the rest chose one or none of them.

Bodea (2010) reviews benefits and disadvantages of both institutions such as increasing credibility of monetary policy which is a benefit of both institutions and the common cost which is restricting the reaction of the government to domestic shocks. Moreover, there are particular disadvantages for each institution. CBI cannot give the same level of transparency as fixed exchange rates can.[7] On the other hand, fixed rates impose the risk of currency devaluation. Taking all these factors into account, Bodea (2010) explains that a mix of institutions is adopted because each institution achieves its target -which is low inflation- imperfectly. She insists that a mix of monetary institutions is most likely to happen whenever the political costs of fixed rates are low and CBI is relatively transparent.

Although Bodea (2010) could adjust mix of institutions, she neglects to analyse these institutions under interaction between the government and the central bank. O'Mahony (2007) considers this issue and represents that after an independent central bank controls monetary policy, the government will try to set a fixed exchange rate regime to weaken the power of central bank. To show this point, she defines a utility function with respect to monetary policy for the government:

$$U_G = -(\tilde{\pi} - \tilde{\pi}_G)^2 \tag{2.36}$$

where $\tilde{\pi}$ is actual monetary conditions and $\tilde{\pi}_G$ is the government's desired monetary conditions. The government faces a trade-off between domestic independent monetary

[7] See Keefer and Stasavage (2002).

policy and a fixed exchange rate. Adopting a fixed exchange rate regime leads to losing control of monetary policy and vice versa. The following equation illustrates this fact:

$$\tilde{\pi} = \alpha\tilde{\pi}_D + (1-\alpha)\tilde{\pi}_w \tag{2.37}$$

where α is domestic power to control monetary policy which is between 0 and 1 and when $\alpha = 1$, there is full control over monetary policy, $\tilde{\pi}_D$ represents monetary policy conditions under full domestic control and $\tilde{\pi}_w$ shows monetary policy which is needed to keep a fixed exchange rate.

When central bank independence increases then domestic monetary policy is not only controlled by the government and it creates a gap between the value of domestic monetary policy and the government's desired monetary conditions. This is captured in (2.38):

$$\tilde{\pi}_D = (1-\eta)\tilde{\pi}_G \tag{2.38}$$

where η shows central bank independence which is between 0 and 1. Substituting (2.38) and (2.37) into (2.36) and maximising subject to α, leads to:

$$\alpha = \frac{\tilde{\pi}_G - \tilde{\pi}_w}{(1-\eta)\tilde{\pi}_G - \tilde{\pi}_w}. \tag{2.39}$$

The last equation shows the possibility in which the government does not adopt a fixed exchange rate regime. As O'Mahony (2007) mentions, (2.39) illustrates that, when CBI increases, the likelihood that the government chooses a fixed exchange rate regime increases.

Hence, O'Mahony wants to provide this point that, since CBI removes the power of the government on monetary policy, ignoring fixed exchange rates to retain domestic control on monetary policy becomes less preferred. In other words, in contrast to the literature, O'Mahony (2007) insists that the government sometimes adopts a fixed exchange rate regime not as a remedy to the time-inconsistency problem but to reduce the effect of anti-inflationary monetary policy conducted by an independent central bank.

Although the literature can explain theoretically the existence of both CBI and the fixed exchange rate regime institutions, which means that the correlation between them may be positive, it should be noticed that having a fixed exchange rate can reduce the power of both instrument and goal independence of the central bank. In other words, the instrument of the central bank is only used to keep a fixed exchange rate and the goal of the fixed exchange rate regime becomes superior to other targets and the central bank is restricted to choose its goals. As a result, it casts doubt on the positive relation between two institutions. As a benchmark, I have calculated the correlation between the existence of the fixed exchange rate regime and CBI for 70 countries.

Table 2.1. Correlations between the fixed exchange rate regime and CBI

	GMT	CWN	GMT-0	CWN-0	GMT-1	CWN-1
FER	-0.279	-0.128				
GMT	1.00	0.690				
CWN		1.00				
FER-0			-0.226	0.044		
GMT-0			1.00	0.609		
CWN-0				1.00		
FER-1					-0.215	-0.015
GMT-1					1.00	0.650
CWN-1						1.00

Note: FER is the index of the fixed exchange rate regime, GMT: an index for CBI suggested by Grilli et al. (1991), CWN: an index for CBI proposed by Cukierman et al. (1992), -0: the sample is restricted to developed countries, -1: the sample is restricted to developing countries.

To construct an index for the fixed exchange rate regime, I have used the *de facto* classification of exchange rate regimes published by the International Monetary Fund. Appendix 2.1 shows how the index which is between 0 and 7 is formed. The index increases when the power of domestic monetary policy reduces. I also use two indices to calculate CBI; the first one is suggested by Cukierman et al. (1992) and the other by Grilli et al. (1991) (henceforth, respectively CWN and GMT).[8]

Table 2.1 represents the fact that the correlation between two institutions are negative whether CBI is calculated by CWN or GMT. It should be mentioned that there is only one positive correlation which is between CWN and the index of the fixed exchange rate regime in developed countries but it is very low. However the correlation between two institutions for developed economies, using GMT for CBI, is negative. Hence, data support this idea that when a country accepts one institution it is likely to ignore the other one.

2.6. Conclusions

By reviewing the basic New Keynesian model, this chapter emphasises on the theoretical foundations of CBI which are conservativeness and credibility. The majority of empirical works support the theoretical policy implication, which is the more CBI, the less inflation occurs. Moreover, the literature cannot suggest a common result about the real effects of CBI.

Some papers believe that CBI is not a sufficient condition for price stability and recommend other institutions like the fixed exchange rate regime. Although the literature

[8] To capture CBI for countries, I have used Cukierman et al. (2002), de Haan et. al. (2003), Jacome and Vazquez (2008).

supports this idea that CBI and fixed exchange rate institutions are, together, likely to be chosen by an economy, the chapter, by investigating these two institutions in 70 countries, suggests that the existence of one institution reduces the probability of the other one being adopted.

Appendix 2.1: Index for Exchange Rate Regimes

Exchange rate Regimes	**Index**
Exchange arrangements with no separate legal tender	7
Currency board arrangements	6
Conventional fixed peg arrangements	5
Pegged exchange rates within horizontal bands	4
Crawling pegs	3
Exchange rates within crawling bands	2
Managed floating with no predetermined path for the exchange rate	1
Independently floating	0

Note: For more details about each regime, see the IMF website:
http://www.imf.org/external/np/mfd/er/2006/eng/0706.htm.

CHAPTER THREE

Central Bank Independence and Effects of Oil Price on Monetary Policy

3.1. Introduction

The second chapter reviewed the literature about the effect of central bank independence (CBI) on inflation and monetary policy. It concluded that the greater the central bank independence, the more contractionary monetary policy occurs, and inflation would be less. In this chapter, I want to examine whether this process can be seen in oil-exporting countries. Hence, we expect that an oil-exporting economy with greater CBI implements more contractionary monetary policy compared to another country with less CBI after an oil price shock, and this is the main hypothesis which will be investigated in this chapter.

As discussed, Bibow (2004) indicates central bank independence is supported by theoretical and empirical analyses. Time-inconsistency which was popularised by Kydland and Prescott (1977) and Barro and Gordon (1983), sustains this theoretically. Empirical defence focuses on the negative relationship between inflation and central bank independence in developed and developing countries. There are pros and cons relating to this idea presented in numerous papers, such as Bade and Parkin (1985), Alesina (1988), Grilli, Masciandaro and Tabellini (1991), Cukierman(1992), Doyle and Weale (1994), Campillo and Miron (1997), Forder (1998), Cukierman, Miller and Neyapti (2001), Issing (2006), Brumm (2006), Crowe (2008) and Jacome and Vazquez (2008). It is true that earlier papers only consider the correlation between CBI and inflation but empirical analyses are not limited to inflation. Whereas some authors have investigated cost of less inflation under the central bank independence situation; others have assessed macroeconomic performance under such circumstances.[1] This chapter extends the empirical literature of CBI, and its contribution to the field is that CBI is applied to analyse the reaction of the central bank in an oil-exporting country to an oil price shock.

To examine the hypothesis, the thesis considers the top nine oil-exporting countries.[2] Then, a panel data model is used. The reason is that the CBI index is constant for each country for a long time, so to study the impact of it on another variable, it is necessary to gather data from different countries. Moreover, the model also requires time series data to assess the reaction of central bank to changes in oil price. Hence, data should be cross sectional and time series which confirms that a panel data model should be used in this chapter.

The reminder of the chapter is organised as follows. Section 2 introduces two legal CBI indices which are used in the model and explains why these are better than other proxies of CBI; it then calculates indices for all countries in the sample. In Section 3, the econometric model and its virtues are described and an explanation of how the model can investigate the theoretical hypothesis is given. Section 4 deals with the time series properties of the variables and examines whether they are stationary or not. Estimation results and their economic interpretations are presented in section 5. Section 6 concludes.

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[1]See, e.g. Parkin (1987), De Long and Summers (1992), Alesina and Summers (1993), Cukierman, Kalaitzidakis, Summers and webb (1993), Cukeirman (1994), Fischer (1995), Cukeiman and Gerlach (2003), Herrendorf and Neumann (2003), Demertzis (2004) and Down (2004).

[2] As it was hard to find available data and especially laws of central banks to calculate CBI indices, the sample is restricted to nine countries.

3.2. Indicators of CBI

Chapter 2 explained the definition of CBI and provided two components of CBI: goal independence and instrument independence. Some authors believe that CBI is just instrument independence and goal independence is related to the conservative (i.e. inflation aversion) property of the central bank.[3] They try to find the impacts that instrument independence has, but not conservativeness and they have to remove it from CBI indices. However we do need a comprehensive index with two properties of central bank.

The thesis considers two famous legal indicators of CBI. The first one was proposed by Cukierman, Webb and Neyapti (1992), and the second one was suggested by Grilli, Masciandaro and Tabellini (1991) (henceforth, CWN and GMT, respectively). They are more inclusive than alternatives like indices built by Alesina (1988) and Eijffinger and Schaling (1993). CWN and GMT focus on a wide range of issues including the goal of central bank which is essential for this chapter.

Tables 3.1 and 3.2 show the CWN and GMT for the top nine oil-exporting countries. The indices have been calculated for current central banks' legislations. It is very important to consider the fact that most countries in the sample modified their regulations to establish more independent central bank during the 1990s, so the indices could illustrate the situation of central banks at the end of 1990s until today. CWN includes 16 criteria with different weights (see appendix 3.1) and they are coded between 0 (the lowest level of independence) and 1 (the highest level of independence). CWN is a weighted average of all

[3] See Hann et al. (2003).

16 criteria. GMT covers 15 issues which can be 0 or 1 then it will be constructed by the sum of them. Hence the GMT range is 0 to 15.

Comparing the two tables illustrates that the ranking of countries are very similar. This is a good sign that we can neglect the subjective judgment problem stressed by Eijffinger and Schaling (1993) and Mangano (1998). Eijfinger and Schaling (1993) explain "there are three types of choice involved when constructing any such index, in which some degree of personal judgment unavoidably intervenes: (i) which criteria should be included in the index? (ii) How should the legislation be interpreted with respect to each retained criterion (which leads to their individual valuation)? And (iii) what weight should be attributed to each criterion in the composite index?" (p.50). As one focuses on the comprehensive aspect of these indices and their similar ranking, this criticism could be overlooked. Moreover, it is possible to calculate the degree of correlation between them. If the correlation is high, one can simply ignore the criticism.

Mangano (1998) splits each index into two proxies which emerge from common and exclusive criteria of CWN and GMT, as shown in tables 3.1 and 3.2. Following Mangano's lead, GMT9 and CWN9 show CBI through the common criteria in GMT and CWN respectively and GMTN and CWNN are derived from their exclusive issues.[4] Table 3.3 indicates degrees of correlation between these six indices. As expected, the correlation between CWN and GMT is high (0.92) which is interestingly less than the correlation between CWN9 and GMT9 (0.98). In other words, small difference between CWN and GMT is due to the exclusive criteria and the smallest degree in table 3.3, which is for the

[4] Scale of GMT9 is between 0 and 9, GMTN between 0 and 6, but CWN9 and CWNN are like CWN.

Table 3.1. CWN Index for the Independence of Central Banks

	Weight	Iran	Kuwait	Mexico	Nigeria	Norway	Russia	Saudi Ara	UAE	Venezuela
Central Bank Governer	0.2	**0.625**	**0.645**	**0.813**	**0.583**	**0.52**	**0.645**	**0.27**	**0.583**	**0.708**
Term of office		0.25	0.5	0.75	0.5	0.75	0.25	0.5	0.25	0.5
Who appoints		0.25	0.25	0.5	0	0	0.5	0.25	0.25	0.5
Dismissal*		1	0.83	1	0.83	0.33	0.83	0.33	0.83	0.83
Other responsibility*		1	1	1	1	1	1	0	1	1
Central Bank primary objective	0.15	**0.4**	**0.4**	**0.6**	**0.6**	**0**	**0.6**	**0.4**	**0.4**	**0.6**
Price stability		0.4	0.4	0.6	0.6	0	0.6	0.4	0.4	0.6
Policy Formulation	0.15	**0.223**	**0.223**	**0.667**	**0.6**	**0.177**	**0.557**	**0.223**	**0.467**	**0.667**
Who formulates monetary policy		0.67	0.67	1	1	0.33	0.67	0.67	1	1
Conflict resolution		0	0	1	0.8	0.2	0.2	0	0.4	1
Central Bank role government Budget*		0	0	0	0	0	1	0	0	0
Central Bank Lending										
Limits in advances to government*	0.15	**0**	**0.67**	**0.67**	**0.33**	**0**	**1**	**0**	**0.67**	**1**
Limits in loans to government	0.1	**0**	**0.67**	**0.67**	**0.33**	**0**	**0**	**0**	**0.67**	**0.67**
Who decides terms of Lending*	0.1	**0.33**	**0.33**	**1**	**1**	**0**	**0**	**0.33**	**1**	**1**
Beneficiaries*	0.05	**N/A**	**0**	**1**	**0**	**0**	**0.33**	**0**	**0**	**1**
Type of Limits*	0.025	**0**	**0.33**	**0.67**	**0.33**	**N/A**	**N/A**	**N/A**	**0.33**	**0.67**
Maturity of Loans	0.025	**0**	**0.67**	**0**	**0.67**	**0.67**	**0**	**0**	**1**	**N/A**
Restrictions on interest rates	0.025	**0**	**0.5**	**1**	**0.75**	**0.5**	**0.75**	**0**	**0**	**1**
Prohibition lending to government	0.025	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**
CWN Index		**0.259**	**0.46**	**0.754**	**0.523**	**0.17**	**0.49**	**0.184**	**0.55**	**0.803**

*denotes exclusive criteria of CWN

Table 3.2.GMT Index for the Independence of Central Banks

	Iran	Kuwait	Mexico	Nigeria	Norway	Russia	Saudi Ara	UAE	Venezuela
Index of Political Independence	**1**	**1**	**8**	**1**	**1**	**1**	**1**	**2**	**7**
Government does not appoint Governor	0	0	1	0	0	0	0	0	1
Governor in office more than 5 years	0	0	1	0	1	0	0	0	1
Government does not appoint Board*	0	0	1	0	0	0	0	0	0
Board in office more than 5 years*	0	0	1	0	0	0	0	0	1
Government participation in Board*	0	0	1	0	0	0	0	0	1
Government does not approve mon. policy	0	0	1	0	0	0	0	1	1
Price stability as statutory objective	1	1	1	1	0	1	1	1	1
Power of CB for conflict resolution	0	0	1	0	0	0	0	0	1
Index of Economic Independence	**1**	**5**	**5**	**5**	**3**	**4**	**0**	**4**	**6**
Direct credit not automatic*	0	1	0	1	1	1	0	0	1
Lending to Gov. at market interest rates	0	1	1	1	0	1	0	1	1
Lending maturity to 1 year or less	0	1	1	1	1	0	0	1	1
Limited amount of lending	0	1	1	1	0	1	0	1	0
Primary market participation	0	0	0	0	0	0	0	0	1
Discount rate set by CB*	1	1	1	1	1	1	0	1	1
Banking supervision responsibility*	0	0	1	0	0	0	0	0	1
Total GMT	**2**	**6**	**13**	**6**	**4**	**5**	**1**	**6**	**13**

*denotes exclusive criteria of GMT

correlation between CWNN and GMTN, supports this outcome. Hence, it can be expected that the difference between the estimation results of the two indices would be small and it is because of the exclusive criteria.

Another issue worth mentioning about using legal independence (de jure) indices is whether they can show independence in practice (de facto). Cukierman (1992) mentions that de jure measures may better show the actual level of independence in developed countries than developing ones, so he proposes another index for developing countries, which is the turnover of central bank governors. The logic behind this proxy is that a higher turnover level indicates a lower level of CBI. However, it is clear that this proxy is not suitable for the thesis; because it does not include conservativeness which is essential here and it is not as comprehensive as legal indices.

On the other hand, one may point out that although the central banks have changed their regulations, most economies in the sample are developing and the law is not obeyed in practice in these countries, as it is in developed countries, so we need de facto indices. In order to address this, it is useful to refer to the measures in tables 3.1 and 3.2. CWN and GMT illustrate that, with the exception of Mexico and Venezuela, all countries suffer from low CBI; hence there is no chance that countries have modified central banks' regulations for having more CBI but they do not follow it. As a result, the suggested CBI indices are robust in front of relevant criticisms.

Table 3.3. Correlations between indices*

	CWN	CWN9	CWNN	GMT	GMT9	GMTN
CWN	1.00	0.95	0.96	0.92		
CWN9		1.00	0.83		0.98	
CWNN			1.00			0.71
GMT				1.00	0.98	0.95
GMT9					1.00	0.88
GMTN						1.00

* Values of GMT, GMT9 and GMTN have been normalised to be in [0, 1].

3.3. The Econometric Model

To investigate whether more CBI results in more monetary tightening after an increase in oil prices, this model can be estimated: [5]

$$M_{i,t} = \alpha_i + \beta_1 O_{i,t-1} + \sum_{l=1}^{3} \beta_{l+1} \pi_{i,t-l} + \gamma_1 O_{i,t-1} I_i + u_{i,t} \qquad (3.1)$$

where M is the annual percentage change in real money, O is the yearly percentage change in oil price, π is the consumer price percentage change per year, I is the central bank independence index, $i = 1, \ldots, N(= 9)$ is the number of countries $t = 1, \ldots, T(= 132)$ is the time-months, and $u_{i,t}$ is the error term that we have $E(u_{i,t}) = 0, E(u_{i,t}u_{j,s}) = \sigma^2$ when $i = j$ and $t = s$, and $E(u_{i,t}u_{j,s}) = 0$ otherwise.[6] As discussed above, the CBI indices are calculated after the regulatory reforms in the 1990s, so other data should correspond to this period. Data are from January 1997 until December 2007.[7]

[5] The model can be used for other countries with different primary products; however the key point is that exports of primary products should have a significant share of total exports, otherwise parameters are not statistically meaningful. It should be noticed that as the model is linear it can be also applied to analyse oil price cuts.

[6] As the consumer price index includes expenditures on energy, one may conclude that there is a collinearity problem. However the degree of correlation between $O_{i,t-1}$ and $\pi_{i,t-1}$ is 0.07 and the issue can be ignored.

[7] Data have been gathered from International Financial Statistics and central banks' data.

As Bernanke and Mihov (1998) argue, economists use different methods to measure and find the direction of changes in monetary policy and there is no consensus. In other words, choosing a criterion depends on the nature of the research concerned, with its aims, bottlenecks and the prevailing economic situation. For instance, whereas Romer and Romer (1989) use the minutes of the Federal Open Market Committee to show monetary policy in the US, Bernanke and Blinder (1992) think that federal funds rate is a better indicator; and while Thornton (1988) and Christiano and Eichenbaum (1992) suggest the quantity of non-borrowed reserves as the measure of monetary policy Cosimano and Sheehan (1994) propose borrowed reserves. Hence, the researcher has to find an indicator and justify it.

It is common to use the interest rate to show monetary policy in a model like this, but as some countries in the sample do not present sufficient monthly data in this area, it would be useful to exploit money stock (nominal money).

Moreover, McCallum (1989) points out that the monetary authority can influence *instrument variables* (such as the interest rate) to reach the *goals* (say, real GDP). Yet he explains a two-stage process to approach the goals in monetary policy. First a central bank defines a time path to an *intermediate target*, then from this target to the final goal. In other words, he believes that the central bank can affect intermediate targets easier than the goals. When intermediate targets are met, the final goals could be attainable. So, after instrument variables, the central bank can affect intermediate targets. Since there is hardly any available data about instrument variables for the sample, it is reasonable to include the intermediate target in the model; this means that reactions of the monetary policymaker can be monitored through changes in real money instead of the interest rate. The logic behind this is clear: the central bank changes the interest rate to affect (real) money. It is true that banks and people also influence (real) money, but obviously their impact is weaker than the central bank's. Hence, real money indicates monetary policy in the model.

Another group of variables regarding monetary policy is *indicator variables*. McCallum (1989) explains that this category indicates the state of the economy to the policymaker. Whereas inflation is a final goal for the central bank, lags of it could be useful indicator variables for the policymaker. In the model, inflation rates for last quarter describe the state of the economy to the authority. It is possible to use more lags, however as the central bank focuses on recent months to know the current situation of the economy, the model applies data for the last three months.

It is expected that the coefficients of inflation lags would be negative. Because (real) money is an intermediate target, one can assume (real) money is a function of the gap between inflation and desired inflation in previous periods:

$$When\ \pi_{t-l} < \pi^* \quad for\ l = 1,2,3 \Rightarrow \pi_{t-l} - \pi^* < \Rightarrow M_t\ should\ be\ positive \qquad (3.2)$$

$$When\ \pi_{t-l} \geq \pi^* \quad for\ l = 1,2,3 \Rightarrow \pi_{t-l} - \pi^* \geq 0 \Rightarrow M_t \leq 0.$$

In other words, when inflation is less than the desired level, (real) money will increase in the next periods, otherwise will decrease. Hence M_t has a negative relationship with the gap and it means that in a linear equation the coefficients of inflation lags should be negative.

Oil price and independence index are the main explanatory variables to investigate the reaction of the monetary authority to an oil price shock. The model considers oil price as an individual time-varying variable[8], because each country has its oil price, although

[8] Hsiao (2003, p27) defines an individual time-varying variable as one which varies across cross-sectional units at a given period and shows variations through time.

their trends are almost the same. However, as described, CBI proxy (I_i) is time-invariant. The interactive term represents the effect of independence on the response of the central bank to a change in oil price. Since it is expected that the central bank in an oil-exporting country implements tighter monetary policy after an oil shock, the main hypothesis to test is $\gamma_1 < 0$.

Another issue about the model specification is that the coefficients are supposed to be common. Is this assumption of homogeneity valid in the model? Because the thesis considers the average effect of CBI on real money, it is reasonable to follow Zellner (1969) and have a fixed effects model with common slopes. Zellner (1969) points out when one is interested in the average effect of explanatory variables it is the way to find it, another method could be estimating regression for each individual and averaging the slopes. It is not possible, however, to use the latter method in this case, because CBI is constant for each individual's regression and the model suffers from multicollinearity.

Model (3.1), however, has the scale problem. In other words, the coefficient of oil change depends on the scale of CBI index. For example, one can change GMT scale from 0-15 to 5-20. This affects the main influence of oil change on real money.

Suppose the scale of CBI index has been changed to become $I_i^* = I_i - a$, so model (3.1) will be:

$$M_{i,t} = \alpha_i + (\beta_1 + \gamma_1 a)O_{i,t-1} + \sum_{l=1}^{3} \beta_{l+1}\pi_{i,t-l} + \gamma_1 O_{i,t-1} I_i^* + u_{i,t}\ . \qquad (3.3)$$

Model (3.3) demonstrates that the main effect of oil change is $\beta_1 + \gamma_1 a$, and if one decides to determine $a = -\frac{\beta_1}{\gamma_1}$ then the main effect will disappear. On the other hand, it is possible to show a strong main effect by choosing a large amount of a. Hence, the main effect of oil varies with different scales of the CBI index. It is obvious that the standardised coefficient and standard error also change. In other words, it is not possible to draw a conclusion or test a hypothesis about the main effect.

However, it is very easy to show that the whole effect of oil on real money does not vary with different coding in the CBI index. Model (3.3) shows that:

$$\frac{\partial M_{i,t}}{\partial O_{i,t-1}} = \beta_1 + \gamma_1 a + \gamma_1 I_i^* = \beta_1 + \gamma_1 a + \gamma_1 (I_i - a) = \beta_1 + \gamma_1 I_i \,. \tag{3.4}$$

So, this partial derivative is like that for model (3.1). However, to have a correct specification, it is necessary to find a way in order to remove the part of the main effect which is depending on the scale of CBI index.

A common method in linear regressions is *mean-centring* form. This could be used in a panel data model. Hence, model (3.1) is extended to:

$$M_{i,t} = \alpha_{2i} + \beta_{21} O_{2i,t-1} + \sum_{l=1}^{3} \beta_{l+1} \pi_{i,t-l} + \gamma_{21} O_{2i,t-1} I_{2i} + u_{2i,t} \tag{3.5}$$

where $O_{2i,t-1} = O_{i,t-1} - \overline{O_{\iota,t}}$ and $I_{2i} = I_i - \overline{I_\iota}$. This model does not have the scale problem. Let us assume that $I_i^* = I_i - a$, so

$$I_{2i}^* = I_i^* - \overline{I_i^*} = (I_i - a) - (\overline{I_\iota} - a) = I_i - \overline{I_\iota} = I_{2i}.$$

This means that I_{2i} shows no change after a transformation in the CBI index. Therefore the main effect of oil change is invariant after any change in the scale of CBI index and any relating test can be done without any statistical obstacle. Model (3.5) has the properties of the first model without the scale problem; thus it is estimated to assess the impact of CBI on the relation between monetary policy and oil price. As with model (3.1), one can expect that $\gamma_{21} < 0$.

3.4. Time Series Properties

To make confidence intervals or test hypotheses by the usual tables and standard estimators have standard distribution, one has to assess stationarity. One method to assess time series properties is to use the Dickey-Fuller (1979) (DF) test for each individual. The assumption for this test is, when all individual time series are stationary, panel data will be stationary. DF is, however, a very weak test for panel data and it cannot often reject non-stationarity for an actual stationary time series. Hence many researchers have proposed unit-root tests for panel data such as Levin and Lin (1993), Maddala and Wu (1999), Choi (2002), Levin, Lin and Chu (2002) and Im, Pesaran and Shin (2003). This chapter tests the existence of unit-root according to Levin and Lin (LL) and Im, Pesaran and Shin (IPS).

Levin and Lin (1993) explain that unit-root tests in panel data require that data have to be independent across individuals. To ensure this, the cross-section average should be subtracted from the observed data. Thus, to test the series $\{y_{i,t}\}$, we have:

$$x_{i,t} = y_{i,t} - \frac{1}{N}\sum_{i=1}^{N} y_{i,t}. \qquad (3.6)$$

The null hypothesis supposes that each individual time series has a unit-root by this model:

$$\Delta x_{i,t} = a_i + \tau_i t + \delta_i x_{i,t-1} + \sum_{d=1}^{p_i} \theta_{id}\, \Delta x_{i,t-d} + \varepsilon_{i,t} \qquad (3.7)$$

where $\Delta x_{i,t} \equiv x_{i,t} - x_{i,t-1}$. The null and alternative hypotheses are:

$$H_0\colon\ \delta_1 = \delta_2 = \cdots = \delta_N = 0 \tag{3.8a}$$

$$H_1\colon\ \delta_1 = \delta_2 = \cdots = \delta_N = \delta < 0. \tag{3.8b}$$

To find the LL test statistic, the first stage is to calculate two residuals:

$$\hat{e}_{i,t} = \Delta x_{i,t} - \hat{a}_{1i} - \hat{\tau}_{1i} t - \sum_{d=1}^{p_i} \theta_{1id}\, \Delta x_{i,t-d} \tag{3.9}$$

$$\hat{v}_{i,t-1} = x_{i,t-1} - \hat{a}_{2i} - \hat{\tau}_{2i} t - \sum_{d=1}^{p_i} \theta_{2id}\, \Delta x_{i,t-d}\,, \tag{3.10}$$

then δ can be achieved by:

$$\hat{e}_{i,t} = \delta \hat{v}_{i,t-1} + \xi_{i,t}. \tag{3.11}$$

To control for heterogeneity across i, they normalise $\hat{e}_{i,t}$ and $\hat{v}_{i,t-1}$ by the regression standard error for equation (3.11):

$$\hat{\sigma}_{ei}{}^2 = \frac{1}{T - p_i - 1} \sum_{t=p_i+2}^{T} (\,\hat{e}_{i,t} - \hat{\delta}\, \hat{v}_{i,t-1})^2 \tag{3.12}$$

$$\tilde{e}_{i,t} = \frac{\hat{e}_{i,t}}{\hat{\sigma}_{ei}} \quad , \qquad \tilde{v}_{i,t-1} = \frac{\hat{v}_{i,t-1}}{\hat{\sigma}_{ei}} \tag{3.13}$$

then rewrite equation (11):

$$\tilde{e}_{i,t} = \delta\, \tilde{v}_{i,t-1} + \frac{\xi_{i,t}}{\hat{\sigma}_{ei}}\,. \tag{3.14}$$

The regression t-statistic for $\delta = 0$ is:

$$t_\delta = \frac{\hat{\delta}}{RSE(\hat{\delta})} \tag{3.15}$$

where $\hat{\delta}$ is the OLS estimate of δ, and $RSE(\hat{\delta})$ is the reported standard error which is:

$$RSE(\hat{\delta}) = \frac{\sqrt{(N\tilde{T})^{-1}\sum_{i=1}^{N}\sum_{t=2+p_i}^{T}(\tilde{e}_{i,t} - \hat{\delta}\,\tilde{v}_{i,t-1})^2}}{\sqrt{\sum_{i=1}^{N}\sum_{t=2+p_i}^{T}\tilde{v}_{i,t-1}{}^2}} \tag{3.16}$$

and $\tilde{T} \equiv T - N^{-1}\sum_{i=1}^{N} p_i - 1$ is the average number of observations for each individual. Levin and Lin (1993) adjust this test with:

$$t^* = \frac{t_\delta - N\tilde{T}S_{NT}(\sum_{i=1}^{N}\sum_{t=2+p_i}^{T}\tilde{v}_{i,t-1}{}^2)^{-1}[RSE(\hat{\delta})]^{-1}\mu_{\tilde{T}}}{\sigma_{\tilde{T}}} \tag{3.17}$$

where $\mu_{\tilde{T}}$ and $\sigma_{\tilde{T}}$ are mean and standard deviation adjustment values and Levin and Lin (1993) calculate them applying the Monte Carlo approach; $S_{NT} = N^{-1}\sum_{i=1}^{N}\hat{\sigma}_{xi}\ \hat{\sigma}_{ei}{}^{-1}$ and $\hat{\sigma}_{xi}$ is an estimate for the long-run variance of x_i:

$$\hat{\sigma}_{xi}{}^2 = \frac{1}{T-1}\sum_{t=2}^{T}(\Delta x_{i,t} - \overline{\Delta x_i})^2 + 2\sum_{L=1}^{\bar{K}} w_{\bar{K}L}[\frac{1}{T-1}\sum_{t=2+L}^{T}(\Delta x_{i,t} - \overline{\Delta x_i})(\Delta x_{i,t-L} - \overline{\Delta x_i})] \tag{3.18}$$

$\overline{\Delta x_i}$ is the average of $\Delta x_{i,t}$ for individual i, and $w_{\bar{K}L}$ is the lag kernel to guarantee a positive value of $\hat{\sigma}_{xi}{}^2$. A proposition for it is made by Newey and West (1987):

$$w_{\bar{K}L} = \begin{cases} 1 - \frac{L}{\bar{\bar{K}}} & if\ L < \bar{K} \\ 0 & if\ L \geq \bar{K}. \end{cases} \tag{3.19}$$

Levin and Lin (1993) indicate that the distribution of t*-statistic has a non-zero mean and it can converge to a normal distribution asymptotically when N and T increase.

This convergence is more rapid in respect to T than to N. The distribution is just based on T and N but not individual fixed effects.

As mentioned in equation (3.8), the LL test is based on the assumption of homogeneity (i.e. $\delta_i = \delta_j,\ i \neq j$), but Im, Pesaran and Shin (2003) dismiss this assumption and the alternative hypothesis in their test is:

$$H_1:\ \delta_i < 0 \quad for\ at\ least\ one\ i. \tag{3.20}$$

In the IPS procedure, one has to do the unit-root test for each individual and then calculate the average. Im et al. (2003) particularly suggest using the augmented Dickey-Fuller (1981) (ADF) statistic (τ_i) and show the average of ADF statistics ($\bar{\tau}$) converges to a normal distribution under the null hypothesis (equation (3.8a)) when $N \rightarrow \infty$ and $T \rightarrow \infty$. As they point out, for each individual $E(\tau_i)$ and $Var(\tau_i)$ depend on the lag length in the ADF model, so they find $E(\tau_i)$ and $Var(\tau_i)$ for different lags. Then by using the Monte Carlo approach, they illustrate that the IPS test is more powerful than the LL test for most cases.

Table 3.4 illustrates that the LL test cannot reject the null hypothesis for $M_{i,t}$ and $O_{2i,t-1}$, but it does reject for other variables. The IPS test however shows that all variables are stationary and the model is balanced.

Table 3.4. Stationary tests

	$M_{i,t}$	$O_{2i,t-1}$	$\pi_{i,t-1}$	$\pi_{i,t-2}$	$\pi_{i,t-3}$
LL statistic	-1.02	0.31	-2.47	-2.51	-2.55
	(0.15)	(0.62)	(0.00)	(0.00)	(0.00)
IPS Statistic	-4.02	-3.13	-2.39	-2.38	-2.40
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

Values in parentheses are probabilities to accept the null hypothesis of non-stationarity.

3.5. Estimation Results

Tables 3.5 and 3.6 illustrate the estimation outcomes of fixed effects model (3.5).[9,10] This model has been estimated with two CBI indices and in three groups. All nine top oil-exporting countries are considered in the first estimation but they are categorised in two groups, OPEC and Non-OPEC, and model (3.5) is also estimated with them. R^2 in table 3.5 is not high enough to support the model and implies that there may be a problem with the specification. The Durbin-Watson (D-W) test shows this problem explicitly. The D-W statistic in panel data is:

$$d = \frac{\sum_{i=1}^{N} \sum_{t=2}^{T} \left(u_{2i,t} - u_{2i,t-1}\right)^2}{\sum_{i=1}^{N} \sum_{t=1}^{T} {u_{2i,t}}^2}. \quad (3.21)$$

As this statistic is near zero, one can conclude that there is a positive relationship between residuals and the model suffers from first order autocorrelation. Hence in table 3.6, the model is estimated one more time, given AR(1):

$$M_{i,t} = \alpha_{2i} + \beta_{21} O_{2i,t-1} + \sum_{l=1}^{3} \beta_{l+1} \pi_{i,t-l} + \gamma_{21} O_{2i,t-1} I_{2i} + u_{2i,t} \quad (3.22)$$

$$u_{2i,t} = \rho u_{2i,t-1} + \epsilon_{i,t}.$$

It can be seen that the D-W test is much more appropriate as there is no longer any positive relation between residuals and R^2 is also high in table 3.6. Another test which is considered in this chapter is $p - value\ (\alpha)$.[11]

[9]Although fixed effects regressions present more relevant conditional correlations, I have also performed the Hausman test to select between the random effects and fixed effects approaches. It strongly rejects the random effects method for all models; for example, χ^2 statistic for the all-countries model with CWN is 33.46 which means that the probability of null hypothesis for misspecification is zero.

[10] As discussed in chapter 2, countries adopt different mixture of CBI and the fixed exchange rate regime; however, the fixed effects model can capture all specific characteristics of countries, hence, to conclude about estimations, there is no concern about different exchange rate regimes in the sample.

[11] For more details see Hsiao (2003).

Table 3.5. Fixed effects estimation of model (3.5)

Constant Terms	CWN is the CBI index			GMT is the CBI index		
	All countries	OPEC	Non-OPEC	All countries	OPEC	Non-OPEC
Iran	13.44	-0.40		13.48	-0.36	
	(6.91)**	(-0.14)		(6.93)**	(-0.12)	
Kuwait	11.10	9.30		11.10	9.31	
	(6.41)**	(4.79)**		(6.42)**	(4.79)**	
Nigeria	19.28	8.51		19.31	8.55	
	(10.17)**	(3.24)**		(10.18)**	(3.25)**	
Saudi Arabia	9.16	8.87		9.16	8.87	
	(5.44)**	(4.65)**		(5.35)**	(4.65)**	
UAE	17.56	13.77		17.58	13.78	
	(10.07)**	(6.82)**		(10.09)**	(6.82)**	
Venezuela	41.96	20.52		42.02	20.59	
	(19.14)**	(5.26)**		(19.16)**	(5.28)**	
Mexico	13.64		15.87	13.66		15.91
	(7.65)**		(16.20)**	(7.66)**		(16.36)**
Norway	8.77		9.40	8.76		9.48
	(4.29)**		(8.43)**	(4.28)**		(8.58)**
Russia	29.51		35.23	29.57		35.39
	(13.65)**		(28.55)**	(13.67)**		(28.83)**

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Table 3.5 (continued)

	CWN is the CBI index			GMT is the CBI index		
	All countries	OPEC	Non-OPEC	All countries	OPEC	Non-OPEC
$O_{2i,t-1}$	1.97	3.36	3.88	2.00	3.47	4.92
	(1.37)	(1.70)	(2.87)**	(1.39)	(1.74)*	(3.41)**
$\pi_{i,t-1}$	-1.58	-1.15	-1.53	-1.58	-1.15	-1.51
	(-6.95)**	(-2.10)**	(-10.87)**	(-6.94)**	(-2.10)**	(-10.77)**
$\pi_{i,t-2}$	0.19	0.33	0.26	0.19	0.33	0.27
	(0.52)	(0.40)	(1.18)	(0.53)	(0.40)	(1.22)
$\pi_{i,t-3}$	0.85	1.18	0.48	0.85	1.18	0.45
	(3.83)**	(2.34)**	(3.38)**	(3.78)**	(2.34)**	(3.14)**
$O_{2i,t-1}I_{2i}$	-4.35	6.16	-3.37	-0.36	0.26	-0.74
	(-0.69)	(0.65)	(-0.59)	(-1.05)	(0.52)	(-2.27)**
R^2	0.22	0.15	0.67	0.23	0.16	0.68
D-W test	0.24	0.21	0.54	0.24	0.21	0.53
$p - \text{value}\ (\alpha)$	0.00	0.00	0.00	0.00	0.00	0.00

The table shows the coefficients with t-statistics in parentheses. * and ** illustrate statistical significance at the 10% and 5%, respectively.

Table 3.6. Fixed effects estimation of model (3.5) given AR(1) (Estimation of model (3.22))

	CWN is the CBI index			GMT is the CBI index		
Constant Terms	All countries	OPEC	Non-OPEC	All countries	OPEC	Non-OPEC
Iran	7.51	4.08		7.48	3.98	
	(1.03)	(0.44)		(1.03)	(0.44)	
Kuwait	10.15	9.58		10.15	9.56	
	(1.46)	(1.27)		(1.46)	(1.27)	
Nigeria	18.90	16.28		18.89	16.29	
	(2.61)**	(1.92)**		(2.61)**	(1.90)*	
Saudi Arabia	9.74	9.41		9.70	9.40	
	(1.41)	(1.27)		(1.41)	(1.26)	
UAE	19.51	18.18		19.50	18.16	
	(2.80)**	(2.38)**		(2.80)**	(2.37)**	
Venezuela	27.16	23.29		27.22	23.23	
	(3.56)**	(2.32)**		(3.57)**	(2.31)**	
Mexico	11.65		15.38	11.57		15.46
	(1.67)*		(30.51)**	(1.69)*		(30.56)**
Norway	7.62		9.23	7.63		9.38
	(0.93)		(16.00)**	(0.93)		(16.26)**
Russia	27.21		34.03	27.15		34.32
	(3.67)**		(53.25)**	(3.66)**		(53.60)**

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Table 3.6 (continued)

	CWN is the CBI index			GMT is the CBI index		
	All countries	OPEC	Non-OPEC	All countries	OPEC	Non-OPEC
$O_{2i,t-1}$	0.87	0.42	6.31	0.87	-0.07	7.64
	(0.62)	(0.21)	(8.77)**	(0.61)	(-0.04)	(10.11)**
$\pi_{i,t-1}$	-0.19	0.05	-0.19	-0.19	0.05	-0.19
	(-1.99)**	(0.22)	(-2.24)**	(-2.00)**	(0.23)	(-2.28)**
$\pi_{i,t-2}$	0.16	0.58	-1.40	0.16	0.57	-1.36
	(1.58)	(2.44)**	(-10.93)**	(1.59)	(2.46)**	(-10.74)**
$\pi_{i,t-3}$	-0.37	-0.80	0.86	-0.37	-0.80	0.80
	(3.95)**	(-3.48)**	(11.46)**	(-3.95)**	(-3.50)**	(10.87)**
$O_{2i,t-1}I_{2i}$	-4.93	-15.53	0.12	-0.53	-1.02	-0.93
	(-0.76)	(-1.66)*	(0.04)	(-1. 57)	(-2.10)**	(-5.50)**
ρ	0.90	0.89	0.72	0.90	0.89	0.73
	(70.64)**	(59.38)**	(19.69)**	(70.75)**	(59.43)**	(19.90)**
R^2	0.87	0.85	0.90	0.87	0.85	0.92
D-W test	2.28	2.34	2.02	2.28	2.35	2.01
$p-\text{value}\ (\alpha)$	0.32	0.51	0.00	0.32	0.52	0.00

The table shows the coefficients with t-statistics in parentheses. * and ** illustrate statistical significance at the 10% and 5%, respectively.

Table 3.7 Estimation of model (3.5) in first difference

	CWN is the CBI index			GMT is the CBI index		
	All countries	OPEC	Non-OPEC	All countries	OPEC	Non-OPEC
$\Delta O_{2i,t-1}$	0.66	0.08	1.32	0.64	-0.46	1.38
	(0.46)	(0.04)	(0.92)	(0.45)	(-0.23)	(0.93)
$\Delta \pi_{i,t-1}$	-0.09	0.30	-0.20	-0.09	0.30	-0.20
	(-0.94)	(1.34)	(-3.12)**	(-0.95)	(1.35)	(-3.11)**
$\Delta \pi_{i,t-2}$	0.23	0.79	0.07	0.23	0.80	0.07
	(2.37)**	(3.48)**	(1.05)	(2.39)**	(3.50)**	(1.03)
$\Delta \pi_{i,t-3}$	-0.28	-0.50	-0.22	-0.28	-0.51	-0.22
	(-3.06)**	(-2.33)**	(-3.43)**	(-3.05)**	(-2.34)**	(-3.43)**
$\Delta O_{2i,t-1} I_{2i}$	-5.33	-16.53	10.60	-0.566	-1.10	0.17
	(-0.82)	(-1.77)*	(1.70)	(-1.65)*	(-2.36)**	(0.50)
R^2	0.02	0.03	0.08	0.16	0.03	0.07
D-W test	2.37	2.46	1.81	2.37	2.46	1.81
$p - \text{value } (\alpha)$	0.935	0.936	0.939	0.938	0.939	0.940

The table shows the coefficients with t-statistics in parentheses. * and ** illustrate statistical significance at the 10% and 5%, respectively.

Table 3.8. Fixed effects estimation of model (3.5) given AR(1) with real oil price

	CWN is the CBI index			GMT is the CBI index		
Constant Terms	All countries	OPEC	Non-OPEC	All countries	OPEC	Non-OPEC
Iran	7.50	4.06		7.46	3.95	
	(1.03)	(0.45)		(1.02)	(0.43)	
Kuwait	10.14	9.58		10.15	9.56	
	(1.46)	(1.27)		(1.46)	(1.27)	
Nigeria	18.89	16.28		18.88	16.22	
	(2.61)**	(1.91)*		(2.61)**	(1.90)*	
Saudi Arabia	9.74	9.40		9.68	9.39	
	(1.41)	(1.27)		(1.41)	(1.26)	
UAE	19.50	18.18		19.50	18.16	
	(2.80)**	(2.38)**		(2.80)**	(2.37)**	
Venezuela	27.16	23.28		27.21	23.22	
	(3.56)**	(2.32)**		(3.57)**	(2.31)**	
Mexico	11.64		15.36	11.75		15.39
	(1.66)*		(30.12)**	(1.69)*		(30.47)**
Norway	7.62		9.23	7.63		9.31
	(0.93)		(15.85)**	(0.93)		(16.17)**
Russia	27.21		34.06	27.15		34.16
	(3.67)**		(52.83)**	(3.66)**		(53.41)**

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Table 3.8 (continued)

	CWN is the CBI index			GMT is the CBI index		
	All countries	OPEC	Non-OPEC	All countries	OPEC	Non-OPEC
$O_{2i,t-1}$	0.91	0.46	6.30	0.90	-0.03	6.95
	(0.65)	(0.23)	(8.79)**	(0.65)	(-0.01)	(9.26)**
$\pi_{i,t-1}$	-0.19	0.05	-0.19	-0.19	0.05	-0.19
	(-1.99)**	(0.22)	(-2.20)**	(-2.00)**	(0.23)	(-2.16)**
$\pi_{i,t-2}$	0.16	0.58	-1.40	0.16	0.58	-1.39
	(1.58)	(2.44)**	(-10.96)**	(1.59)	(2.46)**	(-10.97)**
$\pi_{i,t-3}$	-0.37	-0.80	0.86	-0.37	-0.80	0.84
	(3.95)**	(-3.48)**	(11.48)**	(-3.95)**	(-3.50)**	(11.23)**
$O_{2i,t-1}I_{2i}$	-4.81	-15.36	0.18	-0.53	-1.01	-0.43
	(-0.74)	(-1.64)*	(0.06)	(-1. 55)	(-2.08)**	(-2.56)**
ρ	0.90	0.89	0.73	0.90	0.89	0.73
	(70.64)**	(59.39)**	(19.69)**	(70.75)**	(59.45)**	(19.69)**
R^2	0.87	0.85	0.91	0.87	0.85	0.92
D-W test	2.29	2.35	2.02	2.29	2.35	2.03
$p - \text{value}\ (\alpha)$	0.32	0.52	0.00	0.32	0.52	0.00

The table shows the coefficients with t-statistics in parentheses. * and ** illustrate statistical significance at the 10% and 5%, respectively.

It displays the probability value of the hypothesis that the intercept in the fixed effects model (3.5) is common for all individuals. In table 3.5 all individual intercepts are significant except for Iran in the OPEC model, and it is reasonable that $p - value\ (\alpha)$ is zero for all specifications. However, in table 3.6, it is shown that intercepts are not significant for some countries and, obviously $p - value\ (\alpha)$ is greater. However it also rejects the common intercept hypothesis for the Non-OPEC countries.

What are the economic interpretations of the estimation results? It is of great importance that, except for the sign of $\pi_{i,t-3}$ in table 3.5 which has the AR(1) problem and the Non-OPEC group in table 3.6, and the coefficient of $\pi_{i,t-2}$ in table 3.6 for the OPEC group only, all significant coefficients have the predicted sign. This means that variables affect real money in the way that has been described in theory. In table 3.5, the first lag of inflation has a significant effect on real money in all specifications and it is negative like the prediction in equation (3.2). In table 3.6, this variable influences real money significantly in four specifications. The second lag, however, affects significantly only in the specifications of table 3.6. The third lag of inflation in model (3.22) (model (3.5) without the first order autocorrelation problem) has a significantly negative coefficient for all specifications except the Non-OPEC group. For instance, it is -0.37 in the model with all countries which implies that if inflation increases for 1 unit, real money will diminish 0.37 percentage points over the next three months.

As described, the coefficient of the interactive term in model (3.5) should be negative. All the significant coefficients are negative in tables 3.5 and 3.6. Moreover, there are just two positive signs whose t-statistics are very small. Moreover, since table 3.6 illustrates that the coefficient in the AR(1) process is close to one, model (3.5) is estimated one more time in first difference. Table 3.7 presents the results. As it can be seen the significant coefficients of the interactive term are negative like two previous tables. Table 3.8 also shows the results with real oil price instead of nominal oil price.[12,13]

In table 3.5, when GMT is used as the CBI index, the coefficient of the interactive term for the Non-OPEC economies is significantly negative. However, in table 3.6, when the model does not encounter the AR(1) problem, specifications with GMT have significantly negative coefficients for interactive terms. On the other hand, there is one coefficient which is significant in the CWN specifications. It shows that GMT is a better proxy for CBI and the GMT specifications can support the theory more powerfully than the CWN specifications. This issue can also be adopted by reviewing R^2.

It was shown in table 3.3 that the correlation between two proxies is high and the difference is because of the exclusive criteria in each index. Hence, it is reasonable to conclude that the exclusive criteria of GMT result in better specifications for model (3.5). Table 3.9 demonstrates this fact. It shows only the coefficients of model (3.5) when there is no AR(1) problem. As expected, the model with the GMTN (index of exclusive criteria of GMT) is much better than the CWNN (index of exclusive criteria of CWN). In the CWNN specifications, there is no truly significant value for the coefficient of the interactive term, but in the GMTN specifications, all coefficients of interactive term are right and significant at the 5% level. Moreover, tables 3.6 and 3.9 show that the GMTN specifications are more significant than the GMT specifications whereas the CWNN models are weaker than the CWN ones.

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[12] To calculate real oil price, I have used the consumer price index for the world published by International Financial Statistics.

[13] Another variable can be used instead of (real) oil price is oil income.

Table 3.9. Model (3.22) with exclusive criteria of CWN and GMT

	CWNN is the CBI index			GMTN is the CBI index		
	All countries	OPEC	Non-OPEC	All countries	OPEC	Non-OPEC
$O_{2i,t-1}$	0.88	0.44	6.01	0.98	-0.45	9.10
	(0.62)	(0.22)	(8.62)**	(0.70)	(-0.22)	(10.90)**
$\pi_{i,t-1}$	-0.19	0.05	-0.16	-0.19	0.06	-0.19
	(-1.98)**	(0.23)	(-1.91)**	(-1.99)**	(0.26)	(-2.25)**
$\pi_{i,t-2}$	0.15	0.58	-1.40	0.16	0.58	-1.35
	(1.58)	(2.43)**	(-11.19)**	(1.61)	(2.48)**	(-10.72)**
$\pi_{i,t-3}$	-0.37	-0.80	0.81	-0.37	-0.80	-0.79
	(3.96)**	(-3.47)**	(11.13)**	(-3.97)**	(-3.52)**	(-10.65)**
$O_{2i,t-1}I_{2i}$	-13.87	-55.84	68.00	-10.64	-19.08	-18.93
	(-0.54)	(-1.57)	(5.32)**	(-2.07)**	(-2.60)**	(-6.56)**
ρ	0.90	0.89	0.73	0.90	0.89	0.73
	(70.60)**	(59.39)**	(20.03)**	(70.80)**	(59.51)**	(20.01)**
R^2	0.87	0.85	0.92	0.87	0.85	0.92
D-W test	2.29	2.35	2.04	2.29	2.35	2.02
$p - \text{value}\ (\alpha)$	0.32	0.52	0.00	0.32	0.52	0.00

The table shows the coefficients with t-statistics in parentheses. * and ** illustrate statistical significance at the 10% and 5%, respectively.

Table 3.10.Total effect of oil price

	Model (3.5)					
	CWN is the CBI index			GMT is the CBI index		
	All countries	OPEC	Non-OPEC	All countries	OPEC	Non-OPEC
Iran	2.91	2.08		3.55	2.37	
	(2.10)	(0.58)		(2.87)*	(0.79)	
Kuwait	2.00	3.32		2.09	3.41	
	(1.93)	(2.84)*		(2.09)	(2.96)*	
Nigeria	1.72	3.71		2.09	3.41	
	(1.36)	(3.24)*		(2.09)	(2.96)*	
Saudi Arabia	3.25	1.62		3.91	2.11	
	(1.87)	(0.24)		(2.75)*	(0.49)	
UAE	1.59	3.88		2.09	3.41	
	(1.10)	(3.25)*		(2.09)	(2.96)*	
Venezuela	0.45	5.44		-0.47	5.22	
	(0.03)	(2.03)		(0.03)	(1.60)	
Mexico	0.67		2.91	-0.47		-0.11
	(0.08)		(2.08)	(0.03)		(0.00)
Norway	3.32		4.87	2.82		6.59
	(1.83)		(4.55)**	(2.88)*		(12.96)**
Russia	1.87		3.80	2.45		5.63
	(1.68)		(7.76)**	(2.62)*		(12.87)**

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Table 3.10 (continued)

	Model (3.22)					
	CWN is the CBI index			GMT is the CBI index		
	All countries	OPEC	Non-OPEC	All countries	OPEC	Non-OPEC
Iran	1.89	3.63		3.12	4.24	
	(0.95)	(1.84)		(2.42)	(2.63)*	
Kuwait	0.90	0.51		0.98	0.15	
	(0.41)	(0.07)		(0.49)	(0.01)	
Nigeria	0.59	-0.47		0.98	0.15	
	(0.16)	(0.05)		(0.49)	(0.01)	
Saudi Arabia	2.26	4.80		3.65	5.27	
	(0.96)	(2.25)		(2.63)*	(3.17)*	
UAE	0.46	-0.88		0.98	0.15	
	(0.09)	(0.16)		(0.49)	(0.01)	
Venezuela	-0.79	-4.81		-2.75	-7.01	
	(0.09)	(1.58)		(1.03)	(2.60)	
Mexico	-0.54		6.34	-2.75		1.30
	(0.05)		(36.04)**	(1.03)		(1.30)
Norway	2.33		6.27	2.05		9.72
	(0.96)		(27.88)**	(1.66)		(103.72)**
Russia	0.76		6.31	1.52		8.78
	(0.28)		(77.83)**	(1.07)		(106.79)**

The table shows the coefficients with F-statistics in parentheses. * and ** illustrate statistical significance at the 10% and 5%, respectively.

Although it cannot be ignored that the exclusive criteria are only a part of each CBI index and they are not as comprehensive as original indices and thus the estimates cannot be interpreted, table 3.9 illustrates that the exclusive criteria of GMT create a superior model and because of them the CWN model is dominated by the GMT one.

Another factor that can be identified from tables 3.5 and 3.6 is that the model of the Non-OPEC countries is better than the model of the OPEC economies or all countries. All tests improve from the all countries column to the Non-OPEC one. In table 3.5, R^2 for the Non-OPEC models is more than two times that of other models and in table 3.6 the greatest R^2 is for the Non-OPEC countries. The D-W test also shows a weaker autocorrelation in the Non-OPEC countries compared to the other models in table 3.5. Table 3.6 also illustrates that the D-W test for the Non-OPEC models is very close to 2. In table 3.6 when $p-value\,(\alpha)$ is not zero for the other models, it is zero only for the Non-OPEC economies.

Hence, it appears reasonable that, if one compares the last column in table 3.6 with other columns, it will be concluded that the GMT model with the Non-OPEC countries is the best model. All coefficients are right and significant at the 5% level; individual intercepts are also significant at this level and R^2, D-W test and $p-value\,(\alpha)$ reject any misspecification.

Therefore, it was demonstrated that the coefficient of the interactive term is negative in model (3.5); i.e. the higher the central bank independence, the more contractionary (or less expansionary) monetary policy after an oil shock.

Moreover, one can analyse the total effect of oil price on monetary policy. It is the point illustrated in table 3.10. Table 3.10 shows that the total influence of oil price on real money for each individual in the panel data model and indicates which one is significant. The total effect from model (3.5) is:

$$\frac{\partial M_{i,t}}{\partial O_{i,t-1}} = \beta_{21} + \gamma_{21} I_{2i}.$$

In other words, it is the main effect plus the influence through the CBI index. It is calculated for models (3.5) and (3.22) when there is no first autocorrelation problem.

F-statistic which is mentioned in table 3.10 simply emerges from comparing restricted and unrestricted forms of the model. To clarify it, suppose the null hypothesis is:

$$H_0: \quad \frac{\partial M_{i,t}}{\partial O_{i,t-1}} = \beta_{21} + \gamma_{21} I_{2i} = 0$$

and SSR_R is the restricted residual sum of squares; i.e., the sum of squares of residuals under the null hypothesis and SSR_U is the unrestricted residual sum of squares when the null hypothesis is not imposed. Hence F-statistic can be written as:

$$\frac{(SSR_R - SSR_U)/r}{SSR_U/(n-K)} \sim F_{r,n-K},$$

where r is the number of restrictions which is 1, n is total pool observations which is $T.N = (132)9 = 1188$ when all countries are in the model, and K is the number of regressors with individual intercepts (i.e. 5+9=14) . If the model had no identical slope coefficients, to calculate K, the number of regressors should be multiplied by the number of individuals. Thus F distribution has 1 and 1174 degrees of freedom for the column of all countries in table 3.10.

Table 3.10 demonstrates that most signs and all significant values are positive; i.e. oil price has a positive impact on real money. This appears reasonable because most countries in the sample have relatively dependent central banks and money increases when oil price goes up in this condition. This happens because the dominated central bank follows the government's goal.

If one concentrates on table 3.10, it is clear that the countries with less central bank Independence are more likely to have a positive sign which is statistically significant. CWN and GMT proxies show that Mexico and Venezuela have the highest CBI, but none of them has a significantly positive value.

In the GMT model which was described as the best model, the countries with the least CBI indicate a significantly positive relationship between oil price and real money. In model (3.5) out of all countries in the sample, Iran, Saudi Arabia, Norway and Russia which have the least GMT, have a significant sign. However in the OPEC column, Kuwait, Nigeria and UAE show significant sign; in the Non-OPEC case, Mexico, which is labelled with the highest GMT does not have a significant coefficient, but Norway and Russia illustrate a positive value which is significant at the level of 5%. Moreover, in the GMT model when the AR(1) problem is eliminated (model (3.22)), only Iran, Saudi Arabia, Norway and Russia, whose GMT values are least, show a significantly positive value.

Hence, it can be concluded that, when central banks are dependent, after an oil shock, real money will increase, which means that they implement expansionary monetary policy (table 3.10 illustrates this); however, countries with more CBI have less expansionary monetary policy (tables 3.5 and 3.6 show this).

3.6. Conclusions

In this chapter, it has been shown that central bank independence plays a crucial role in monetary policy in oil-exporting countries. Since these economies generally suffer from less central bank independence, a monetary expansion emerges after an increase in oil price.

On the other hand the chapter has described that central banks which are more independent implement less expansionary monetary policy relative to countries with less central bank independence after an increase in oil price.

Appendix 3.1, CWN(1992) criteria

Central Bank Governor

Term of office

- 1.00 when longer than or equal to 8 years
- 0.75 when between 6 years and less than 8 years
- 0.5 when equal to 5 years
- 0.25 when equal to 4 years
- 0.00 when smaller than 4 years

Who appoints

- 1.00 when appointed by CB Board
- 0.75 when appointed by legislative and executive branches of Government and by CB board
- 0.5 when appointed by legislative branch
- 0.25 when appointed by executive branch
- 0.00 when appointed by 1 or 2 members of executive branch

Dismissal

- 1.00 when not provided for
- 0.83 when possible only for nonpolicy reasons
- 0.67 when unconditionally possible by CB Board
- 0.50 when conditionally possible by legislative branch
- 0.33 when unconditionally possible by legislative branch
- 0.17 when conditionally possible by executive branch
- 0.00 when unconditionally possible by executive branch

Other responsibility

- 1.00 when prohibited
- 0.50 when subjected to approval by executive branch
- 0.00 when not prohibited

Central Bank primary objective

Price stability

- 1.00 when only objective and CB has only authority
- 0.80 when only objective
- 0.60 when other non-conflicting objectives
- 0.40 when other conflicting objectives
- 0.20 when no objectives in CB charter
- 0.00 when only other objectives in CB charter

Policy Formulation

Who formulates monetary policy

- 1.00 when granted to CB alone
- 0.67 when granted to both CB and Government
- 0.33 when CB's capacity only advisory
- 0.00 when granted to Government only

Conflict resolution

- 1.00 when attributed to CB for CB's objectives
- 0.80 when attributed to Government only for non-objectives
- 0.60 when attributed to CB Board, legislative and executive branches of Government
- 0.40 when unconditionally attributed to legislative branch
- 0.20 when conditionally attributed to executive branch
- 0.00 when unconditionally attributed to executive branch

Policy Formulation

Central Bank role government Budge

- 1.00 when active role for CB
- 0.00 when no active role for CB

Central Bank Lending

Limits in advances to government

- 1.00 when no advances permitted
- 0.67 when permitted with strict limits
- 0.33 when permitted with accommodative limits
- 0.00 when unlimited

Limits in loans to governr

- 1.00 when not permitted
- 0.67 when permitted with strict limits
- 0.33 when permitted with accommodative limits
- 0.00 when unlimited

Who decides terms of Lendin

- 1.00 when controlled by CB
- 0.67 when specified by the CB charter
- 0.33 when agreed between CB and executive
- 0.00 when decided by executive branch

Beneficiaries

- 1.00 when only for central Government
- 0.67 when for all levels of Government
- 0.33 when all of the above and public firm
- 0.00 when all of the above and private sector

Type of Limits

- 1.00 when absolute cash amount
- 0.67 when percentage of CB capital
- 0.33 when percentage of Government revenues
- 0.00 when percentage of Government expenditures

Maturity of Loans

- 1.00 when limited to 6 months
- 0.67 when limited to 12 months
- 0.33 when limited to more than 12 months
- 0.00 when unlimited

Restrictions on interest rate

- 1.00 when must be at market level
- 0.75 when cannot be lower than a certain floor
- 0.50 when cannot be higher than a certain ceiling
- 0.25 when not restricted
- 0.00 when no interest payment required

Prohibition lending to government

- 1.00 when CB prohibited from buying or selling government securities in the primary market
- 0.00 when CB permitted to buy or sell government securities in the primary market

CHAPTER FOUR

Impact of Oil Price in a Time Varying VAR Model for Monetary Policy

4.1. Introduction

Recent studies show that linear vector autoregression (VAR) specifications cannot describe sufficiently the dynamic process of economic time series (see for example Granger and Teräsvirta, 1993, Stock and Watson, 1996, Frances and van Dijk, 2000, van Dijk et al., 2002, Camacho, 2004 and Christopoulos and León-Ledesma, 2008) and researchers have been trying to design nonlinear models in order to explain and forecast the behaviour of variables. In this regard, models in which the behaviour of time series depends on the state of the system have become popular. The smooth transition model is one of those regime switching models that will be used in this chapter to construct a VAR model for monetary policy in which coefficients are varying over time.

The main incentive to use the time varying model, instead of a constant-coefficients one, is that variables can show their possible asymmetric effects. In other words, this model can investigate whether variables have different influences during periods of recession and boom. Some papers, for example Thoma (1994), Weise (1999), Garcia (2002), Chien and Piger (2005) and Christopoulos and León-Ledesma (2008), illustrate that monetary policy impact on macroeconomic indicators depends on the state of the economy in the business cycle. Moreover, although there is some evidence to support the asymmetric effect of oil price in an oil-importing country (see for example Hamilton, 1996 and Jimenez-Rodriguez and Sanchez, 2005), to the author's knowledge, it has not been investigated in an oil-exporting economy. Hence, the chapter contributes to the asymmetric effect literature demonstrating effects of monetary policy and oil price in an oil-exporting country through a time varying VAR model.

There is a strong base of literature about impact of oil price on an economy. Although these results are usually opposite in oil-importing and exporting countries, no one can ignore them in analysing economic activities. The model indicates how oil price can affect monetary policy in an oil-exporting economy and alter the central bank's effect on inflation. Oil-exporting countries usually suffer from *oil dominance* (Da Costa and Olivo, 2008) which means that macroeconomic indices are influenced by oil exports. Thus, coefficients in the model depend on oil price to show oil dominance.

Moreover, some authors, such as Beaudry and Koop (1993), Thoma (1994), Diebold and Rudebusch (1996), Kim and Nelson (1998), Chauvet (1998, 1999), Weise (1999), Fukuda and Onodera (2001), Chauvet and Potter (2002) and Kim and Murray (2002) exploit the economy's state in a regime switching model to show asymmetries, and most of them use the growth rate of real output. Oil price, however, can be interpreted as a yardstick of recession and expansion in an oil-based economy. In this regard, a high level of oil price means a high level of income for an oil-based country and it presages a boom, however, a low level of oil price indicates a recession. Oil price, therefore, is used as the transition variable and a threshold is determined to distinguish the position of the economy in the business cycle.

This chapter proposes a time varying VAR model in which parameters are subject to a smooth structural change. A logistic smooth transition (LSTR) function which is a subset of smooth transition regression (STR) is used to depict the time varying characteristic of coefficients. The STR model was initially developed by Teräsvirta and Anderson (1992), Granger and Teräsvirta (1993), Teräsvirta (1994), Teräsvirta (1998) and Potter (1999) for a single equation model. However, Camacho (2004) and Christopoulos and León-Ledesma (2008) have extended it to a multiple equation model, and Camacho (2004) has called it the vector smooth transition regression (VSTR).

This model has several characteristics to investigate economic behaviours. Firstly, the transition between two regimes is smooth. Secondly, the threshold level which is the changing point is determined by the data. Thirdly, the null hypothesis of the model is a linear VAR. Fourthly, because a linear VAR model is considered under the null hypothesis, the model has a standard distribution.

Another advantage of the model is that it has more power to forecast compared to linear models. Many studies have indicated this; for instance, Teräsvirta and Anderson (1992), Teräsvirta (1995) and Sarantis (1999) forecast with univariate models. Then other researchers, for example Granger et al. (1993), Filardo (1994), Hamilton and Perez-Quiros (1996), Krolzig (1997, 2000), Estrella and Mishkin (1998), Blix (1999), Warne (2000), Beine et al. (2002), Camacho and Perez-Quiros (2002) and van Dijk et al. (2002), have extended the models with more economic indices and improved predictions. Finally, some authors have applied the nonlinear VAR and vector error correction models to forecast, such as Camacho (2004), Christopoulos and León-Ledesma (2008) and Kavkler et al. (2008).

Using a VSTR model, the thesis investigates the effectiveness of monetary policy in an oil-based economy on inflation in the business cycle. It also can test the impact of oil price on monetary policy and inflation. Furthermore, it addresses the question of whether the central bank considers inflation more during a recession, or during a period of expansion. The model is based on the quarterly data over 1970-2008 for Iran.

Following Camacho (2004), the chapter also tries to extend some aspects of the single equation model of the STR to the multiple equation model (i.e. VSTR). In the section of the specification tests, the chapter proves the LM statistic suggested by Camacho (2004) for testing the error autocorrelation by a simple method and it extends the approach of estimating of parameters and their standard errors in a single equation model to a VSTR model.

An outline of the remainder of the chapter is as follows. The next section explains the VSTR and the properties of the smooth transition functions. Section 3 describes the specification methodology including tests for linearity and evaluating the adequacy of the model. Section 4 explains how to estimate the VSTR model. The empirical results are presented in section 5. The last section draws the conclusions.

4.2. The Model

Consider the following VAR(q) model:

$$\begin{bmatrix} y_t \\ x_t \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \end{bmatrix} + \begin{bmatrix} \beta_{1,11} & \beta_{1,12} \\ \beta_{2,11} & \beta_{2,12} \end{bmatrix} \begin{bmatrix} y_{t-1} \\ x_{t-1} \end{bmatrix} + \cdots + \begin{bmatrix} \beta_{1,q1} & \beta_{1,q2} \\ \beta_{2,q1} & \beta_{2,q2} \end{bmatrix} \begin{bmatrix} y_{t-q} \\ x_{t-q} \end{bmatrix} + \begin{bmatrix} e_{1t} \\ e_{2t} \end{bmatrix} \qquad (4.1)$$

where $\{e_{1t}\}$ and $\{e_{2t}\}$ have zero means, constant variances and are individually serially distributed. The coefficients in the VAR are not constant and vary over time. They follow a smooth transition function so that the model is called the vector smooth transition regression (VSTR):

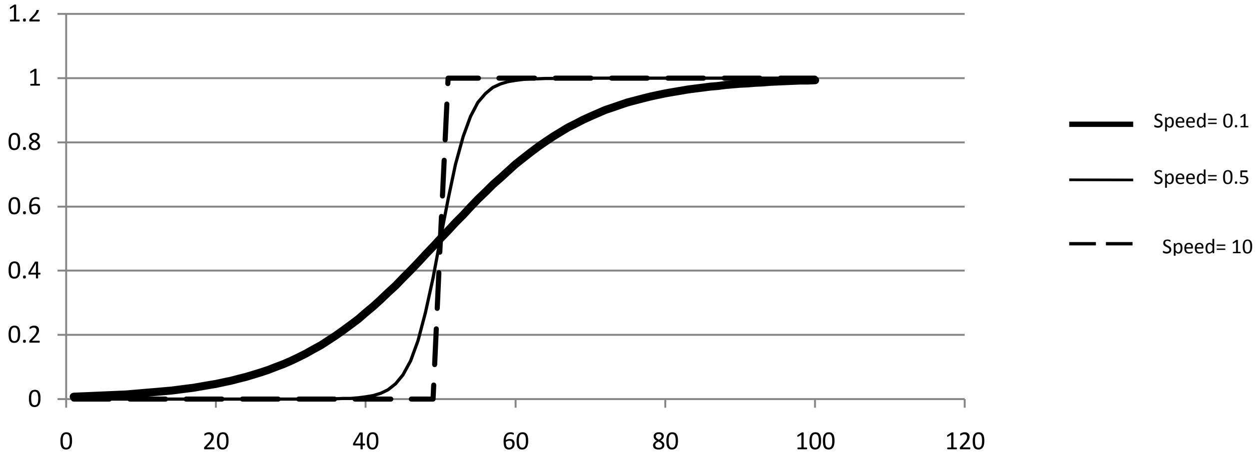
$$\beta_{1,ij} = \beta_{1,ij}{}^{*} + \beta_{1,ij}{}^{**}.F_1(\tau_1, c_1, z_t) = \beta_{1,ji}{}^{*} + \beta_{1,ji}{}^{**}(1 + \exp(-\tau_1(z_t - c_1)))^{-1}$$

$$\beta_{2,ij} = \beta_{2,ij}{}^{*} + \beta_{2,ij}{}^{**}.F_2(\tau_2, c_2, z_t) = \beta_{2,ij}{}^{*} + \beta_{2,ij}{}^{**}(1 + \exp(-\tau_2(z_t - c_2)))^{-1} \quad (4.2)$$

where $F_1$and F_2 are continuous transition functions and bounded between 0 and 1. In this model, they are the logistic smooth transition (LSTR) function. It is possible to interpret the LSTR model in two ways. It can be considered as a regime switching framework which is associated with two extreme cases when $F_i = 0$ and $F_i = 1$ and values between these 0 and 1 show the transition between two regimes. On the other hand, it can be interpreted that the model has continuous regimes and each one is related to a value of the LSTR function. This thesis uses the first interpretation of the LSTR model.

z_t in (4.2) is the transition variable and the parameters c_1 and c_2 are thresholds between two regimes. Once the transition variable is greater (smaller) than the threshold, the transition function is greater (less) than 0.5. Alternatively, when they are equal, F_i=0.5. τ_1 and τ_2 are the speed of the change between two regimes and they are positive. When τ_i becomes greater, the LSTR function approaches 1 (0), if the transition variable is greater (smaller) than the threshold. When the transition speed approaches to zero, however, the LSTR function approximates 0.5. Finally, it is worth mentioning that if the speed is zero the LSTR model reduces to a linear model. Figure 4.1 illustrates a LSTR function with different transition speeds. To plot it, the transition variable has been determined from 1 to 100 and 50 has been chosen as the breakpoint. It can be seen that when the transition variable is equal to the threshold (=50), the transition function is 0.5 and this holds true with different transition speeds.

Figure 4.1. The LSTR function



It should be mentioned that the other transition function is the exponential smooth transition (ESTR) function:

$$F(\tau, c, z_t) = 1 - \exp(-\tau(z_t - c)^2). \tag{4.3}$$

For $z_t = c$, the value of the transition function is zero, and when the transition variable approaches positive and negative infinity, F approximates 1. Although there is a test to determine which function is suitable for the data which will be investigated in this chapter, one can nevertheless choose a smooth transition function based on theoretical issues of research. In this chapter, for example, effects of monetary policy are investigated in the business cycle; therefore a function is required to show expansions which can be done by applying the LSTR model.

4.3. Specification of the Model

4.3.1. Tests for Nonlinearity

The best nonlinear VSTR model can be achieved by a process including specification tests and this section describes the process. The first step is to investigate whether a nonlinear specification is better than a linear one. Researchers always focus on the specific test which determines a smooth transition specification against the linear model. This thesis, however, proposes to perform two tests for nonlinearity. The first one is the regression error specification test (RESET) which examines linearity against general nonlinearity, and then the specific test is performed to determine a specification from the set of smooth transition models.

Test against general nonlinearity

The RESET has been suggested for a single equation model, but it can be extended to a VAR model. The first stage is to estimate the best-fitting linear VAR which is chosen by the Akaike or Schwartz criteria, and find residuals and fitted values. Using (4.1), one can estimate:

$$e_{1t} = \boldsymbol{\delta w_t} + \sum_{i=1}^{H} \theta_{1i} \hat{y}_t^{\,i+1} + \zeta_{1t}$$

$$e_{2t} = \boldsymbol{\delta w_t} + \sum_{i=1}^{H} \theta_{2i} \hat{x}_t^{\,i+1} + \zeta_{2t} \qquad (4.4)$$

where e_{1t} and e_{2t} are the residuals from the linear VAR, $\boldsymbol{w_t}$ is the vector of right-hand side variables of (4.1), $\hat{y}_t$ and $\hat{x}_t$ are fitted values and $H \geq 1$. Now, one can reject the linear VAR, if the following null hypothesis is rejected:

$$H_0: \quad \theta_{11} = \theta_{12} = \cdots = \theta_{21} = \theta_{22} = \cdots = 0.$$

Imposing this restriction on system (4.4), the Wald statistic having a χ^2 distribution with degrees of freedom equal to restrictions can be used to see whether the restriction is binding or not.

Test against the VSTR

The null hypothesis of linearity in (4.1) can be $H_0: \beta_{1,ij}{}^{**} = \beta_{2,ij}{}^{**} = 0$, so the coefficients of model (4.1) will be independent over time. As first explained by Davies (1977), however, there is the problem of unidentified nuisance parameters under the null, and parameters τ_i and c_i are unidentified. Therefore, Luukkonen et al. (1988) and Saikkonen and Luukkonen (1988) in a single equation model, and Camacho (2004) in a multiple equation model, suggest using a Taylor approximation of model (4.1) around $\tau_i = 0$. Hence, to examine the existence of the VSTR, the following auxiliary regressions should be estimated:

$$y_t = \alpha_{10} + \boldsymbol{\alpha'_{11} X_t} + \boldsymbol{\alpha'_{12} X_t} z_t + \boldsymbol{\alpha'_{13} X_t} {z_t}^2 + \boldsymbol{\alpha'_{14} X_t} {z_t}^3 + \epsilon_{1t}$$

(4.5)

$$x_t = \alpha_{20} + \boldsymbol{\alpha'_{21} X_t} + \boldsymbol{\alpha'_{22} X_t} z_t + \boldsymbol{\alpha'_{23} X_t} {z_t}^2 + \boldsymbol{\alpha'_{24} X_t} {z_t}^3 + \epsilon_{2t}$$

where $\boldsymbol{X}_t' = (y_{t-1}, x_{t-1}, \dots, y_{t-q}, x_{t-q})$ and z_t is the transition variable. It is clear that the linear VAR can be accepted if this null hypothesis is not rejected:

$$H_0: \quad \boldsymbol{\alpha}_{i2}' = \boldsymbol{\alpha}_{i3}' = \boldsymbol{\alpha}_{i4}' = \mathbf{0}. \tag{4.6}$$

(4.5) has not the identification problem and a Lagrange Multiplier (LM) statistic with an asymptotic χ^2 distribution can be applied. Degrees of freedom are again equal to restrictions; for example in (4.5), given (4.6), the LM statistic has 12q degrees of freedom.

The auxiliary regressions also determine which transition function has to be used and the decision criterion is based on the order of the polynomial. A sequence of nested hypotheses can specify the order of (4.5):

$$\begin{aligned} &H_{04}: \boldsymbol{\alpha}_{i4} = \mathbf{0} \\ &H_{03}: \boldsymbol{\alpha}_{i3} = \mathbf{0} | \boldsymbol{\alpha}_{i4} = \mathbf{0} \\ &H_{02}: \boldsymbol{\alpha}_{i2} = \mathbf{0} | \ \boldsymbol{\alpha}_{i4} = \boldsymbol{\alpha}_{i3} = \mathbf{0}. \end{aligned} \tag{4.7}$$

To find the appropriate model, one has to calculate the LM statistics for each hypothesis in (4.7). The strongest rejection determines which smooth transition function is suitable for the data. If the strongest rejection is for H_{04} or H_{02}, then the logistic function should be applied for the VSTR; this is called a logistic vector smooth transition regression (LVSTR) model. When H_{03}, has the strongest rejection the exponential function is appropriate. Teräsvirta (1998) proposes that rejection of H_{03} mentions that the ESTR function or the

LSTR with two thresholds (c_i^1 and c_i^2) are suitable and if the null hypothesis $c_i^1 = c_i^2$ cannot be rejected the exponential function is selected. [1]

To obtain the LM statistic, first the sum of squared residuals under the null hypothesis is calculated (SSR_0). Then, the model under the alternative is estimated and the residuals and the sum of squared of them (SSR_1) are computed. Therefore, the LM statistic becomes:

$$LM = \frac{T(SSR_0 - SSR_1)}{SSR_0},$$

where, T is the number of observations. It is worth noting that the F version of the LM statistic is suggested in small samples. One can also calculate the LM statistic by computing TR^2 from the regression of the residuals under the null on the auxiliary regressors:

$$\epsilon_{1t} = \boldsymbol{\alpha}'_{32}\boldsymbol{X_t}z_t + \boldsymbol{\alpha}'_{33}\boldsymbol{X_t}{z_t}^2 + \boldsymbol{\alpha}'_{34}\boldsymbol{X_t}{z_t}^3 + \mu_{1t}$$

$$\epsilon_{2t} = \boldsymbol{\alpha}'_{42}\boldsymbol{X_t}z_t + \boldsymbol{\alpha}'_{43}\boldsymbol{X_t}{z_t}^2 + \boldsymbol{\alpha}'_{44}\boldsymbol{X_t}{z_t}^3 + \mu_{2t}.$$

As indicated, there should be a theoretical reason to choose one form of the STR functions or the nested hypotheses are performed. In this chapter, the LVSTR model is selected based on the theoretical and empirical reasons.

Teräsvirta (1998) also suggests this heuristic specification method for selecting the transition variable. While the transition function is determined, the linearity test is implemented with different possible transition variables and the strongest rejection shows

[1] The form of this LSTR function is: $F(\tau, c^1, c^2, z_t) = (1 + exp(-\tau(z_t - c^1)(z_t - c^2)))^{-1}$

the true transition variable. Researchers usually choose different lags of the endogenous variable and select the one with the best the heuristic specification strategy. If there is, however, a prior reason to select a variable, there will be no need to carry out the strategy. This chapter selects the transition variable based on a theoretical reason. As the model belongs to an oil-based country and it tries to figure out the relationship between monetary policy and inflation in two different regimes with high and low oil price, oil price will be elected as the transition variable. Furthermore, these regimes can be interpreted as expansion and recession.

4.3.2. Testing No Error Autocorrelation

Eitrheim and Teräsvirta (1996) suggest three tests to check the adequacy of the model. They are tests for no error autocorrelation, no remaining nonlinearity and parameter constancy. Camacho (2004) has developed them for a VSTR model.

Camacho (2004) considers a bivariate system to explain the error autocorrelation test, this thesis, however, extends it to a multivariate system and tries to achieve the LM statistic in a simpler method than Camacho's. Suppose a VSTR model:

$$\boldsymbol{Y_t} = G(\boldsymbol{A_t}, \propto, \boldsymbol{\Psi}) + \boldsymbol{U_t} \tag{4.8}$$

$$\boldsymbol{U_t} = \boldsymbol{\Phi}'\boldsymbol{V_t} + \boldsymbol{\varepsilon_t}, \qquad \boldsymbol{\varepsilon_t} \sim N[\boldsymbol{0}, \boldsymbol{\Omega}]$$

where $\boldsymbol{U_t} = (u_{y1t}, \dots u_{ynt})'$, $\boldsymbol{Y_t} = (y_{1t}, \dots, y_{nt})'$, $G(\boldsymbol{A_t}, \propto, \boldsymbol{\Psi}) = (G_{y1}(\boldsymbol{A_t}, \propto_{y1}, \boldsymbol{\Psi}_{y1}), \dots,$ $G_{yn}(\boldsymbol{A_t}, \propto_{yn}, \boldsymbol{\Psi}_{yn}))'$, $G_{yi}(\boldsymbol{A_t}, \propto_{yi}, \boldsymbol{\Psi}_{yi}) = \propto_{yi} + (\boldsymbol{\beta_i}^* + \boldsymbol{\beta_i}^{**} F_i(\tau_i, c_i, z_t))' \boldsymbol{A_t}$, $\boldsymbol{A_t} = (y_{1,t-1}, y_{2,t-1}, \dots, y_{n-1,t-q}, y_{n,t-q})'$. Moreover, $\boldsymbol{V_t}$ is an $nr \times 1$ matrix: $\boldsymbol{V_t} = (\boldsymbol{v}_{y1t}, \dots, \boldsymbol{v}_{ynt})'$ and $\boldsymbol{v}_{it} = (u_{i,t-1}, \dots, u_{i,t-r})$. $\boldsymbol{\Psi}_{yi} = (\boldsymbol{\beta_i}^*, \boldsymbol{\beta_i}^{**}, \tau_i, c_i)$ is the vector of coefficients for each regression in the VSTR model and each block of $\boldsymbol{\Phi'}$ is $\boldsymbol{\Phi'}_{ij} = (\Phi_{ij}^1, \dots, \Phi_{ij}^r)$, where $i, j = y_1, \dots, y_n$, so $\boldsymbol{\Phi}$ is an $nr \times n$ matrix. As it can be seen, errors in (4.8) are assumed to depend on their lags until r periods. One can also suppose $\boldsymbol{\theta} = (\propto, \boldsymbol{\Psi})$ to show all parameters in the VSTR and for each regression we have $\boldsymbol{\theta}_{yi} = (\propto_{yi}, \boldsymbol{\Psi}_{yi})$. To prove uncorrelated errors, the null hypothesis which is H_0: $\boldsymbol{\Phi} = \boldsymbol{0}$, should not be rejected. The LM statistic is obtained from the likelihood function of (4.8). Replacing $\boldsymbol{\Phi' V_t} + \boldsymbol{\varepsilon_t}$ instead of $\boldsymbol{U_t}$ leads to the following likelihood function:

$$L = -\frac{Tn}{2}\ln(2\pi) - \frac{\mathrm{T}}{2}\ln|\boldsymbol{\Omega}| - \frac{1}{2}\sum(\boldsymbol{\varepsilon_t}'\boldsymbol{\Omega}^{-1}\boldsymbol{\varepsilon_t}). \tag{4.9}$$

As we have two groups of unknown parameters ($\boldsymbol{\Phi}$ and $\boldsymbol{\theta}$) and the null restriction is only for one of them, I follow Breusch and Pagan (1980) to derive the LM statistic. They prove the LM statistic is:

$$LM = \tilde{L}_{\boldsymbol{\Phi}}' \left(\tilde{L}_{\boldsymbol{\Phi\Phi}} - \tilde{L}_{\boldsymbol{\Phi\theta}} \tilde{L}_{\boldsymbol{\theta\theta}}^{-1} \tilde{L}_{\boldsymbol{\theta\Phi}}'\right)^{-1} \tilde{L}_{\boldsymbol{\Phi}}, \tag{4.10}$$

where ~ denotes the maximum likelihood estimate, $\tilde{L}_{\boldsymbol{\Phi}} = \partial L/\partial \boldsymbol{\Phi}$, $\tilde{L}_{\boldsymbol{\Phi\Phi}} = -\,\partial^2 L/\partial \boldsymbol{\Phi}\, \partial \boldsymbol{\Phi'}$, $\tilde{L}_{\boldsymbol{\Phi\theta}} = \tilde{L}_{\boldsymbol{\theta\Phi}} = -\,\partial^2 L/\partial \boldsymbol{\Phi}\, \partial \boldsymbol{\theta'}$ and $\tilde{L}_{\boldsymbol{\theta\theta}} = -\,\partial^2 L/\partial \boldsymbol{\theta}\, \partial \boldsymbol{\theta'}$. Given $\boldsymbol{\varepsilon_t} = \boldsymbol{U_t} - \boldsymbol{\Phi' V_t}$ and the matrix differentiation rules, there is the $n^2 r \times 1$ matrix:[2]

$$\tilde{L}_{\boldsymbol{\Phi}} = \partial L/\partial \boldsymbol{\Phi} = \sum (\widetilde{\boldsymbol{\Omega}}^{-1}\, \boldsymbol{\varepsilon}_t \otimes \widetilde{\boldsymbol{V}}_t),$$

where $\otimes$ denotes the Kronecker product. Let $\boldsymbol{S_t} = (s_{y1t}, \ldots, s_{ynt})$ and $s_{yit} = \partial G_{yi}\left(\boldsymbol{A_t}, \propto_{yi}, \boldsymbol{\Psi}_{yi}\right)/\partial\, \boldsymbol{\theta}_{yi}$; thus we have:

$$\tilde{L}_{\boldsymbol{\Phi\Phi}} = \sum (\widetilde{\boldsymbol{\Omega}}^{-1} \otimes \widetilde{\boldsymbol{V}}_t \widetilde{\boldsymbol{V}}_t')$$

$$\tilde{L}_{\boldsymbol{\Phi\theta}} = \sum (\widetilde{\boldsymbol{\Omega}}^{-1}\, \tilde{\boldsymbol{S}}_t' \otimes \widetilde{\boldsymbol{V}}_t) \qquad (4.11)$$

$$\tilde{L}_{\boldsymbol{\theta\theta}} = \sum (\tilde{\boldsymbol{S}}_t \widetilde{\boldsymbol{\Omega}}^{-1}\, \tilde{\boldsymbol{S}}_t').^{3}$$

When H_0: $\boldsymbol{\Phi} = \boldsymbol{0}$ is true, the LM statistic in (4.10) is asymptotically distributed as χ^2. Since degrees of freedom are equal to the number of parameters which are supposed to be zero under the null and $\boldsymbol{\Phi}$ has $n^2 r$ elements, the χ^2 distribution has $n^2 r$ degrees of freedom.

---

[2] The crucial rule is that, when there are three matrices (Λ, X, Y), and assuming matrix dimensions coincide, we have: $\frac{\partial}{\partial \Lambda}(X \times Y) = \frac{\partial X}{\partial \Lambda} \times (I_k \otimes Y) + X \times \frac{\partial Y}{\partial \Lambda}$, where k is the number of columns for Λ.

[3] To see whether matrix dimensions coincide, it is worth noting that $\tilde{\boldsymbol{L}}_{\boldsymbol{\Phi\Phi}}$ is an $\mathrm{n^2 r \times n^2 r}$ matrix, and since $\boldsymbol{S_t}$ is $2(\mathrm{q}+1) \times \mathrm{n}$, dimensions of $\tilde{\boldsymbol{L}}_{\boldsymbol{\Phi\theta}}$ are $\mathrm{n^2 r} \times 2(\mathrm{q}+1)$ and $\tilde{\boldsymbol{L}}_{\boldsymbol{\theta\theta}}$ is a $2(\mathrm{q}+1) \times 2(\mathrm{q}+1)$ matrix. Thus, dimensions of $\tilde{L}_{\boldsymbol{\Phi}}' \left(\tilde{L}_{\boldsymbol{\Phi\Phi}} - \tilde{L}_{\boldsymbol{\Phi\theta}} \tilde{L}_{\boldsymbol{\theta\theta}}^{-1} \tilde{L}_{\boldsymbol{\theta\Phi}}'\right)^{-1} \tilde{L}_{\boldsymbol{\Phi}}$ are $\mathrm{n^2 r \times n^2 r}$ and the LM statistic is a number.

4.3.3. Testing No Remaining Nonlinearity

This test is similar to the test applied for investigating the null of linearity in part 3.1, so the identification problem occurs one more time and it is necessary to use the Taylor series approximation. Thus, to assess remaining nonlinearity, the following regressions should be estimated:

$$y_t = \alpha_{10} + \boldsymbol{\beta_1}'\boldsymbol{X_t} + \boldsymbol{\alpha}'_{\boldsymbol{12}}\boldsymbol{X_t}z_t + \boldsymbol{\alpha}'_{\boldsymbol{13}}\boldsymbol{X_t}{z_t}^2 + \boldsymbol{\alpha}'_{\boldsymbol{14}}\boldsymbol{X_t}{z_t}^3 + e_{1t}$$

$$x_t = \alpha_{20} + \boldsymbol{\beta_2}'\boldsymbol{X_t} + \boldsymbol{\alpha}'_{\boldsymbol{22}}\boldsymbol{X_t}z_t + \boldsymbol{\alpha}'_{\boldsymbol{23}}\boldsymbol{X_t}{z_t}^2 + \boldsymbol{\alpha}'_{\boldsymbol{24}}\boldsymbol{X_t}{z_t}^3 + e_{2t}$$

where $\boldsymbol{X}'_{\boldsymbol{t}} = (y_{t-1}, x_{t-1}, \dots, y_{t-q}, x_{t-q})$, $\boldsymbol{\beta_i}' = ({\boldsymbol{\beta_i}^*}' + {\boldsymbol{\beta_i}^{**}}'\boldsymbol{F_i}(\tau_i, c_i, z_t))$ and F_i is the smooth transition function. One can assert that there is no further nonlinearity, if the following null hypothesis is not rejected:

$$H_0: \ \boldsymbol{\alpha}'_{\boldsymbol{i2}} = \boldsymbol{\alpha}'_{\boldsymbol{i3}} = \boldsymbol{\alpha}'_{\boldsymbol{i4}} = \boldsymbol{0}.$$

The LM statistic is computed to investigate the null. It is obtained by TR^2 already described in the nonlinear test, but the only difference is that, the residuals deriving from the null hypothesis of no remaining nonlinearity should be regressed on the auxiliary terms and the partial derivatives of the regression under the null with respect to parameters.[4] The LM statistic has an asymptotic χ^2 distribution with the number of restrictions under the

[4] The vector of the partial derivatives is $\boldsymbol{S_t}$ defined in the previous part when n=2.

null as degrees of freedom. It is worth mentioning that a similar test can be performed to examine omission of lags from the model, as Eitrheim and Teräsvirta (1996) have asserted.

4.3.4. Testing Parameter Constancy

This test is trying to examine whether $\beta_{1,ij}{}^{*}$, $\beta_{1,ij}{}^{**}$, $\beta_{2,ij}{}^{*}$ and $\beta_{2,ij}{}^{**}$ in (4.1) are constant. Under the alternative, one may consider another STR part for each parameter; for example:

$$\beta_{1,ji}{}^{*}(t) = \beta_{1,ji}{}^{*} + \kappa_{1,ji}{}^{*}(1 + \exp\,(-\tau_{1,ji}^{*}\big(t - T_{1,ji}^{*}\big)))^{-1}.$$

Note that the transition variable is now time and the null hypothesis of parameter constancy is $H_0\colon\ \kappa_{ji}{}^{*} = 0$. To investigate the null for all parameters, the Taylor auxiliary regression is performed one more time and the LM statistic is computed as the previous tests were. The auxiliary regression is

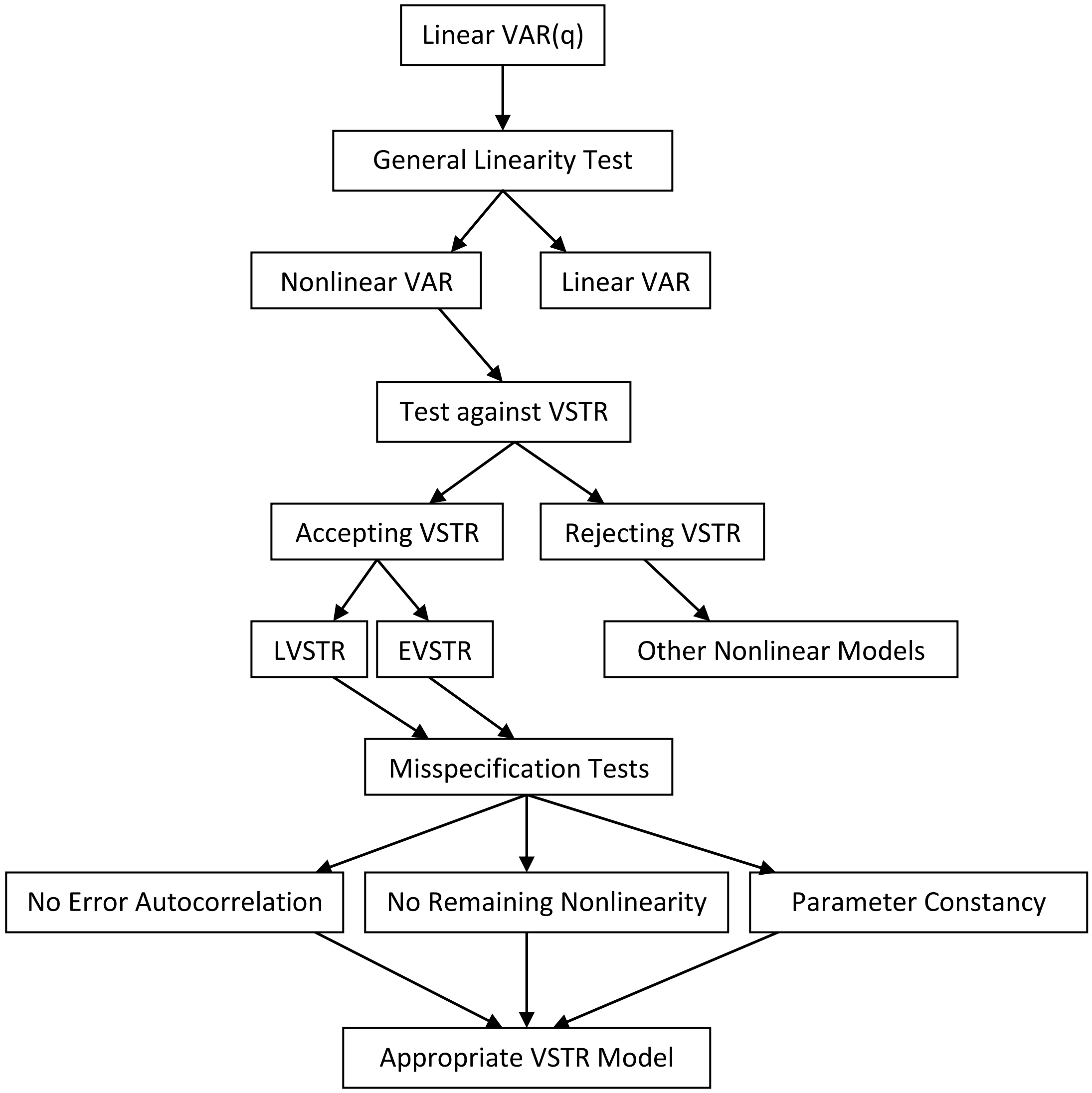
$$y_t = \alpha_{10} + \boldsymbol{\beta_{11}}'\boldsymbol{X_t} + \boldsymbol{\beta_{12}}'\boldsymbol{X_t}t + \boldsymbol{\beta_{13}}'\boldsymbol{X_t}t^2 + \boldsymbol{\beta_{14}}'\boldsymbol{X_t}t^3 + \varsigma_t$$

$$x_t = \alpha_{20} + \boldsymbol{\beta_{21}}'\boldsymbol{X_t} + \boldsymbol{\beta_{22}}'\boldsymbol{X_t}t + \boldsymbol{\beta_{23}}'\boldsymbol{X_t}t^2 + \boldsymbol{\beta_{24}}'\boldsymbol{X_t}t^3 + \varsigma_t$$

where $\boldsymbol{X_t'} = (y_{t-1}, x_{t-1}, \dots, y_{t-q}, x_{t-q})$ and $\boldsymbol{\beta_{ij}}' = (\boldsymbol{\beta_{ij}}^{*'} + \boldsymbol{\beta_{ij}}^{**'}\boldsymbol{F_i}(\tau_i, c_i, z_t))$. The null of constant parameters becomes:

$$H_0\colon\ \ \boldsymbol{\beta_{i2}}^{*'} = \boldsymbol{\beta_{i3}}^{*'} = \boldsymbol{\beta_{i4}}^{*'} = \boldsymbol{\beta_{i2}}^{**'} = \boldsymbol{\beta_{i3}}^{**'} = \boldsymbol{\beta_{i4}}^{**'} = \boldsymbol{0}.$$

Figure 4.2. The model selection



The asymptotic χ^2 distribution with the number of restrictions as degrees of freedom is also applied to assess whether the null hypothesis can be accepted or not.

Process of selecting a VSTR model

Following Camacho (2004) and regarding the linearity, identification tests and misspecification ones, a process is illustrated in figure 4.2 to obtain an appropriate VSTR model. When a linear VAR is selected, the RESET investigates the existence of any nonlinearity in the model. If the nonlinear VAR can be accepted, it is examined whether any STR function can be fitted into the data or not. If the VSTR is rejected, it means that another nonlinear VAR should be applied; otherwise the kind of STR function is determined. If a logistic function is accepted the time varying VAR model is called the LVSTR; otherwise it is an exponential smooth transition VAR model (EVSTR). Three tests introduced to evaluate the adequacy of the estimation should be carried out to reach an appropriate VSTR model. It is interesting to note that authors, in the literature of STR models, apply only a nonlinearity test against STR and if the test fails to accept the STR model, they suggest the linear VAR. This thesis, however, recommends that the STR model can be used once the linear VAR is rejected generally. Therefore, another kind of nonlinear VAR should be investigated if the null of the REST is rejected and the test for the VSTR cannot accept it.

4.4. Estimation of the Model

After the VSTR model is accepted and the transition variable and function are chosen, the model should be estimated. The parameters can be estimated by the nonlinear least squares (NLS) method. In model (4.8), when errors ($\boldsymbol{U_t}$) are assumed to be normally distributed and parameters are assumed to be as $\boldsymbol{\theta} = (\propto, \boldsymbol{\Psi})$ and $\boldsymbol{D} = (1, \boldsymbol{A_t'})'$, NLS implies:

$$\widetilde{\boldsymbol{\theta}} = \underset{\boldsymbol{\theta}}{argmin}\ Q(\boldsymbol{\theta}) = \underset{\boldsymbol{\theta}}{argmin}\ \sum q_t(\boldsymbol{\theta}) = \underset{\boldsymbol{\theta}}{argmin}\ \sum\left(\boldsymbol{Y_t} - G(\boldsymbol{D}, \boldsymbol{\theta})\right)'\left(\boldsymbol{Y_t} - G(\boldsymbol{D}, \boldsymbol{\theta})\right). \qquad (4.12)$$

The NLS estimates are tantamount to the maximum likelihood ones and when the distribution of errors is not normal, NLS is equivalent to quasi maximum likelihood. As Wooldridge (1994) describes, the NLS estimates of parameters are asymptotically normal and consistent:

$$\sqrt{T}(\widetilde{\boldsymbol{\theta}} - \overline{\boldsymbol{\theta}}) \rightarrow N(\mathbf{0}, \boldsymbol{C})$$

where $\overline{\boldsymbol{\theta}}$ is the vector of true values of parameters and $\mathbf{C}$ denotes the asymptotic covariance matrix of estimates. As Wooldridge (2002, p: 351) derives $\mathbf{C}$ in a single nonlinear regression, I extend it to a nonlinear VAR model. It is proven that $\boldsymbol{C} = \overline{\boldsymbol{H}}^{-\mathbf{1}}\overline{\boldsymbol{B}}\overline{\boldsymbol{H}}^{-\mathbf{1}}$, where $\overline{\boldsymbol{H}}$ is the expected value of Hessian of the objective function, $q_t(\boldsymbol{\theta})$.[5] Using (4.12), the Hessian matrix becomes:

$$\boldsymbol{H_t} \equiv \frac{\partial^2 q_t(\boldsymbol{\theta})}{\partial \boldsymbol{\theta} \partial \boldsymbol{\theta}'} = \nabla^2 q_t(\boldsymbol{\theta}) = \nabla G(\boldsymbol{D}, \boldsymbol{\theta})' \nabla G(\boldsymbol{D}, \boldsymbol{\theta}) - \nabla^2 G(\boldsymbol{D}, \boldsymbol{\theta}) \times [\boldsymbol{I}_p \otimes (\boldsymbol{Y_t} - G(\boldsymbol{D}, \boldsymbol{\theta}))] \quad (4.13)$$

where p illustrates the number of parameters. As $\boldsymbol{Y_t} - G(\boldsymbol{D}, \boldsymbol{\theta}) = \boldsymbol{U_t}$, the expected value of (4.13) at $\boldsymbol{\theta} = \overline{\boldsymbol{\theta}}$ will be

$$\overline{\boldsymbol{H}} = \boldsymbol{E}\left[\nabla G(\boldsymbol{D}, \overline{\boldsymbol{\theta}})' \nabla G(\boldsymbol{D}, \overline{\boldsymbol{\theta}})\right],$$

This matrix is generally positive definite. Another matrix to calculate the asymptotic covariance matrix is $\overline{\boldsymbol{B}}$ which is the variance of $\nabla q_t(\overline{\boldsymbol{\theta}})$:

[5] To drive gradients, I have divided the objective function by two, for simplicity, and if one differentiates directly, she will end up the same $\boldsymbol{C}$.

$$\overline{\boldsymbol{B}} = \boldsymbol{E}\left[\nabla q_t(\overline{\boldsymbol{\theta}})'\nabla q_t(\overline{\boldsymbol{\theta}})\right] = \boldsymbol{E}\left[\boldsymbol{U}_t'\boldsymbol{U}_t\nabla G(\boldsymbol{D},\overline{\boldsymbol{\theta}})'\nabla G(\boldsymbol{D},\overline{\boldsymbol{\theta}})\right].$$

$\overline{\boldsymbol{H}}$ and $\overline{\boldsymbol{B}}$ are not available because we have not $\overline{\boldsymbol{\theta}}$ and the distribution of $\boldsymbol{D}$, so consistent estimates of them should be applied to obtain $\boldsymbol{C}$. Replacing $\widetilde{\boldsymbol{\theta}}$ with $\overline{\boldsymbol{\theta}}$, we have:

$$\widetilde{\boldsymbol{H}} = T^{-1}\sum \boldsymbol{H}_t(\widetilde{\boldsymbol{\theta}}) \tag{4.14}$$

$$\widetilde{\boldsymbol{B}} = T^{-1}\sum \nabla q_t(\widetilde{\boldsymbol{\theta}})'\nabla q_t(\widetilde{\boldsymbol{\theta}}).$$

It is true that $\widetilde{\boldsymbol{H}}$ is available but it is not necessary to be positive definite or positive semidefinite for any sample. Thus, it may be that case that for a sample, we cannot define asymptotic standard errors and test statistics; however, this chapter has not encountered this problem.

4.5. Empirical Results

I apply a VSTR model to analyse the interaction of inflation and monetary policy in Iran, and in different regimes. As an oil-based economy, the important macroeconomic indices and the economic policies are influenced by oil price.[6] This chapter uses quarterly data over 1970q1-2008q4, including inflation (π_t) which is the consumer price percentage change per year, the annual percentage change in real money (m_t) which is money stock

[6] See, for example, Amuzegar (2008), Bonato (2008), Esfahani et al. (2009), Esfahani and Pesaran (2009) and Mojaver (2009).

Table 4.1. The regression error specification test

	χ^2-statistic	
Period	H= 2	H=3
1970:1-2008:4	7.540 (0.11)	11.383 (0.07)

Note: Values in parentheses are p-values for the null hypothesis of linearity.

adjusted by the price index and oil price (o_t).[7]

To construct the VSTR, first I construct the following linear VAR(1) model:[8]

$$\begin{bmatrix} \pi_t \\ m_t \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \end{bmatrix} + \begin{bmatrix} \beta_{11} & \beta_{12} & \beta_{13} \\ \beta_{21} & \beta_{22} & \beta_{23} \end{bmatrix} \begin{bmatrix} \pi_{t-1} \\ m_{t-1} \\ o_{t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}. \qquad (4.15)$$

Then it should be tested whether there is any evidence to support nonlinearity. Table 4.1 illustrates the results of the RESET which have already been described. This test is performed for H=2 and H=3 in (4.4). As can be seen, the null hypothesis of linearity is weak when H=2, but it is rejected for H=3. However, the RESET is a general test and it does not mention which kind of nonlinear models can be applied. To find a particular model, we have to follow the process in figure 4.2. Therefore, the next step is to test against the VSTR.

---

[7] The data have been gathered from International Financial Statistics and the US Energy Information Administration.

[8] The Schwartz criterion weakly supports the VAR(2) compared to the VAR (1) (12.12 relative to 12.16); however, as we need to forecast and the VAR(1) has more power to predict (i.e. the root mean square error of the VAR(1) is smaller), I choose VAR(1). Moreover, estimating and performing the misspecification tests for the nonlinear VAR(2) is much more complicated than the VAR(1), so the benefit of the VAR(2) is much less than its cost.

Table 4.2. Testing linearity against the VSTR model

	$H_{04}: \alpha_{i4} = 0$	$H_{03}: \alpha_{i3} = 0 \vert \alpha_{i4} = 0$	$H_{02}: \alpha_{i2} = 0 \vert \alpha_{i4} = \alpha_{i3} = 0$	VSTR Model
1970:1-2008:4	3.27603 (0.51)	2373.5842 (0.00)	2378.3270 (0.00)	LVSTR

Note: Values are LM test statistics and values in parentheses are p-values for the null hypotheses.

Table 4.2 reports the LM statistic for each null hypothesis based on (4.5). To implement the test, we need a transition variable. Hence, oil price, is used in this regard in order to distinguish conditions of the economy in the business cycle. As described in section 3.1, the degree of freedom is equal to the number of restrictions imposed by the null hypothesis. Since we have the VAR(1) model with two endogenous variables, degrees of freedom for each hypothesis is 4. Although H_{04} is not rejected, H_{03} and H_{02} are rejected. Hence, the VSTR(1) is accepted instead of the linear VAR(1). But which kind of the functions of the VSTR should be applied?

H_{02} is rejected by a larger LM statistic compared to H_{03}, so the VSTR(1) can be accepted as stronger by rejecting $\alpha_{i2} = 0$ in (4.5) and this means that the logistic function should be used in the VSTR(1); as mentioned, we call it the logistic vector smooth transition regression (LVSTR) model with order one. Thus, the coefficients in (4.15) are:

$$\beta_{1i}{}^{*} + \beta_{1i}{}^{**}(1 + \exp(-\tau_1(o_{t-1} - c_1)))^{-1}$$

$$\beta_{2i}{}^{*} + \beta_{2i}{}^{**}(1 + \exp(-\tau_2(o_{t-1} - c_2)))^{-1}.$$

Estimation results are presented in table 4.3. The first equation supports that there is a positive relationship between inflation and real money which is used as the monetary

Table 4.3. Estimation of the model

$$\hat{\pi}_t = \underset{(0.189)}{1.043} + \left(\underset{(0.015)}{0.003} + \underset{(0.009)}{0.015}\hat{F}_1\right)m_{t-1} + \left(\underset{(0.039)}{0.961} - \underset{(0.056)}{0.123}\hat{F}_1\right)\pi_{t-1} + \left(\underset{(0.071)}{0.011} + \underset{(0.074)}{0.014}\hat{F}_1\right)o_{t-1}$$

$$\hat{m}_t = \underset{(1.244)}{6.089} - \left(\underset{(0.021)}{0.159} + \underset{(0.176)}{0.149}\hat{F}_2\right)\pi_{t-1} + \left(\underset{(0.037)}{0.754} + \underset{(0.247)}{0.029}\hat{F}_2\right)m_{t-1} - \left(\underset{(0.031)}{0.071} - \underset{(0.021)}{0.063}\hat{F}_2\right)o_{t-1}$$

$$\hat{F}_1 = (1 + \exp(-\underset{(546.395)}{52.318}(o_{t-1} - \underset{(4.314)}{22.464}))^{-1}$$

$$\hat{F}_2 = (1 + \exp(-\underset{(123.204)}{10.158}(o_{t-1} - \underset{(1.708)}{36.987}))^{-1}$$

$$\sigma_{11}^2 = 2.882 \qquad \sigma_{12}^2 = -1.307 \qquad \sigma_{22}^2 = 7.464$$

Note: Standard errors are in parentheses and σ_{ij}^2 denotes elements of the variance-covariance matrix.

instrument. The effect of the monetary authority on inflation in recessions, when oil price is less than the threshold, is very small and insignificant but it becomes stronger and statistically meaningful in expansions. Table 4.4 illustrates better the change in the effect of the central bank on inflation. The impact of monetary instrument on inflation in expansions is five times its effect in recessions. It means that real money in recessions adhered by lower inflation compared to expansions, has less effect on inflation. This endorses those authors who have found the asymmetric effects of monetary policy in the business cycle, such as Weise (1999), Garcia (2002), Dufrénot et al. (2004) and Lo and Piger (2005).

It can be also asserted that the central bank does not care about inflation in recessions as much as in booms based on the second equation. As expected from the third chapter, the coefficient of inflation is negative in the second equation and the absolute value of the coefficient becomes larger in booms. In other words, the central bank pays more attention to inflation during periods of expansion. The change in the reaction of the central bank between two regimes is reported in table 4.4; it is a considerable change (93.7%).

Results also demonstrate that inflation persistence becomes smaller when the economy is in an expansion. This can be explained if we consider that, in expansions, real wages are less sticky and more flexible, so they do not induce persistence of inflation as much as in recessions. Table 4.4, however, reports that the decrease in the coefficient of the first lag of inflation is small (12.8%).

As expected in an oil-exporting country, oil price, in the model has positive effect on inflation and its influence becomes greater when oil price passes the threshold (the economy heads towards a boom). The change in the impact of oil price on inflation is 127% which shows the asymmetric effect of oil price (like money) on the economy, although the model reports insignificant coefficients for oil price. The second regression in table 4.3, however, infers that there is a negative relation between monetary policy and oil price. In other words, an increase in oil price, for the central bank, is a signal for an increase in inflation in the next period, so the monetary authority reacts to it and implements a contractionary monetary policy. Whereas we expect that this reaction intensifies when oil price is high, the model reports a smaller reaction. To explain this issue, suppose the change in the monetary base is:

$$\Delta MB = \Delta NA_F + \Delta(A_G - D_G) + \Delta NA_D,$$

where MB is the monetary base, NA_F is net foreign assets, A_G is the central bank credit to the government, D_G is deposits of the government in the central bank and NA_D is net

Table 4.4. Parameters in the business cycle

		π_{t-1}	m_{t-1}	o_{t-1}
Inflation	Recession	0.961	0.003	0.011
	Expansion	0.838	0.018	0.025
	Change	-12.8%	500%	127%
Real Money	Recession	-0.159	0.754	-0.071
	Expansion	-0.308	0.783	-0.008
	Change	93.7%	3.8%	-88.7%

domestic assets. Iran has a fixed exchange rate regime, so the government exchanges all dollars of oil income to the national currency through the central bank. When the government accumulates oil income at the central bank, there are two changes: an increase in NA_F and D_G. Therefore, there is no impact on the monetary base. The monetary base, however, will increase when the government spends oil income because government deposits (D_G) decrease. The higher the oil price, the greater the increase in monetary base. Hence, real money tends to be increased in expansions, which has been illustrated by a decline in the absolute value of the coefficient for oil price in the second regression.

As mentioned, the first regression implies that inflation persistence becomes weaker in expansions; however, the coefficient of the first lag of real money in the second regression increases when the economy moves to expansion. This reveals that the persistence of monetary shocks is higher and thus inflation persistence should be increased. How can this conflict be justified? First, the change in the coefficient of m_{t-1} in the second equation is very small (3.8%) and it is not statistically meaningful as the standard error of the coefficient of $\hat{F}_2$ is too high. Thus, the effect of m_{t-1} on current monetary policy does not change in the business cycle and it means that less inflation persistence is not attributed to monetary persistence. Second, it is more likely that in an expansion with high inflation,

Figure 4.3. Transition functions of the model

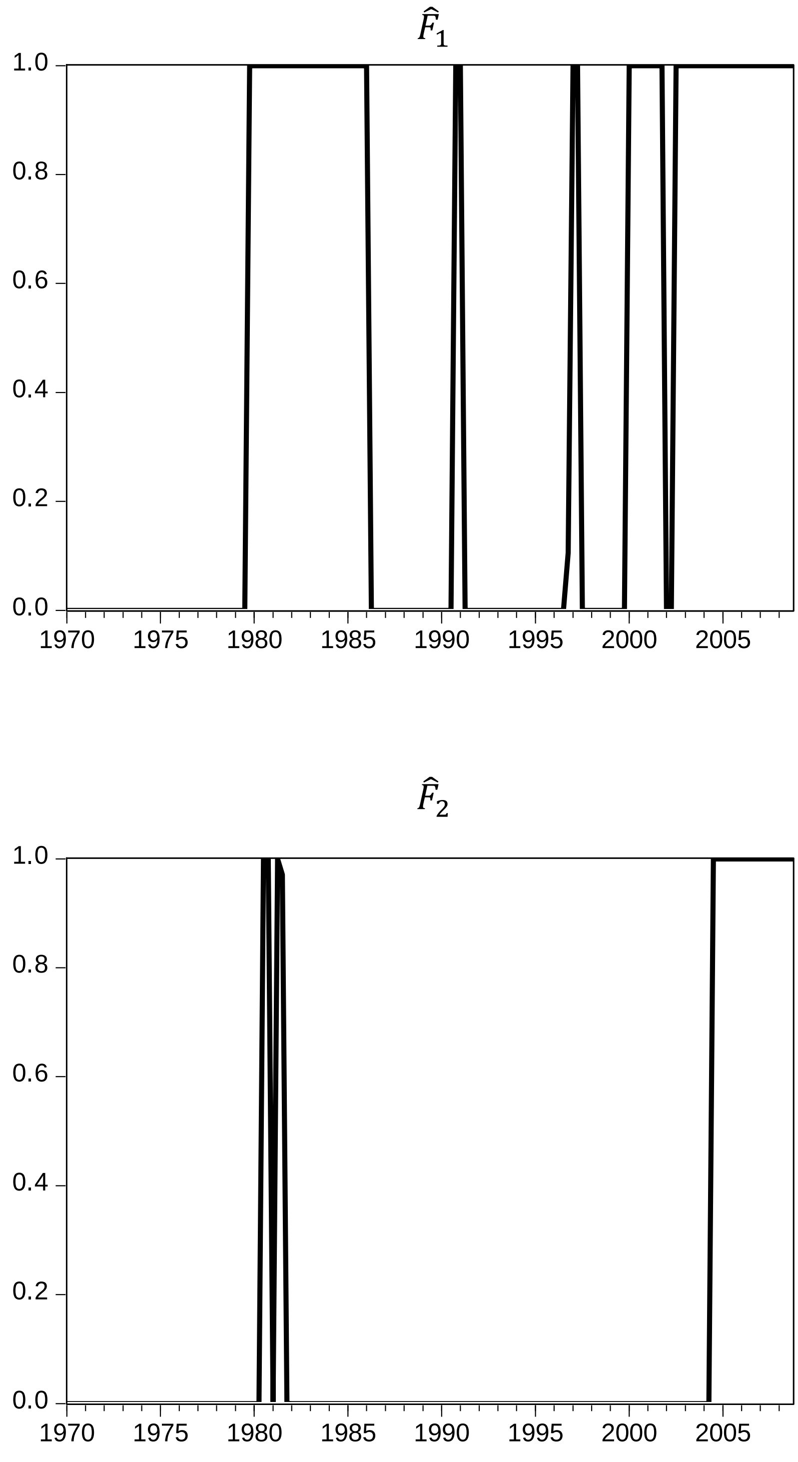


Table 4.5. Specification and diagnostic tests

	NEA Test				NRN Test	PC Test
	r=1	r=2	r=3	r=4		
LVSTR 1970:1-2008:4	0.00002	0.000018	0.000014	0.000001	0.99	0.21

Note: Values are p-values for each test and NEA, NRN and PC refer to No Error Autocorrelation, No Remaining Nonlinearity, and Parameter Constancy, respectively.

especially for Iran with two digit inflation in some years, the duration of price and wage contracts become shorter, so the shorter the duration of contracts, the lower persistence of inflation.[9] Third, when the state of the economy is in an expansion, based on the first regression, it does not mean that the central bank is also convinced that the economy is really in an expansion and treats in this regime. Hence, there is a gap between the thresholds of two regressions and they are different (i.e. 22.46 and 36.99).

It is possible -and easier- to estimate one threshold for two regressions but since the second regression tries to illustrate the manner of the monetary authority, it is reasonable to assume that the central bank does not comprehend the occurrence of the business cycle simultaneously. Therefore, it is more relevant to find different thresholds and the model shows that the monetary authority is not convinced that an expansion happens until it observes higher levels of oil price. Two thresholds lie within the boundaries of oil prices and the difference between them is not large relative to the spread of the data.[10] Figure 3 depicts the transition functions over time and since $\hat{F}_1$ has a less threshold relative to $\hat{F}_2$, the transition function of the first regression is 1 in more periods.

---

[9] There are many papers introducing causes of inflation persistence; for example, Taylor(1999), Rabanal and Rubio-Ramirez (2003) and Whelan (2007).

[10] According to the data the lowest level of oil price is \$3.31 and the highest one is \$123.96.

Table 4.6. Root mean squared forecast errors

	Forecast Periods				
	2006:1-2008:4	2007:1-2008:4	2008:1-2008:4	2008:3-2008:4	2008:4
LVSTR	1.9884107	1.4505565	0.48126422	0.55690936	0.21551425
Linear VAR	2.0035580	1.7457257	1.2026094	1.4822758	1.8171033

The values of τ_i are large and it means that the model is very similar to threshold models and changing from one regime to another is carried out quickly.[11] As Bates and Watts (1988) discuss, when the speed of transition is large, it is often statistically insignificant. However, it does not mean that the evidence of nonlinearity is weak, since t-statistic has not its common distribution and it happens because of the identification problem explained above. Moreover, whereas the effect of large changes in τ_i is very small on the transition function, it is not necessary to estimate it very accurately.

Table 4.5 presents diagnostic tests to explore whether it is appropriate to rely on the model or not. The first test rejects the null hypothesis of serially independent errors. Since the standard errors in the model are estimated with the quasi maximum likelihood covariance matrix $\boldsymbol{C}$ and it is robust, there is no concern about overestimating of t-statistics. The other two tests do not reject the nulls, so this means that the model does not suffer from the remaining nonlinearity and the estimated parameters do not depend on time.[12]

Table 4.6 reports the root mean squared forecast errors (RMS) of inflation for the time-varying and linear VAR models. The RMSs for the LVSTR are lower than the VAR

[11] See figure 4.1, when speed=10.
[12] Clearly, it does not mean that coefficients in model (4.15) are constant.

for each period. Hence, the computed forecast of the time varying model is superior to that of the linear model. Moreover, the shorter period of forecast, the larger difference between the RMSs for two models, appears. In other words, the LVSTR is better than the linear VAR especially for the short-run predictions.

4.6. Conclusions

In the theoretical section of this chapter, it is illustrated how the RESET can be applied for the VAR. Using a new method, the chapter obtains the LM statistic to test error autocorrelation in the VSTR model suggested by Camacho (2004) in a more general case. Furthermore, the estimation of NLS is extended to a multiple equation model.

In the empirical part, a VSTR model is applied to analyse the relationship between monetary policy and inflation in Iran which is an oil-based economy. The intuition is that the economy acts in two different regimes based on high and low oil price, which are interpreted as expansion and recession; thus oil price is applied as the transition variable. The logistic smooth transition function is used to show these regimes. Results reveal that the transition between two regimes occurs quickly. Real money and oil price have asymmetric effects on inflation with a higher impact in the regime with a high level of oil price. Also the central bank pays more attention to inflation in expansions compared to recessions. Moreover, the chapter shows that the VSTR model can predict inflation better than the linear model. Forecasts of the time varying model are especially superior to predictions of the VAR in the short-run.

Appendix 4.1. The Gauss Codes

```
/*Linearity test*/

new;
output file=xt_1.out reset;
library optmum;
optset;
#include optmum.ext;
load y[]=Z:\inflation.txt; /*we lost the last observation*/
load x[]=Z:\rm.txt;
load o[]=Z:\oil.txt;
z=y~x~o;
t=rows(z);
y=z[3:t,1];y=y[1:rows(y)];
x=z[3:t,2];x=x[1:rows(x)];
y2=z[1:t-2,1];y2=y2[1:rows(y2)];
x2=z[1:t-2,2];x2=x2[1:rows(x2)];
y1=z[2:t-1,1];y1=y1[1:rows(y1)];
x1=z[2:t-1,2];x1=x1[1:rows(x1)];
o=z[2:t-1,3];o=o[1:rows(o)];
tvy=o;

o1cua=o^2;
o1cub=o^3;
tef=rows(y);


/*+++++++++++++++ Under the alternative   ++++++++++++++++++++++*/

proc logl1(ti1);
   local e1,i,ss11,ss21,ima1,o1,io1,deo1,jdr,h,nu,jal,r1;
   e1=zeros(2,tef);
   i=1;
   do until i==tef+1;
      e1[1,i]=y[i]-ti1[1]*x1[i]-ti1[2]-ti1[3]*y1[i]-ti1[4]*o[i]+
                  (-ti1[5]*x1[i]-ti1[6]*o[i]-ti1[7]*y1[i])*o[i]+
                  (-ti1[8]*x1[i]-ti1[9]*o[i]-ti1[10]*y1[i])*o1cua[i]+
                  (-ti1[11]*x1[i]-ti1[12]*o[i]-ti1[13]*y1[i])*o1cub[i];

      e1[2,i]=x[i]-ti1[17]*x1[i]-ti1[16]-ti1[15]*y1[i]-ti1[14]*o[i]+
                  (-ti1[18]*x1[i]-ti1[27]*o[i]-ti1[23]*y1[i])*o[i]+
                  (-ti1[24]*x1[i]-ti1[28]*o[i]-ti1[25]*y1[i])*o1cua[i]+
                  (-ti1[26]*x1[i]-ti1[29]-ti1[22]*y1[i])*o1cub[i];
      i=i+1;
   endo;
   ss11=ti1[19]~0;
```

```
   ss21=ti1[21]~ti1[20];
   ima1=ss11|ss21;
   o1=ima1'ima1;
   io1=inv(o1);
   deo1=det(io1);
   jdr=zeros(tef,1);
   h=1;
   do until h==tef+1;
      jdr[h]=e1[.,h]'io1*e1[.,h];
      h=h+1;
   endo;
   nu=(-tef*2/2)*ln(2*pi);
   jal=(tef/2)*ln(deo1);
   r1=nu+jal-(1/2)*sumc(jdr);
   retp(-r1);
 endp;

ti01=.7*ones(26,1)|.75|.7|.15;
 {ti1,ff,gg,retcode}=optprt(optmum(&logl1,ti01));
 ss11=ti1[19]~0;
 ss21=ti1[21]~ti1[20];
 ima1=ss11|ss21;
 ome1=ima1'ima1;
 ome1;

/*+++++++++++  Under the null  +++++++++++++++++*/
proc logl0(ti0);
   local e0,i,ss10,ss20,ima0,o0,io0,deo0,jdr,h,nu,jal,r0;
   e0=zeros(2,tef);
   i=1;
   do until i==tef+1;
      e0[1,i]=y[i]-ti0[1]*x1[i]-ti0[2]-ti0[3]*y1[i]-ti0[4]*o[i];
      e0[2,i]=x[i]-ti0[5]*x1[i]-ti0[6]-ti0[10]*y1[i]-ti0[11]*o[i];
       i=i+1;
   endo;

   ss10=ti0[7]~0;
   ss20=ti0[9]~ti0[8];
   ima0=ss10|ss20;
   o0=ima0'ima0;
   io0=inv(o0);
   deo0=det(io0);
   jdr=zeros(tef,1);
   h=1;
   do until h==tef+1;
      jdr[h]=e0[.,h]'io0*e0[.,h];
      h=h+1;
   endo;
```

```
   nu=(-tef*2/2)*ln(2*pi);
   jal=(tef/2)*ln(deo0);
   r0=nu+jal-(1/2)*sumc(jdr);
   retp(-r0);
 endp;

ti00=.1*ones(8,1)|.75|.7|.15;
 {ti0,ff,gg,retcode}=optprt(optmum(&logl0,ti00));
 ss10=ti0[7]~0;
 ss20=ti0[9]~ti0[8];
 ima0=ss10|ss20;
 ome0=ima0'ima0;


/*+++++++++++++++  Linearity test ++++++++++++++++++*/
"This should be compared with a chi with 2 degrees of freedom";
chi=tef*(ln(det(ome0))-ln(det(ome1))); chi;



/*++++++++++++++++++++++++++    TEST 1  +++++++++++++++++++++++++*/
/*+++++++++++++++ Under the alternative   ++++++++++++++++++++++*/
      @The same than ome1 @
/*+++++++++++++++ Under the null   +++++++++++++++++++++*/
proc logl2(ti2);
   local e2,i,ss12,ss22,ima2,o2,io2,deo2,jdr,h,nu,jal,r2;
   e2=zeros(2,tef);
   i=1;
   do until i==tef+1;
      e2[1,i]=y[i]-ti2[1]*x1[i]-ti2[2]-ti2[3]*y1[i]-ti2[4]*o[i]+
                (-ti2[5]*x1[i]-ti2[6]*o[i]-ti2[7]*y1[i])*o[i]+
                (-ti2[8]*x1[i]-ti2[9]*o[i]-ti2[10]*y1[i])*o1cua[i];

      e2[2,i]=x[i]-ti2[11]*x1[i]-ti2[12]-ti2[13]*y1[i]-ti2[14]*o[i]+
                (-ti2[18]*x1[i]-ti2[19]*o[i]-ti2[20]*y1[i])*o[i]+
                (-ti2[23]*x1[i]-ti2[22]-ti2[21]*y1[i])*o1cua[i];

      i=i+1;
   endo;
   ss12=ti2[15]~0;
   ss22=ti2[17]~ti2[16];
   ima2=ss12|ss22;
   o2=ima2'ima2;
   io2=inv(o2);
   deo2=det(io2);
   jdr=zeros(tef,1);
   h=1;
   do until h==tef+1;
```

```
      jdr[h]=e2[.,h]'io2*e2[.,h];
      h=h+1;
   endo;
   nu=(-tef*2/2)*ln(2*pi);
   jal=(tef/2)*ln(deo2);
   r2=nu+jal-(1/2)*sumc(jdr);
   retp(-r2);
 endp;

ti02=.1*ones(20,1)|.75|.7|.15;
 {ti2,ff,gg,retcode}=optprt(optmum(&logl2,ti02));
 ss12=ti2[15]~0;
 ss22=ti2[17]~ti2[16];
 ima2=ss12|ss22;
 ome2=ima2'ima2;
 ome2;
          /*+++++++++   test 1   +++++++*/
"This should be compared with a chi with 4 degrees of freedom";
chi2=tef*(ln(det(ome2))-ln(det(ome1))); chi2;
/*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++*/

/*++++++++++++++++++++++++++    TEST 2  +++++++++++++++++++++++++*/
/*+++++++++++++++ Under the alternative   ++++++++++++++++++++++*/
      @The same than ome2 @
/*+++++++++++++++ Under the null   ++++++++++++++++++++++*/
proc logl3(ti3);
   local e3,i,ss13,ss23,ima3,o3,io3,deo3,jdr,h,nu,jal,r3;
   e3=zeros(2,tef);
   i=1;
   do until i==tef+1;
      e3[1,i]=y[i]-ti3[1]*x1[i]-ti3[2]-ti3[3]*y1[i]-ti3[4]*o[i]+
                  (-ti3[5]*x1[i]-ti3[6]*o[i]-ti3[7]*y1[i])*o[i];


      e3[2,i]=x[i]-ti3[8]*x1[i]-ti3[9]-ti3[10]*y1[i]-ti3[14]*o[i]+
                  (-ti3[15]*x1[i]-ti3[16]*o[i]-ti3[17]*y1[i])*o[i];


      i=i+1;
   endo;
   ss13=ti2[11]~0;
   ss23=ti2[13]~ti2[12];
   ima3=ss13|ss23;
   o3=ima3'ima3;
   io3=inv(o3);
   deo3=det(io3);
   jdr=zeros(tef,1);
   h=1;
```

```
   do until h==tef+1;
      jdr[h]=e3[.,h]'io3*e3[.,h];
      h=h+1;
   endo;
   nu=(-tef*2/2)*ln(2*pi);
   jal=(tef/2)*ln(deo3);
   r3=nu+jal-(1/2)*sumc(jdr);
   retp(-r3);
 endp;

ti03=.1*ones(14,1)|.75|.7|.15;
 {ti3,ff,gg,retcode}=optprt(optmum(&logl3,ti03));
 ss13=ti3[11]~0;
 ss23=ti3[13]~ti3[12];
 ima3=ss13|ss23;
 ome3=ima3'ima3;
 ome3;
           /*+++++++++   test 2   +++++++*/
"This should be compared with a chi with 4 degrees of freedom";
chi3=tef*(ln(det(ome2))-ln(det(ome3))); chi3;
/*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++*/


/*+++++++++++++++++++++++++++    TEST 3  +++++++++++++++++++++++++*/
/*+++++++++++++++ Under the alternative   ++++++++++++++++++++++*/
      @The same than ome3 @

/*+++++++++++++++ Under the null   ++++++++++++++++++++++*/
           /*+++++++++   test 3   +++++++*/
"This should be compared with a chi with 4 degrees of freedom";
chi4=tef*(ln(det(ome0))-ln(det(ome3))); chi4;
/*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++*/

 output off;
 end;



/*LVSTR*/
new;
output file=y2.out reset;
library optmum;
optset;
#include optmum.ext;
load y[]=Z:\inflation.txt; /*we lost the last observation*/
load x[]=Z:\rm.txt;
load o[]=Z:\oil.txt;
z=y~x~o;
```

```
t=rows(z);
y=z[3:t,1];y=y[1:rows(y)];
x=z[3:t,2];x=x[1:rows(x)];
y2=z[1:t-2,1];y2=y2[1:rows(y2)];
x2=z[1:t-2,2];x2=x2[1:rows(x2)];
y1=z[2:t-1,1];y1=y1[1:rows(y1)];
x1=z[2:t-1,2];x1=x1[1:rows(x1)];
o=z[2:t-1,3];o=o[1:rows(o)];
tvy=o;
tvx=o;
tef=rows(y);

proc logl3(ti2);
   local e2,i,fg1,fg2,ss12,ss22,ima2,o2,io2,deo2,jdr,h,nu,jal,r2;
   e2=zeros(2,tef);
   fg1=ones(tef,1)+exp(-1*ti2[1]*(tvy-ti2[2]));
   fg1=fg1^(-1);
   fg2=ones(tef,1)+exp(-1*ti2[3]*(tvx-ti2[4]));
   fg2=fg2^(-1);
   i=1;
   do until i==tef+1;
      e2[1,i]=y[i]-(ti2[10]*x1[i]+ti2[9]*y1[i]+ti2[20]*o[i])*fg1[i]
      -ti2[7]*x1[i]-ti2[5]-ti2[6]*y1[i]-ti2[8]*o[i];
      e2[2,i]=x[i]-ti2[11]-(ti2[16]*x1[i]+ti2[15]*y1[i]+ti2[21]*o[i])*fg2[i]
      -ti2[13]*x1[i]-ti2[12]*y1[i]-ti2[14]*o[i];
      i=i+1;
   endo;

   ss12=ti2[17]~0;
   ss22=ti2[19]~ti2[18];
   ima2=ss12|ss22;
   o2=ima2'ima2;
   io2=inv(o2);
   deo2=det(io2);
   jdr=zeros(tef,1);
   h=1;
   do until h==tef+1;
      jdr[h]=e2[.,h]'io2*e2[.,h];
      h=h+1;
   endo;
   nu=(-tef*2/2)*ln(2*pi);
   jal=(tef/2)*ln(deo2);
   r2=nu+jal-(1/2)*sumc(jdr);
   retp(-r2);
 endp;

ti02=10|25|10|35|.7*ones(11,1)|.75|.7|.15|.75|.7|.15;
 {ti2,ff,gg,retcode}=optprt(optmum(&logl3,ti02));
```

```
 ss12=ti2[17]~0;
 ss22=ti2[19]~ti2[18];
 ima2=ss12|ss22;
 ome2=ima2'ima2;

p=hessp(&logl3,ti2);
va=eigrs(p);
if minc(va)<=0;
   "Negative Hessian is not positive definite";"";
   "Initial params: ";ti02';"";
   "Estimated params: ";ti2';
   end;
endif;
hi=invpd(p)/tef;
gr=gradfd(&trans,ti2);
Hfin=hi*gr*hi';
std=diag(Hfin)^.5;

proc trans(varia);
   local vari,rv,ss1,ss2,ima,o1,vv;
   vari=varia;
   rv=rows(varia);

   vari[3]=varia[3];
   vari[10]=varia[10];

   ss1=varia[rv-5]~0;
   ss2=varia[rv-3]~varia[rv-4];
   ima=ss1|ss2;
   o1=ima'ima;
   vari[rv-5]=o1[1,1];
   vari[rv-4]=o1[2,2];
   vari[rv-3]=o1[1,2];

   ss1=varia[rv-2]~0;
   ss2=varia[rv]~varia[rv-1];
   ima=ss1|ss2;
   o1=ima'ima;
   vari[rv-2]=o1[1,1];
   vari[rv-1]=o1[2,2];
   vari[rv]=o1[1,2];

   retp(vari);
endp;
```

```
/*............. Here we obtain some outputs ...........*/

fg1e=ones(tef,1)+exp(-1*ti2[1]*(tvy-ti2[2]));
fg1e=fg1e^(-1);
ye=(ti2[20]*o+ti2[10]*x1+ti2[9]*y1).*fg1e+ti2[7]*x1+ti2[5]*ones(tef,1)+ti2[6]*y
1+ti2[8]*o;

output file=yey2.out reset;
ye;
output off;

mse=(y-ye)^2;
(sumr(mse)/cols(mse))^0.5;

output file=msey2.out reset;
mse;
output off;

output file=rey2.out reset;
1-fg1e;
output off;



output off;
end;


/*testing serial correlation*/
new;
output file=y2.out reset;
library optmum;
optset;
#include optmum.ext;
load y[]=Z:\inflation.txt; /*we lost the last observation*/
load x[]=Z:\rm.txt;
load o[]=Z:\oil.txt;
z=y~x~o;
t=rows(z);
y=z[3:t,1];y=y[1:rows(y)];
x=z[3:t,2];x=x[1:rows(x)];
y2=z[1:t-2,1];y2=y2[1:rows(y2)];
x2=z[1:t-2,2];x2=x2[1:rows(x2)];
y1=z[2:t-1,1];y1=y1[1:rows(y1)];
x1=z[2:t-1,2];x1=x1[1:rows(x1)];
o=z[2:t-1,3];o=o[1:rows(o)];
tvy=o;
tvx=o;
```

```
tef=rows(y);


      /*+++++++++++++ Unrestricted  Estimation   +++++++++++++++++*/

proc logl(ti);
   local e2,i,fg1,fg2,ss12,ss22,ima2,o2,io2,deo2,jdr,h,nu,jal,r;
   e2=zeros(2,tef);
   fg1=ones(tef,1)+exp(-1*ti[4]*(tvy-ti[5]));
   fg1=fg1^(-1);
   fg2=ones(tef,1)+exp(-1*ti[12]*(tvx-ti[13]));
   fg2=fg2^(-1);
   i=1;
   do until i==tef+1;
      e2[1,i]=y[i]-(ti[8]*o[i]+ti[10]*x1[i]+ti[9]*y1[i])*fg1[i]-ti[7]*x1[i]-
ti[1]-ti[6]*y1[i]-ti[20]*o[i];
      e2[2,i]=x[i]-ti[11]-(ti[14]*o[i]+ti[16]*x1[i]+ti[15]*y1[i])*fg2[i]-
ti[3]*x1[i]-ti[2]*y1[i]-ti[21]*o[i];
      i=i+1;
   endo;

   ss12=ti[17]~0;
   ss22=ti[19]~ti[18];
   ima2=ss12|ss22;
   o2=ima2'ima2;
   io2=inv(o2);
   deo2=det(io2);
   jdr=zeros(tef,1);
   h=1;
   do until h==tef+1;
      jdr[h]=e2[.,h]'io2*e2[.,h];
      h=h+1;
   endo;
   nu=(-tef*2/2)*ln(2*pi);
   jal=(tef/2)*ln(deo2);
   r=nu+jal-(1/2)*sumc(jdr);
   retp(-r);
 endp;

ti0=.95*ones(18,1)|.75|.7|.15;

 {ti,ff,gg,retcode}=optprt(optmum(&logl,ti0));


     /*++++++++      LM test of serial correlation   ++++++++++*/

 ss12=ti[17]~0;
```

```
ss22=ti[19]~ti[18];
ima=ss12|ss22;
ome=ima'ima;
oi=inv(ome);



           /*-----------   r=1  --------------*/
r=1;
ma=zeros(4*r,1);
Maa=zeros(4*r,4*r);
Map=zeros(4*r,8);
Mpp=zeros(8,8);
t=r+1;
do until t==tef+1;
   fyn=1+exp(-ti[4]*(tvy[t]-ti[5]));Fy=fyn^(-1);
   fxn=1+exp(-ti[12]*(tvx[t]-ti[13]));Fx=fxn^(-1);
   fyn1=1+exp(-ti[4]*(tvy[t-1]-ti[5]));Fy1=fyn1^(-1);
   fxn1=1+exp(-ti[12]*(tvx[t-1]-ti[13]));Fx1=fxn1^(-1);


ye=(ti[8]*o[t]+ti[10]*x1[t]+ti[9]*y1[t])*Fy+ti[7]*x1[t]+ti[1]+ti[6]*y1[t]+ti[20
]*o[t];

xe=ti[11]+(ti[14]*o[t]+ti[16]*x1[t]+ti[15]*y1[t])*Fx+ti[3]*x1[t]+ti[2]*y1[t]+ti
[21]*o[t];
    ye1=(ti[8]*o[t-1]+ti[10]*x1[t-1]+ti[9]*y1[t-1])*Fy1+ti[7]*x1[t-
1]+ti[1]+ti[6]*y1[t-1]+ti[20]*o[t-1];
    xe1=ti[11]+(ti[14]*o[t-1]+ti[16]*x1[t-1]+ti[15]*y1[t-1])*Fx1+ti[3]*x1[t-
1]+ti[2]*y1[t-1]+ti[21]*o[t-1];



  uy=y[t]-ye;ux=x[t]-xe;
  uy1=y[t-1]-ye1;ux1=x[t-1]-xe1;
  U=uy|ux;

  vy=uy1;vx=ux1;
  V=vy|vx;

  A=1|y1[t]|x1[t]|o[t-1];

  AFy=A.*Fy;
  AFx=A.*Fx;

  By=ti[8:10];Bx=ti[14:16];
  Dy=tvy[t]-ti[5];Dx=tvx[t]-ti[13];
  Ey=exp(-ti[4]*(tvy[t]-ti[5]));Ex=exp(-ti[12]*(tvx[t]-ti[13]));
```

```
   Jy=fyn^2;Jx=fxn^2;
   Ggy=(Dy*Ey/Jy).*(By'A);Ggx=(Dx*Ex/Jx).*(Bx'A);
   Gcy=(-ti[4]*Ey/Jy).*(By'A);Gcx=(-ti[12]*Ex/Jx).*(Bx'A);

   Zy=A|Afy|Ggy|Gcy;Zx=A|Afx|Ggx|Gcx;
   Z=Zy~Zx;


   man=(oi*U).*.V;ma=ma+man;
   Maan=oi.*.(V*V');Maa=Maa+Maan;
   Mapn=(oi*Z').*.V;Map=Map+Mapn;
   Mppn=Z*oi*Z';Mpp=Mpp+Mppn;

   t=t+1;
endo;

LM=ma'*inv(Maa-Map*inv(Mpp)*Map')*ma;
"The foolowing statistic has to be compared with a Chi with 4 (4*r) dof";
"LM(r=1)=";;LM;


            /*-----------   r=2  --------------*/
 r=2;
 ma=zeros(4*r,1);
 Maa=zeros(4*r,4*r);
 Map=zeros(4*r,8);
 Mpp=zeros(8,8);
 t=r+1;
 do until t==tef+1;
    fyn=1+exp(-ti[4]*(tvy[t]-ti[5]));Fy=fyn^(-1);
    fxn=1+exp(-ti[12]*(tvx[t]-ti[13]));Fx=fxn^(-1);
    fyn1=1+exp(-ti[4]*(tvy[t-1]-ti[5]));Fy1=fyn1^(-1);
    fxn1=1+exp(-ti[12]*(tvx[t-1]-ti[13]));Fx1=fxn1^(-1);
    fyn2=1+exp(-ti[4]*(tvy[t-2]-ti[5]));Fy2=fyn2^(-1);
    fxn2=1+exp(-ti[12]*(tvx[t-2]-ti[13]));Fx2=fxn2^(-1);


ye=(ti[8]*o[t]+ti[10]*x1[t]+ti[9]*y1[t])*Fy+ti[7]*x1[t]+ti[1]+ti[6]*y1[t]+ti[20
]*o[t];

xe=ti[11]+(ti[14]*o[t]+ti[16]*x1[t]+ti[15]*y1[t])*Fx+ti[3]*x1[t]+ti[2]*y1[t]+ti
[21]*o[t];
    ye1=(ti[8]*o[t-1]+ti[10]*x1[t-1]+ti[9]*y1[t-1])*Fy1+ti[7]*x1[t-
1]+ti[1]+ti[6]*y1[t-1]+ti[20]*o[t-1];
    xe1=ti[11]+(ti[14]*o[t-1]+ti[16]*x1[t-1]+ti[15]*y1[t-1])*Fx1+ti[3]*x1[t-
1]+ti[2]*y1[t-1]+ti[21]*o[t-1];
    ye2=(ti[8]*o[t-2]+ti[10]*x1[t-2]+ti[9]*y1[t-2])*Fy2+ti[7]*x1[t-
2]+ti[1]+ti[6]*y1[t-2]+ti[20]*o[t-2];
```

```
    xe2=ti[11]+(ti[14]*o[t-2]+ti[16]*x1[t-2]+ti[15]*y1[t-2])*Fx2+ti[3]*x1[t-
2]+ti[2]*y1[t-2]+ti[21]*o[t-2];

   uy=y[t]-ye;ux=x[t]-xe;
   uy1=y[t-1]-ye1;ux1=x[t-1]-xe1;
   uy2=y[t-2]-ye2;ux2=x[t-2]-xe2;
   U=uy|ux;

   vy=uy1|uy2;vx=ux1|ux2;
   V=vy|vx;

   A=1|y1[t]|x1[t];


   AFy=A.*Fy;
   AFx=A.*Fx;

   By=ti[8:10];Bx=ti[14:16];
   Dy=tvy[t]-ti[5];Dx=tvx[t]-ti[13];
   Ey=exp(-ti[4]*(tvy[t]-ti[5]));Ex=exp(-ti[12]*(tvx[t]-ti[13]));
   Jy=fyn^2;Jx=fxn^2;
   Ggy=(Dy*Ey/Jy).*(By'A);Ggx=(Dx*Ex/Jx).*(Bx'A);
   Gcy=(-ti[4]*Ey/Jy).*(By'A);Gcx=(-ti[12]*Ex/Jx).*(Bx'A);

   Zy=A|Afy|Ggy|Gcy;Zx=A|Afx|Ggx|Gcx;
   Z=Zy~Zx;

   man=(oi*U).*.V;ma=ma+man;
   Maan=oi.*.(V*V');Maa=Maa+Maan;
   Mapn=(oi*Z').*.V;Map=Map+Mapn;
   Mppn=Z*oi*Z';Mpp=Mpp+Mppn;

   t=t+1;
endo;

LM=ma'*inv(Maa-Map*inv(Mpp)*Map')*ma;
"The foolowing statistic has to be compared with a Chi with 8 (4*r)dof";
"LM(r=2)=";;LM;


        /*-----------   r=3  --------------*/
 r=3;
 ma=zeros(4*r,1);
 Maa=zeros(4*r,4*r);
 Map=zeros(4*r,8);
 Mpp=zeros(8,8);
 t=r+1;
 do until t==tef+1;
```

```
    fyn=1+exp(-ti[4]*(tvy[t]-ti[5]));Fy=fyn^(-1);
    fxn=1+exp(-ti[12]*(tvx[t]-ti[13]));Fx=fxn^(-1);
    fyn1=1+exp(-ti[4]*(tvy[t-1]-ti[5]));Fy1=fyn1^(-1);
    fxn1=1+exp(-ti[12]*(tvx[t-1]-ti[13]));Fx1=fxn1^(-1);
    fyn2=1+exp(-ti[4]*(tvy[t-2]-ti[5]));Fy2=fyn2^(-1);
    fxn2=1+exp(-ti[12]*(tvx[t-2]-ti[13]));Fx2=fxn2^(-1);
    fyn3=1+exp(-ti[4]*(tvy[t-3]-ti[5]));Fy3=fyn3^(-1);
    fxn3=1+exp(-ti[12]*(tvx[t-3]-ti[13]));Fx3=fxn3^(-1);


ye=(ti[8]*o[t]+ti[10]*x1[t]+ti[9]*y1[t])*Fy+ti[7]*x1[t]+ti[1]+ti[6]*y1[t]+ti[20
]*o[t];

xe=ti[11]+(ti[14]*o[t]+ti[16]*x1[t]+ti[15]*y1[t])*Fx+ti[3]*x1[t]+ti[2]*y1[t]+ti
[21]*o[t];
    ye1=(ti[8]*o[t-1]+ti[10]*x1[t-1]+ti[9]*y1[t-1])*Fy1+ti[7]*x1[t-
1]+ti[1]+ti[6]*y1[t-1]+ti[20]*o[t-1];
    xe1=ti[11]+(ti[14]*o[t-1]+ti[16]*x1[t-1]+ti[15]*y1[t-1])*Fx1+ti[3]*x1[t-
1]+ti[2]*y1[t-1]+ti[21]*o[t-1];
    ye2=(ti[8]*o[t-2]+ti[10]*x1[t-2]+ti[9]*y1[t-2])*Fy2+ti[7]*x1[t-
2]+ti[1]+ti[6]*y1[t-2]+ti[20]*o[t-2];
    xe2=ti[11]+(ti[14]*o[t-2]+ti[16]*x1[t-2]+ti[15]*y1[t-2])*Fx2+ti[3]*x1[t-
2]+ti[2]*y1[t-2]+ti[21]*o[t-2];
    ye3=(ti[8]*o[t-3]+ti[10]*x1[t-3]+ti[9]*y1[t-3])*Fy3+ti[7]*x1[t-
3]+ti[1]+ti[6]*y1[t-3]+ti[20]*o[t-3];
    xe3=ti[11]+(ti[14]*o[t-3]+ti[16]*x1[t-3]+ti[15]*y1[t-3])*Fx3+ti[3]*x1[t-
3]+ti[2]*y1[t-3]+ti[21]*o[t-3];

   uy=y[t]-ye;ux=x[t]-xe;
   uy1=y[t-1]-ye1;ux1=x[t-1]-xe1;
   uy2=y[t-2]-ye2;ux2=x[t-2]-xe2;
   uy3=y[t-3]-ye3;ux3=x[t-3]-xe3;
   U=uy|ux;

   vy=uy1|uy2|uy3;vx=ux1|ux2|ux3;
   V=vy|vx;

   A=1|y1[t]|x1[t];


   AFy=A.*Fy;
   AFx=A.*Fx;

   By=ti[8:10];Bx=ti[14:16];
   Dy=tvy[t]-ti[5];Dx=tvx[t]-ti[13];
   Ey=exp(-ti[4]*(tvy[t]-ti[5]));Ex=exp(-ti[12]*(tvx[t]-ti[13]));
   Jy=fyn^2;Jx=fxn^2;
   Ggy=(Dy*Ey/Jy).*(By'A);Ggx=(Dx*Ex/Jx).*(Bx'A);
```

```
   Gcy=(-ti[4]*Ey/Jy).*(By'A);Gcx=(-ti[12]*Ex/Jx).*(Bx'A);

   Zy=A|Afy|Ggy|Gcy;Zx=A|Afx|Ggx|Gcx;
   Z=Zy~Zx;

   man=(oi*U).*.V;ma=ma+man;
   Maan=oi.*.(V*V');Maa=Maa+Maan;
   Mapn=(oi*Z').*.V;Map=Map+Mapn;
   Mppn=Z*oi*Z';Mpp=Mpp+Mppn;

   t=t+1;
endo;

LM=ma'*inv(Maa-Map*inv(Mpp)*Map')*ma;
"The foolowing statistic has to be compared with a Chi with 12 (4*r)dof";
"LM(r=3)=";;LM;


        /*-----------   r=4  --------------*/
 r=4;
 ma=zeros(4*r,1);
 Maa=zeros(4*r,4*r);
 Map=zeros(4*r,8);
 Mpp=zeros(8,8);
 t=r+1;
 do until t==tef+1;
    fyn=1+exp(-ti[4]*(tvy[t]-ti[5]));Fy=fyn^(-1);
    fxn=1+exp(-ti[12]*(tvx[t]-ti[13]));Fx=fxn^(-1);
    fyn1=1+exp(-ti[4]*(tvy[t-1]-ti[5]));Fy1=fyn1^(-1);
    fxn1=1+exp(-ti[12]*(tvx[t-1]-ti[13]));Fx1=fxn1^(-1);
    fyn2=1+exp(-ti[4]*(tvy[t-2]-ti[5]));Fy2=fyn2^(-1);
    fxn2=1+exp(-ti[12]*(tvx[t-2]-ti[13]));Fx2=fxn2^(-1);
    fyn3=1+exp(-ti[4]*(tvy[t-3]-ti[5]));Fy3=fyn3^(-1);
    fxn3=1+exp(-ti[12]*(tvx[t-3]-ti[13]));Fx3=fxn3^(-1);
    fyn4=1+exp(-ti[4]*(tvy[t-4]-ti[5]));Fy4=fyn4^(-1);
    fxn4=1+exp(-ti[12]*(tvx[t-4]-ti[13]));Fx4=fxn4^(-1);


ye=(ti[8]*o[t]+ti[10]*x1[t]+ti[9]*y1[t])*Fy+ti[7]*x1[t]+ti[1]+ti[6]*y1[t]+ti[20
]*o[t];

xe=ti[11]+(ti[14]*o[t]+ti[16]*x1[t]+ti[15]*y1[t])*Fx+ti[3]*x1[t]+ti[2]*y1[t]+ti
[21]*o[t];
    ye1=(ti[8]*o[t-1]+ti[10]*x1[t-1]+ti[9]*y1[t-1])*Fy1+ti[7]*x1[t-
1]+ti[1]+ti[6]*y1[t-1]+ti[20]*o[t-1];
    xe1=ti[11]+(ti[14]*o[t-1]+ti[16]*x1[t-1]+ti[15]*y1[t-1])*Fx1+ti[3]*x1[t-
1]+ti[2]*y1[t-1]+ti[21]*o[t-1];
```

```
    ye2=(ti[8]*o[t-2]+ti[10]*x1[t-2]+ti[9]*y1[t-2])*Fy2+ti[7]*x1[t-
2]+ti[1]+ti[6]*y1[t-2]+ti[20]*o[t-2];
    xe2=ti[11]+(ti[14]*o[t-2]+ti[16]*x1[t-2]+ti[15]*y1[t-2])*Fx2+ti[3]*x1[t-
2]+ti[2]*y1[t-2]+ti[21]*o[t-2];
    ye3=(ti[8]*o[t-3]+ti[10]*x1[t-3]+ti[9]*y1[t-3])*Fy3+ti[7]*x1[t-
3]+ti[1]+ti[6]*y1[t-3]+ti[20]*o[t-3];
    xe3=ti[11]+(ti[14]*o[t-3]+ti[16]*x1[t-3]+ti[15]*y1[t-3])*Fx3+ti[3]*x1[t-
3]+ti[2]*y1[t-3]+ti[21]*o[t-3];
    ye4=(ti[8]*o[t-4]+ti[10]*x1[t-4]+ti[9]*y1[t-4])*Fy4+ti[7]*x1[t-
4]+ti[1]+ti[6]*y1[t-4]+ti[20]*o[t-4];
    xe4=ti[11]+(ti[14]*o[t-4]+ti[16]*x1[t-4]+ti[15]*y1[t-4])*Fx4+ti[3]*x1[t-
4]+ti[2]*y1[t-4]+ti[21]*o[t-4];

   uy=y[t]-ye;ux=x[t]-xe;
   uy1=y[t-1]-ye1;ux1=x[t-1]-xe1;
   uy2=y[t-2]-ye2;ux2=x[t-2]-xe2;
   uy3=y[t-3]-ye3;ux3=x[t-3]-xe3;
   uy4=y[t-4]-ye4;ux4=x[t-4]-xe4;
   U=uy|ux;

   vy=uy1|uy2|uy3|uy4;vx=ux1|ux2|ux3|ux4;
   V=vy|vx;

   A=1|y1[t]|x1[t];


   AFy=A.*Fy;
   AFx=A.*Fx;

   By=ti[8:10];Bx=ti[14:16];
   Dy=tvy[t]-ti[5];Dx=tvx[t]-ti[13];
   Ey=exp(-ti[4]*(tvy[t]-ti[5]));Ex=exp(-ti[12]*(tvx[t]-ti[13]));
   Jy=fyn^2;Jx=fxn^2;
   Ggy=(Dy*Ey/Jy).*(By'A);Ggx=(Dx*Ex/Jx).*(Bx'A);
   Gcy=(-ti[4]*Ey/Jy).*(By'A);Gcx=(-ti[12]*Ex/Jx).*(Bx'A);

   Zy=A|Afy|Ggy|Gcy;Zx=A|Afx|Ggx|Gcx;
   Z=Zy~Zx;

   man=(oi*U).*.V;ma=ma+man;
   Maan=oi.*.(V*V');Maa=Maa+Maan;
   Mapn=(oi*Z').*.V;Map=Map+Mapn;
   Mppn=Z*oi*Z';Mpp=Mpp+Mppn;

   t=t+1;
endo;

LM=ma'*inv(Maa-Map*inv(Mpp)*Map')*ma;
```

```
"The foolowing statistic has to be compared with a Chi with 16 (4*r) dof";
"LM(r=4)=";;LM;


output off;
end;


/*testing no remaining nonlinearity*/
new;
output file=y2.out reset;
library optmum;
optset;
#include optmum.ext;
load y[]=Z:\inflation.txt; /*we lost the last observation*/
load x[]=Z:\rm.txt;
load o[]=Z:\oil.txt;
z=y~x~o;
t=rows(z);
y=z[3:t,1];y=y[1:rows(y)];
x=z[3:t,2];x=x[1:rows(x)];
y2=z[1:t-2,1];y2=y2[1:rows(y2)];
x2=z[1:t-2,2];x2=x2[1:rows(x2)];
y1=z[2:t-1,1];y1=y1[1:rows(y1)];
x1=z[2:t-1,2];x1=x1[1:rows(x1)];
o=z[2:t-1,3];o=o[1:rows(o)];
tvy=o;
tvx=o;
o2cua=o^2;
o2cub=o^3;
tef=rows(y);



/*+++++++++++++++ Under the alternative   ++++++++++++++++++++++*/

proc logl1(ti1);
   local e1,i,ss11,ss21,ima1,fy,fx,o1,io1,deo1,jdr,h,nu,jal,r1;
   e1=zeros(2,tef);
   i=1;
   do until i==tef+1;
     fy=ones(tef,1)+exp(-1*ti1[1]*(o[i]-ti1[2]));fy=fy^(-1);
     fx=ones(tef,1)+exp(-1*ti1[3]*(o[i]-ti1[4]));fx=fx^(-1);

    e1[1,i]=y[i]-(ti1[8]*o[i]+ti1[10]*x1[i]+ti1[9]*y1[i])*fy[i]-ti1[7]*x1[i]-
ti1[5]-ti1[6]*y1[i]-ti1[17]*o[i]+
              (-(ti1[18]*o[i]+ti1[19]*x1[i]+ti1[20]*y1[i])*fy[i]-ti1[21]*x1[i]-
ti1[22]-ti1[23]*y1[i]-ti1[24]*o[i])*o[i]+
```

```
        (-(ti1[25]*o[i]+ti1[26]*x1[i]+ti1[27]*y1[i])*fy[i]-ti1[28]*x1[i]-
ti1[29]-ti1[30]*y1[i]-ti1[31]*o[i])*o2cua[i];

     e1[2,i]=x[i]-ti1[11]-(ti1[14]*o[i]+ti1[16]*x1[i]+ti1[15]*y1[i])*fx[i]-
ti1[13]*x1[i]-ti1[12]*y1[i]-ti1[32]*o[i];
       i=i+1;
   endo;
   ss11=ti1[33]~0;
   ss21=ti1[35]~ti1[34];
   ima1=ss11|ss21;
   o1=ima1'ima1;
   io1=inv(o1);
   deo1=det(io1);
   jdr=zeros(tef,1);
   h=1;
   do until h==tef+1;
      jdr[h]=e1[.,h]'io1*e1[.,h];
      h=h+1;
   endo;
   nu=(-tef*2/2)*ln(2*pi);
   jal=(tef/2)*ln(deo1);
   r1=nu+jal-(1/2)*sumc(jdr);
   retp(-r1);
 endp;

ti01=.1*ones(32,1)|.75|.7|.15;
{ti1,ff,gg,retcode}=optprt(optmum(&logl1,ti01));

 ss11=ti1[33]~0;
 ss21=ti1[35]~ti1[34];
 ima1=ss11|ss21;
 ome1=ima1'ima1;
 ome1;



proc logl2(ti2);
   local e2,i,fg1,fg2,ss12,ss22,ima2,o2,io2,deo2,jdr,h,nu,jal,r2;
   e2=zeros(2,tef);
   fg1=ones(tef,1)+exp(-1*ti2[1]*(tvy-ti2[2]));
   fg1=fg1^(-1);
   fg2=ones(tef,1)+exp(-1*ti2[3]*(tvx-ti2[4]));
   fg2=fg2^(-1);
   i=1;
   do until i==tef+1;
      e2[1,i]=y[i]-(ti2[8]*o[i]+ti2[10]*x1[i]+ti2[9]*y1[i])*fg1[i]-
ti2[7]*x1[i]-ti2[5]-ti2[6]*y1[i]-ti2[17]*o[i];
```

```
      e2[2,i]=x[i]-ti2[11]-(ti2[14]*o[i]+ti2[16]*x1[i]+ti2[15]*y1[i])*fg2[i]-
ti2[13]*x1[i]-ti2[12]*y1[i]-ti2[18]*o[i];
      i=i+1;
   endo;

   ss12=ti2[19]~0;
   ss22=ti2[21]~ti2[20];
   ima2=ss12|ss22;
   o2=ima2'ima2;
   io2=inv(o2);
   deo2=det(io2);
   jdr=zeros(tef,1);
   h=1;
   do until h==tef+1;
      jdr[h]=e2[.,h]'io2*e2[.,h];
      h=h+1;
   endo;
   nu=(-tef*2/2)*ln(2*pi);
   jal=(tef/2)*ln(deo2);
   r2=nu+jal-(1/2)*sumc(jdr);
   retp(-r2);
 endp;

ti02=10|25|10|35|.7*ones(11,1)|.75|.7|.15|.75|.7|.15;
 {ti2,ff,gg,retcode}=optprt(optmum(&logl2,ti02));
 ss12=ti2[19]~0;
 ss22=ti2[21]~ti2[20];
 ima2=ss12|ss22;
 ome2=ima2'ima2;


/*+++++++++++++++  Linearity test ++++++++++++++++++*/
"This should be compared with a chi with 3(p+1) degrees of freedom";
chi=tef*(ln(det(ome2))-ln(det(ome1))); chi;



output off;
end;


/*testing parameter constancy*/
new;
output file=y2.out reset;
library optmum;
optset;
#include optmum.ext;
load y[]=Z:\inflation.txt; /*we lost the last observation*/
```

```
load x[]=Z:\rm.txt;
load o[]=Z:\oil.txt;
z=y~x~o;
t=rows(z);
y=z[3:t,1];y=y[1:rows(y)];
x=z[3:t,2];x=x[1:rows(x)];
y2=z[1:t-2,1];y2=y2[1:rows(y2)];
x2=z[1:t-2,2];x2=x2[1:rows(x2)];
y1=z[2:t-1,1];y1=y1[1:rows(y1)];
x1=z[2:t-1,2];x1=x1[1:rows(x1)];
o=z[2:t-1,3];o=o[1:rows(o)];
tvy=o;
tvx=o;
tef=rows(y);
t=seqa(1,1,tef);
t2=t^2;
t3=t^3;



      /*+++++++++++++++ Under the alternative ++++++++++++++++++++++++*/


proc logl1(ti1);
   local e2,i,fg1,fg2,ss12,ss22,ima2,o2,io2,deo2,jdr,h,nu,jal,r1;
   e2=zeros(2,tef);
   fg1=ones(tef,1)+exp(-1*ti1[1]*(tvy-ti1[2]));
   fg1=fg1^(-1);
   fg2=ones(tef,1)+exp(-1*ti1[3]*(tvx-ti1[4]));
   fg2=fg2^(-1);
   i=1;
   do until i==tef+1;
      e2[1,i]=y[i]-(ti1[8]*o[i]+ti1[10]*x1[i]+ti1[9]*y1[i])*fg1[i]-
ti1[7]*x1[i]-ti1[5]-ti1[6]*y1[i]-ti1[17]*o[i]+
              (-(ti1[18]*o[i]+ti1[19]*x1[i]+ti1[20]*y1[i])*fg1[i]-
ti1[21]*x1[i]-ti1[22]-ti1[23]*y1[i]-ti1[24]*o[i])*t[i];

      e2[2,i]=x[i]-ti1[11]-(ti1[14]*o[i]+ti1[16]*x1[i]+ti1[15]*y1[i])*fg2[i]-
ti1[13]*x1[i]-ti1[12]*y1[i]-ti1[25]*o[i]
               +(-ti1[29]-(ti1[30]+ti1[31]*x1[i]+ti1[32]*y1[i])*fg2[i]-
ti1[33]*x1[i]-ti1[34]*y1[i]-ti1[35]*o[i])*t[i];

        i=i+1;
   endo;

   ss12=ti1[26]~0;
   ss22=ti1[28]~ti1[27];
   ima2=ss12|ss22;
```

```
   o2=ima2'ima2;
   io2=inv(o2);
   deo2=det(io2);
   jdr=zeros(tef,1);
   h=1;
   do until h==tef+1;
      jdr[h]=e2[.,h]'io2*e2[.,h];
      h=h+1;
   endo;
   nu=(-tef*2/2)*ln(2*pi);
   jal=(tef/2)*ln(deo2);
   r1=nu+jal-(1/2)*sumc(jdr);
   retp(-r1);
 endp;

   ti01=.1*ones(32,1)|.75|.7|.15;
 {ti1,ff,gg,retcode}=optprt(optmum(&logl1,ti01));
 ss11=ti1[26]~0;
 ss21=ti1[28]~ti1[27];
 ima1=ss11|ss21;
 ome1=ima1'ima1;



     /*++++++++++++++++++ Under the null +++++++++++++++++++++*/


proc logl2(ti2);
   local e2,i,fg1,fg2,ss12,ss22,ima2,o2,io2,deo2,jdr,h,nu,jal,r2;
   e2=zeros(2,tef);
   fg1=ones(tef,1)+exp(-1*ti2[1]*(tvy-ti2[2]));
   fg1=fg1^(-1);
   fg2=ones(tef,1)+exp(-1*ti2[3]*(tvx-ti2[4]));
   fg2=fg2^(-1);
   i=1;
   do until i==tef+1;
      e2[1,i]=y[i]-(ti2[8]*o[i]+ti2[10]*x1[i]+ti2[9]*y1[i])*fg1[i]-
ti2[7]*x1[i]-ti2[5]-ti2[6]*y1[i]-ti2[20]*o[i];
      e2[2,i]=x[i]-ti2[11]-(ti2[14]*o[i]+ti2[16]*x1[i]+ti2[15]*y1[i])*fg2[i]-
ti2[13]*x1[i]-ti2[12]*y1[i]-ti2[21]*o[i];
      i=i+1;
   endo;

   ss12=ti2[17]~0;
   ss22=ti2[19]~ti2[18];
   ima2=ss12|ss22;
   o2=ima2'ima2;
   io2=inv(o2);
```

```
   deo2=det(io2);
   jdr=zeros(tef,1);
   h=1;
   do until h==tef+1;
      jdr[h]=e2[.,h]'io2*e2[.,h];
      h=h+1;
   endo;
   nu=(-tef*2/2)*ln(2*pi);
   jal=(tef/2)*ln(deo2);
   r2=nu+jal-(1/2)*sumc(jdr);
   retp(-r2);
 endp;

ti02=0.4*ones(15,1)|.75|.7|.15|.75|.7|.15;
 {ti2,ff,gg,retcode}=optprt(optmum(&logl2,ti02));
 ss12=ti2[17]~0;
 ss22=ti2[19]~ti2[18];
 ima2=ss12|ss22;
 ome2=ima2'ima2;


/*+++++++++++++++  Linearity test +++++++++++++++++++*/
"This should be compared with a chi with restrictions=15? degrees of freedom";
chi=tef*(ln(det(ome2))-ln(det(ome1))); chi;


output off;
end;
```

CHAPTER FIVE

Concluding Remarks

5.1. Conclusions

Using a fixed-effect model, the thesis shows that the role of central bank independence is significant in monetary policy of oil-exporting countries. Since these countries generally have less central bank independence, monetary policy tends to expand after an increase in oil price; however, central banks which are more independent have less expansionary monetary policy compared to economies with less central bank independence after an increase in oil price. These results are achieved by using two different CBI indices and two different variables for oil price (nominal and real oil price).

In chapter 4, a VSTR model is used to investigate the relation between monetary policy and inflation in Iran. Oil price is chosen to analyse the relation in two different regimes when oil price is high and low. The model indicates that the transition between two regimes is swift and real money and oil price have a higher impact on inflation in the regime with a high level of oil price. Thus, it draws a policy implication that the central bank can follow expansionary policy when oil price is low and the economy is in recession without having concerns about inflation. This means that monetary policy has asymmetric effects. Furthermore, it is shown that the monetary authority cares more about inflation when oil price is high.

A comparison between the predictions of inflation with the VSTR and linear VAR models shows that the time varying VAR can forecast better. It has to be mentioned that the prediction with the VSTR model becomes more superior when it is applied for the shorter period of time.

5.2. Further Issues for Future Research

In chapter 3, the number of countries in the sample can be increased with further effort to access to the central banks' regulations. Although the CBI indices used in chapter 3 are the most important indicators, one can use other legal indices and also apply the *de facto* indicators of CBI. Moreover, the model used in chapter 3 can be constructed for each country separately. In other words, a researcher can focus on one country and calculate CBI changes for a longer period, then examine the impact of oil price on monetary policy through these changes. Further development of the linear model in chapter 3 can be done by investigating any nonlinearity. In other words, the parameters may depend on oil price, so one can test this possibility and construct a nonlinear model with different regimes based on changes in oil price.

Investigating the impact of oil price on central bank independence in oil-exporting countries is a very interesting topic for future research. The hypothesis to test is that a sharp rise in oil income encourages the government to pursue its short-term objectives anxiously; hence CBI, in practice, reduces, although the legal indices of CBI do not change.

Spending more time on programming, the model in chapter 4 can include more variables; another key variable which can be added is output, so the effect of money growth on output can be analysed when oil price varies. Having output in the model allows using output as the transition variable; therefore business cycles are determined by changes in output, which is more meaningful. Moreover, the other nonlinear models can be applied in chapter 4, such as the random walk smooth transition regression and the Fourier approximation. To check forecasts, other criteria such as those suggested by Diebold and Mariano (1995) and Diebold et al. (1998) can be applied.

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