Inflation Dynamics in Finland 1990Q1-2012Q1

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Pauliina Turunen

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INFLATION DYNAMICS IN FINLAND 1990Q1–2012Q1

The objective of this thesis is to study whether inflation dynamics in Finland can be described using the New Keynesian Phillips curve (NKPC) over the period 1990Q1–2012Q1. The NKPC explains current inflation with forward-looking inflation expectations and current real marginal cost. The assumption of rational expectations is relaxed in this thesis and both Consensus Economics and Statistics Finland's survey data are used as proxies for inflation expectations. Since these expectations are expectations for consumer prices, inflation is measured with annual change in the Consumer Price Index. Output gap is used as a proxy for real marginal cost. The NKPC is estimated with both Ordinary Least Squares (OLS) and Generalised Method of Moments (GMM). The variables are also analysed using the frequency domain method, which gives information on the dynamics of both correlations and lead-lag relationships of variables at different frequencies. Estimations in this thesis show that once the rational expectations hypothesis is relaxed and survey-based inflation expectations are used, inflation in Finland can be explained with the New Keynesian Phillips curve over the period 1990Q1–2012Q1. The analysis of variables in this thesis shows that the dynamics of variables used in the NKPC estimations varied at different frequencies.

Key words:

New Keynesian Phillips curve, inflation, inflation expectations, real marginal cost, frequency domain

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1   INTRODUCTION

1.1   Background

Inflation has been of interest to economists for many decades. Worldwide inflation was quite stable for three decades until the latest financial crisis that commenced in year 2008. After this, inflation and deflation fears have followed each other. Inflation has been recognised as an important vehicle to drive the economy back to its long-run growth path.

Research on inflation dynamics has largely been based on the Phillips curve. The foundations of this research are the papers of Phelps (1967) and Friedman (1968) emphasising expectations in inflation process and developing the expectations-augmented Phillips curve. At the moment the most widely recognised model among the central banks to explain inflation dynamics is the New Keynesian Phillips curve. It was developed in a synthesis of New Keynesian macroeconomics and Real Business Cycle (RBC) theory in the 1990s. The New Keynesian Phillips curve (NKPC) explains current inflation by forward-looking inflation expectations and current real marginal cost. The NKPC combines rigidities, imperfect competition and forward-looking expectations.

The New Keynesian Phillips curve emphasises rigidities in price and wage setting to explain persistence of inflation. The first models of nominal rigidities were the models of Fischer (1977) and Phelps and Taylor (1977). The rigidities in the NKPC are usually based on models of Taylor (1980) and Calvo (1983). In Taylor's model only a fraction of wages are reset in each period and wages are assumed to be fixed for a certain number of periods. In Calvo's model only a random fraction $(1 - \omega)$ of firms are able to reset their prices each period and all other firms keep their prices unchanged. Imperfect competition is an important assumption behind nominal price and wage rigidity, since it allows firms to set their prices and labour to set its wage demands. The most applied model is the model of monopolistic competition by Dixit and Stiglitz (1977). Forward-looking expectations are usually assumed to be rational in the studies of NKPC. Rational expectations have been a popular assumption in macroeconomics after Lucas (1976) introduced them to the Phillips curve.

Even though there seems to be a sound theory behind modelling inflation dynamics, it has not done well describing the empirical data. It is interesting to expand this vast literature using Finnish data. There are some studies that concentrate on Finnish inflation from the perspective of the NKPC, but their conclusions are contradictory. According to Juselius (2006a, 2006b) Finnish inflation is primarily determined by excess demand in the product market and not by the standard NKPC. However, Paloviita and Mayes (2006) found that when using the OECD inflation forecast as empirical proxy for inflation expectations and the private consumption deflator as a measure of inflation, Finnish inflation dynamics can be described using the NKPC.

1.2 Objective of the Thesis

The objective of this thesis is to study whether inflation dynamics in Finland can be described using the New Keynesian Phillips curve over the period 1990Q1–2012Q1. After deriving the theory behind the New Keynesian Phillips curve and presenting the latest research, this thesis concentrates on analysing the variables in the NKPC estimations and estimating the New Keynesian Phillips curve.

In this thesis, the theory of the New Keynesian Phillips curve that is presented combines the theories presented by Walsh (2003) and Paloviita (2008). The competition is assumed to be monopolistic and prices are adjusted randomly according to Calvo's (1983) model.

The assumption of rational expectations is relaxed and inflation expectations are measured by survey-based inflation expectations. In the empirical part of this thesis both Consensus Economics and Statistics Finland's survey data are used as proxies for inflation expectations. Inflation is measured with annual change in the Consumer Price Index. Output gap, calculated as the difference between log real GDP and its flexible price equilibrium, is used as a proxy for real marginal cost. The NKPC is estimated with two widely used methods among NKPC literature: Ordinary Least Squares (OLS) and Generalised Method of Moments (GMM). The variables are also analysed using the frequency domain method to gain understanding of inflation in Finland. This method gives information on correlations and lead-lag relationships between variables at different frequencies.

1.3   Results of the Thesis

Estimations in this thesis show that once the rational expectations hypothesis is relaxed and survey-based inflation expectations are used, inflation in Finland can be explained with the New Keynesian Phillips curve over the period 1990Q1–2012Q1. In all estimations the coefficient for output gap is correctly signed and significant. The analysis of variables in this thesis shows, however, that the dynamics of variables used in the NKPC estimations varied at different frequencies. It also shows that inflation expectations are lagging variables for inflation in the short-run.

1.4   Structure of the Thesis

The rest of this thesis is structured as follows. Chapter 2 derives the theory behind the New Keynesian Phillips curve. Chapter 3 summarises the latest research on the New Keynesian Phillips curve. Chapter 4 presents the data. Chapter 5 analyses the dynamics of Finnish inflation, inflation expectations and real marginal cost proxy. Chapter 6 shows the estimation results and chapter 7 concludes the thesis.

2   MICRO FOUNDATIONS OF THE NEW KEYNESIAN PHILLIPS CURVE

This chapter derives the New Keynesian Phillips curve from its micro foundations. The main objective of the NKPC is to explain inflation, which can be described as a continuous rise in the general price level. Therefore the theory of inflation requires the theory of price formation.

The theory of NKPC assumes monopolistic competition, nominal rigidities and forward-looking expectations. Monopolistic competition means that individual firms produce differentiated products and have a power to set nominal prices, while their pricing decisions have no effect on overall price level. Firms set nominal prices to maximise their profits. However, nominal price rigidity means that it takes time to reset the price when economy is hit by a shock. Because of nominal price rigidities, firms use forward-looking expectations in setting nominal prices. Since monopolistic competition has been assumed, the prices are set

some margin over marginal costs. Aggregation of firms' price decisions leads to aggregate inflation and the NKPC.

The theory of profit maximisation and flexible prices presented in subchapter 2.1 follows the theory presented by Walsh (2003). Theories of profit maximisation and rigid prices in subchapter 2.2 and price rigidity in the aggregate economy and the New Keynesian Phillips curve in subchapter 2.3 follow the theory presented by Paloviita (2008).

2.1   Profit Maximisation and Flexible Prices

The theory presented in this thesis consists of firms that hire labour and produce and sell differentiated products in monopolistically competitive markets, while households supply labour and purchase goods for consumption. Both firms and households behave optimally. Firms maximise their profits, while households maximise the expected present value of utility.

Firm j can set price p_{jt} for its differentiated product according to profit maximisation, since markets are monopolistically competitive. There is a continuum of firms $j \in [0,1]$ and the firm j produces the quantity c_{jt} of the differentiated product. The assumption is that each firm produces only one variety of the differentiated product.

Each firm j chooses a price p_{jt} that maximises its profit subject to two constraints. The first constraint is the production function that summarises the available technology, and the second is the demand curve that each firm faces. This chapter derives the profit maximisation problem in an economy where prices are flexible.

The production function is assumed to be

$$c_{jt} = Z_t N_{jt}, \tag{2.01}$$

where c_{jt} is the quantity of the differentiated product produced by firm j at time t, N_{jt} is labour input in firm j at time t, Z_t is an aggregate productivity disturbance at time t and $\mathrm{E}(Z_t) = 1$. For simplicity, labour is the only factor of production and the constant returns to scale has been assumed.

The quantity c_{jt} of the differentiated product produced by firm j at time t is assumed to be same as the demand d_{jt} for the differentiated product produced by firm j at time t. The demand curve d_{jt} can be written as

$$d_{jt} = \left(\frac{p_{jt}}{P_t}\right)^{-\theta} C_t, \tag{2.02}$$

where p_{jt} is a price for the differentiated product produced by firm j at time t, P_t is an aggregate price level at time t, θ is the price elasticity of demand for differentiated product produced by firm j and C_t is an aggregate level of consumption.

In the firm's profit maximisation problem, the constraint of production function can be expressed in the form of marginal cost function. Therefore, before analysing the firm's profit maximisation problem, real marginal cost function λ_t is derived from the cost minimisation problem. The firm's cost minimisation problem as shown in equation (2.03) is to choose labour input N_{jt} to minimise costs subject to marginal productivity of labour Z_t multiplied by labour input N_{jt} being greater than or equal to the quantity c_{jt} of the differentiated product produced. Equation (2.03) takes into account a real wage $\left(\frac{W_t}{P_t}\right)$, where W_t is a wage at time t and P_t is an aggregate price level at time t. Here firm j can only have a decision power on labour input N_{jt} and the quantity c_{jt} of the differentiated product produced.

$$\min_{N_{jt}} \left(\frac{W_t}{P_t} \right) N_{jt} \qquad (2.03)$$

subject to

$$Z_t N_{jt} \geq c_{jt}.$$

The Lagrangian function (2.04) is used to derive real marginal cost function λ_t.

$$\left(\frac{W_t}{P_t} \right) N_{jt} - \lambda_t \left(Z_t N_{jt} - c_{jt} \right) \qquad (2.04)$$

The first order condition for labour input N_{jt} is

$$\frac{W_t}{P_t} - \lambda_t Z_t = 0. \qquad (2.05)$$

Solving equation (2.05) for firm's real marginal cost λ_t yields

$$\lambda_t = \frac{W_t / P_t}{Z_t}. \qquad (2.06)$$

The firm's profit maximisation problem is presented in equation (2.07), where firm j chooses price p_{jt} to maximise profits at time t.

$$\max_{p_{jt}} \left(\frac{p_{jt}}{P_t} - \lambda_t \right) c_{jt} \qquad (2.07)$$

It is assumed that all firms have the same production technology and face demand curves with constant and equal demand elasticity. Since all firms face the same profit maximisation problem, the problem can be written as follows

$$\max_{p_t} \left(\frac{p_t}{P_t} - \lambda_t \right) c_t. \qquad (2.08)$$

Since the New Keynesian Phillips curve explains inflation in the short run and short run costs are mainly wage costs, the deviation of real marginal cost from its steady-state value has a linear relationship with output gap, if additionally perfect competition in the labour market is assumed and all output is consumed as Galí (2008) has shown.

There is a monotonic relationship in production function between output and labour input. Since short-run costs are mainly wage costs, the firm's real marginal cost λ_t is real wage divided by marginal productivity of labour as derived above and shown in equation (2.06).

At the same time, households provide labour input and perfect competition in the labour market is assumed; i.e., the real wage has to be equal to the marginal rate of substitution between leisure and consumption. If all output is consumed and the goods market is in equilibrium, households' optimal labour supply gives a relationship between real wage and output.

Therefore there is also a relationship between firms' real marginal cost and aggregate output. Approximation gives a relationship between output gap and the deviation of real marginal cost from its steady-state value.

Since output gap can be used as a proxy for real marginal cost, the profit maximisation problem in equation (2.08) can be expressed as follows

$$\max_{p_t}\left(\frac{p_t}{P_t} - \zeta(y_t - y_t^*)\right)c_t, \tag{2.09}$$

where $y_t - y_t^*$ is output gap at time t i.e. a difference between output y_t and its flexible price equilibrium y_t^* at time t. Variable ζ shows a linear relationship between output gap and real marginal cost.

This chapter derived profit maximisation problem in an economy where prices are flexible. The NKPC theory assumes prices to be rigid and therefore the profit maximisation problem is also subject to price rigidity. The following chapter 2.2 derives the profit maximisation problem in an economy where price rigidity is determined by Calvo (1983).

2.2 Profit Maximisation and Rigid Prices

The profit maximisation problem of firms in the absence of price rigidity that was derived in the previous chapter 2.1 and presented in equation (2.09) can be used as an input in firms' profit maximisation problem where prices are assumed to be rigid. Prices are assumed to be rigid following the approach developed by Calvo (1983). Each period a fraction $1 - \omega$ of all firms adjust their price while a fraction ω makes no adjustment.

Firms adjusting their price are randomly selected and they maximise the expected discounted value of current and future profits shown in equation (2.10). The choice of price p_t^* at time t affects the profits at some future date T if the firm has not had an opportunity to adjust the price between times t and T. The probability of no price adjustment between times t and T is ω^{T-t}.

The aggregate price level in an economy where prices are assumed to be rigid can be approximated around the steady-state equilibrium. Therefore, log-linearisation is used to approximate equations presented in this and the following subchapter. Log-linearisation is a widely used method that gives a good approximation in a moderate inflation environment.

The optimal price p_t^* is expressed in the following equation (2.10)

$$\sum_{T=t}^{\infty} (\omega\beta)^{T-t} \mathrm{E}_t \left[\log p_t^* - \log P_T - \zeta(y_T - y_T^*) \right] = 0, \tag{2.10}$$

where β is a discount factor that is $0 < \beta < 1$.

Solving equation (2.10) for optimal price p_t^* yields

$$\sum_{T=t}^{\infty} (\omega\beta)^{T-t} \mathrm{E}_t \log p_t^* = \sum_{T=t}^{\infty} (\omega\beta)^{T-t} \mathrm{E}_t \left[\log P_T + \zeta(y_T - y_T^*) \right]$$

$$\Leftrightarrow \log p_t^* = (1 - \omega\beta) \sum_{T=t}^{\infty} (\omega\beta)^{T-t} \mathrm{E}_t \left[\log P_T + \zeta(y_T - y_T^*) \right]$$

$$\Leftrightarrow \log p_t^* = (1 - \omega\beta) \left[\log P_t + \zeta(y_t - y_t^*) \right] + (1 - \omega\beta) \sum_{T=t+1}^{\infty} (\omega\beta)^{T-(t+1)} \mathrm{E}_t \left[\log P_T + \zeta(y_T - y_T^*) \right]$$

$$\Leftrightarrow \log p_t^* = (1 - \omega\beta) \left[\log P_t + \zeta(y_t - y_t^*) \right] + \omega\beta \mathrm{E}_t \log p_{t+1}^*. \tag{2.11}$$

Deducting the term $\log P_t$ on both sides of the previous equation (2.11) gives

$$\log p_t^* - \log P_t = (1 - \omega\beta)\left[\log P_t + \zeta(y_t - y_t^*)\right] + \omega\beta E_t \log p_{t+1}^* - \log P_t$$

$$\Leftrightarrow \log p_t^* - \log P_t = (1 - \omega\beta)\zeta(y_t - y_t^*) - \omega\beta \log P_t + \omega\beta E_t \log p_{t+1}^*$$

$$\Leftrightarrow \log p_t^* - \log P_t = (1 - \omega\beta)\zeta(y_t - y_t^*) + \omega\beta\left[E_t \log p_{t+1}^* - \log P_t\right]. \tag{2.12}$$

Adding and deducting the term $\log P_{t+1}$ on right hand side of equation (2.12) yields

$$\log p_t^* - \log P_t = (1 - \omega\beta)\zeta(y_t - y_t^*) + \omega\beta\left[E_t \log p_{t+1}^* - \log P_t + \log P_{t+1} - \log P_{t+1}\right]. \tag{2.13}$$

Since $\log(\frac{p_t^*}{P_t})$ is optimal relative price $\hat{p}_t^*$ and $\log(\frac{P_t}{P_{t-1}})$ is inflation rate π_t, $\log(\frac{p_{t+1}^*}{P_{t+1}})$ is optimal relative price $\hat{p}_{t+1}^*$ and $\log(\frac{P_{t+1}}{P_t})$ is inflation rate π_{t+1}. Equation (2.13) can be written as follows

$$\hat{p}_t^* = (1 - \omega\beta)\zeta(y_t - y_t^*) + \omega\beta E_t\left[\hat{p}_{t+1}^* + \pi_{t+1}\right]. \tag{2.14}$$

Firms set optimal relative price according to equation (2.14) in an economy where prices are rigid. Price rigidity in the aggregate economy and the New Keynesian Phillips curve are derived in the following chapter 2.3.

2.3   Price Rigidity in the Aggregate Economy and the New Keynesian Phillips Curve

In Calvo's model the aggregate price level P_t at time t is a weighted sum of optimal price p_t^* set at time t and the aggregate price level P_{t-1} prevailed in the previous period $t-1$. The weights are a fraction of firms $1 - \omega$ adjusting the price and ω retaining the previous price respectively. The aggregate price level P_t is shown in equation (2.15). Each period a fraction $1 - \omega$ of all firms adjust their price while a fraction ω make no adjustment.

$$\log P_t = \omega \log P_{t-1} + (1 - \omega)\log p_t^* \tag{2.15}$$

Deducting a term $\omega \log P_t$ on both sides of equation (2.15) gives equation (2.16) that can be rearranged to get finally optimal relative price $\hat{p}_t^*$ expressed as a function of inflation rate π_t.

$$\log P_t - \omega \log P_t = \omega \log P_{t-1} + (1-\omega) \log p_t^* - \omega \log P_t \tag{2.16}$$

Rearranging the terms in equation (2.16) yields equation (2.17).

$$\omega (\log P_t - \log P_{t-1}) = (1-\omega)(\log p_t^* - \log P_t) \tag{2.17}$$

Equation (2.17) can also be expressed as follows

$$\omega \log(\frac{P_t}{P_{t-1}}) = (1-\omega) \log(\frac{p_t^*}{P_t}). \tag{2.18}$$

Since $\log(\frac{P_t}{P_{t-1}})$ is inflation rate π_t and $\log(\frac{p_t^*}{P_t})$ is optimal relative price $\hat{p}_t^*$, equation (2.18) can be written as follows

$$\omega \pi_t = (1-\omega) \hat{p}_t^*. \tag{2.19}$$

Solving equation (2.19) for optimal relative price $\hat{p}_t^*$, optimal relative price $\hat{p}_t^*$ can be expressed as a function of inflation rate π_t as follows

$$\hat{p}_t^* = \frac{\omega}{1-\omega} \pi_t. \tag{2.20}$$

Since optimal relative price $\hat{p}_t^*$ can be expressed as a function of inflation rate π_t as was shown in equation (2.20) also optimal relative price $\hat{p}_{t+1}^*$ can be expressed as a function of inflation rate π_{t+1} as follows

$$\hat{p}_{t+1}^* = \frac{\omega}{1-\omega} \pi_{t+1}. \tag{2.21}$$

And therefore equation (2.14) in previous chapter 2.2 can be written as follows

$$\frac{\omega}{1-\omega}\pi_t = (1-\omega\beta)\zeta(y_t - y_t^*) + \omega\beta E_t\left[\frac{\omega}{1-\omega}\pi_{t+1} + \pi_{t+1}\right]$$

$$\Leftrightarrow \pi_t = \frac{(1-\omega)(1-\omega\beta)}{\omega}\zeta(y_t - y_t^*) + (1-\omega)\beta E_t\left[\frac{\omega}{1-\omega}\pi_{t+1} + \pi_{t+1}\right]$$

$$\Leftrightarrow \pi_t = \frac{(1-\omega)(1-\omega\beta)}{\omega}\zeta(y_t - y_t^*) + \omega\beta E_t\pi_{t+1} + (1-\omega)\beta E_t\pi_{t+1}$$

$$\Leftrightarrow \pi_t = \frac{(1-\omega)(1-\omega\beta)}{\omega}\zeta(y_t - y_t^*) + \beta E_t\pi_{t+1}. \qquad (2.22)$$

The New Keynesian Phillips curve that is derived in this chapter is usually expressed in the following form

$$\pi_t = \beta E_t\{\pi_{t+1}\} + \kappa\hat{y}_t, \qquad (2.23)$$

where $\kappa = \frac{(1-\omega)(1-\omega\beta)}{\omega}\zeta > 0$ and $\hat{y}_t = (y_t - y_t^*)$.

In this thesis the rational expectations hypothesis is relaxed and the following modified New Keynesian Phillips curve is obtained

$$\pi_t = \beta\pi_{t+1}^* + \kappa\hat{y}_t, \qquad (2.24)$$

where $\kappa = \frac{(1-\omega)(1-\omega\beta)}{\omega}\zeta > 0$ and $\hat{y}_t = (y_t - y_t^*)$.

Inflation expectations π_{t+1}^* in equation (2.24) are not necessarily rational. The empirical part of this thesis uses survey-based inflation expectations.

3 LATEST RESEARCH ON THE NEW KEYNESIAN PHILLIPS CURVE

The New Keynesian Phillips curve often faces criticism over its estimation. Since the theory of the NKPC is well-grounded, there have been many attempts to improve its empirical fit. These include discussions on the appropriate proxy for the real marginal cost. The formation of inflation expectations has also been examined, and the role of pure forward-looking rational expectations in inflation dynamics has been questioned. Even lagging variables have been added into empirical estimations, in order to test forward-looking behaviour and to introduce stronger inflation persistence. In the following subchapters the real marginal cost, inflation expectations and inflation persistence are looked at more closely.

3.1 Real Marginal Cost

The real marginal cost is the change in real total cost that arises when the quantity produced increases by one unit. Since the real marginal cost is impossible to measure, the proxy for it has to be estimated. Both the output gap and the real unit labour cost have been widely used proxies.

Output gap is the difference between the actual output and the output that would prevail if prices in the economy were flexible. It is common to use detrending methods such as the Hodrick–Prescott filter to estimate the output gap. However, the empirical fit of the NKPC theory has not been good when detrending methods have been used to estimate the output gap. Galí and Gertler (1999) introduced the labour income share, equivalent to the real unit labour cost, to gain better fit between the theory and empirical data. Rudd and Whelan (2005) showed evidence against the labour income share version of the NKPC, since the discounted sum of current and expected future labour income share explained only a little of the variation in inflation. In a recently published paper, Mazumder (2010) shows that real unit labour cost in the U.S. has been countercyclical, also casting doubt on real unit labour cost as a proxy for a real marginal cost.

3.2 Inflation Expectations

Rational expectations have been widely used in the estimations of NKPC. Lately inflation expectations have also been modelled with learning processes (see e.g. Molnár and Santoro 2010). Learning has been used to either supplement or replace rational expectations. Evans and Honkapohja (2001) summarised the learning processes in their widely recognised book.

Some studies have relaxed the assumption of rational expectations by introducing survey-based inflation expectations. Roberts (1997) and Paloviita (2006) have studied inflation in the U.S. and euro area respectively, using survey-based inflation expectations as a proxy for inflation expectations. Roberts came to the conclusion that inflation expectations are less than perfectly rational. Paloviita found that the European inflation process can be modelled using NKPC if survey-based inflation expectations are applied even when detrended output or labour income share are used as proxies for marginal costs. In a more recent study, Ball and Mazumder (2011) found that inflation expectations in the U.S. have significantly stayed at a fixed level, regardless of any movements in actual inflation showing evidence against rational expectations.

There are also papers studying the importance of forward-looking expectations in the NKPC. Including both the forward- and backward-looking components into the equation gives the possibility to assess the importance of these terms in inflation dynamics. Galí and Gertler (1999) came to the conclusion that even though there is some backward-looking behaviour in the model, the forward-looking behaviour plays an important role. Although Paloviita (2006) found that the European inflation process can be modelled using the NKPC, she also found that European inflation can be modelled more accurately with a hybrid Phillips curve, which has an additional lagged inflation term. The importance of forward- and backward-looking terms differs between countries and time periods. In a low inflation country or period, the forward-looking expectations usually dominate, while in a high inflation country or period the backward-looking expectations are the ones that dominate (see e.g. Paloviita 2006). On the other hand, Paloviita and Mayes (2005) found that the use of real-time data in estimations increases the importance of the forward-looking term. Including real-time data into the estimations is an interesting aspect since the NKPC is based on optimisation, where real-time data on variables are used as an input. Cogley and Sbordone (2008) found that inflation can be explained by the forward-looking NKPC if trend inflation is allowed to fluctuate. This

means that the flexible price inflation rate is allowed to fluctuate. In their studies inflation is explained by forward-looking expectations, and the backward-looking term had no weight.

3.3 Inflation Persistence

In the NKPC nominal price rigidity has been given a major role in explaining the persistence of inflation. It can be implemented in the macroeconomic model with state-dependent or time-dependent pricing. In state-dependent pricing models the frequency of price change is a result of the profit maximisation problem that is dependent on some defined economic variables. In the time-dependent pricing models the price change is a result of the passage of time. The vast number of macroeconomic research uses the time-dependent pricing approach, since it is easier to apply than state-dependent pricing. The most frequently used time-dependent pricing models are the models of Calvo (1983) and Taylor (1980).

However, the persistence of inflation cannot be explained only by frequency of price re-optimisation, since the NKPC estimations (see e.g. Eichenbaum and Fisher 2007) show significantly lower frequency for price re-optimisation than the survey results suggest. The same kinds of results are obtained using scanner data to study price setting. Eichenbaum et al. (2011) studied nominal rigidities using weekly scanner data containing information on prices, quantities and costs from more than 1,000 stores of a major U.S. retailer. They found that nominal rigidities take the form of inertia in the most often quoted prices and costs within a given quarter, called reference prices and costs. Weekly prices and costs changed frequently and fluctuated around reference values. The duration of reference price is almost one year, while the median price duration is only three weeks. Whereas the duration of reference cost is two quarters and median cost duration is two weeks. While costs change more frequently than prices, prices are more volatile than costs. Another interesting finding in their study was that mark-ups were held within relatively narrow bounds and therefore showed evidence for the state-dependent pricing approach.

Since persistence of inflation cannot be explained only by frequency of price re-optimisation or the nominal rigidities in price adjustment, real price rigidities have been introduced to the models. Real price rigidity is explained by supply and demand side factors (see e.g. Bergin and Feenstra 2000). Supply side factors include firm specific factors of production such as

firm specific capital (Altig et al. 2011) and labour (Woodford 2005). Christiano et al. (2005) found that inflation persistence can be acquired by staggered wage contracts and variable capital utilisation. They studied inflation persistence with a dynamic general equilibrium model and found that observed persistence after an expansion (contraction) in monetary policy can be explained by moderate amounts of nominal rigidities if a sharp increase (decrease) in marginal cost is prevented. Demand side factors include a concave demand curve. Dossche et al. (2010) studied a scanner data set from a large euro area supermarket chain and found that items and product categories had a wide variation of estimated price elasticities and curvatures of demand curves. Their results support the use of a concave demand curve, although the fraction of items showing convex demand was substantial. They also found that the degree of curvature is much lower than is generally imposed and therefore the concave demand curve alone fails to generate sufficient real price rigidity.

4 THE DATA

The NKPC that was derived in chapter 2 took the following form

$$\pi_t = \beta \pi_{t+1}^* + \kappa \hat{y}_t, \tag{4.01}$$

where $\kappa = \dfrac{(1-\omega)(1-\omega\beta)}{\omega}\zeta > 0$ and $\hat{y}_t = (y_t - y_t^*)$.

Since this thesis uses quarterly data, the NKPC can be presented as follows

$$\pi_t = \beta \pi_{t+4}^* + \kappa \hat{y}_t, \tag{4.02}$$

where $\kappa = \dfrac{(1-\omega)(1-\omega\beta)}{\omega}\zeta > 0$ and $\hat{y}_t = (y_t - y_t^*)$.

In equation (4.02) inflation π_t at time t is explained by the expected inflation π_{t+4}^* at time t for the period $t+4$ and by output gap $\hat{y}_t$ i.e. a difference between output y_t and its flexible price equilibrium y_t^* at time t. A discount factor β is usually near but less than 1. Paloviita (2006) uses 0.97 as a fixed discount factor.

Inflation is measured with annual change in the Consumer Price Index (CPI). Both Consensus Economics and Statistics Finland's survey data are used to proxy inflation expectations. Output gap is the difference between log real GDP and its flexible price equilibrium at time t. Time series of CPI, Statistics Finland's survey data for inflation expectations and real GDP are published by Statistics Finland. Consensus Economics survey data for inflation expectations is obtained from Consensus Forecasts publications that are published by Consensus Economics Inc.

The data availability projected some restrictions to NKPC estimations. Real GDP is published quarterly 1990Q1 onwards and Statistics Finland's survey data for inflation expectations is published monthly 1995M10 onwards. Time series for both the annual change in CPI and Consensus Economics survey data for inflation expectations are published monthly and were available for the whole period 1990Q1–2012Q1. Because of restrictions in data availability, the NKPC is estimated for two time periods, 1990Q1–2012Q1 and 1996Q1–2012Q1.

The flexible price equilibrium of log real GDP at time t is approximated by using the Hodrick–Prescott filter, where the smoothing parameter is 1600. Hodrick–Prescott filter is a widely used method to define flexible price equilibrium. Hodrick and Prescott (1997) divided the natural logarithm of the variable y_t into the flexible price equilibrium y_t^* and deviation c_t from the flexible price equilibrium as follows

$$y_t = y_t^* + c_t \qquad \qquad \text{for } t = 1,....,\text{T} \qquad \qquad (4.03)$$

The flexible price equilibrium y_t^* is a solution to the following minimisation problem

$$\underset{\{y_t^*\}}{Min} HP = \sum_{t=1}^{\text{T}} \left(y_t - y_t^*\right)^2 + \lambda \sum_{t=2}^{\text{T}-1} \left[\left(y_{t+1}^* - y_t^*\right) - \left(y_t^* - y_{t-1}^*\right)\right]^2. \qquad (4.04)$$

Equation (4.04) minimises the variance of the variable around the flexible price equilibrium subject to the second difference of the flexible price equilibrium. The parameter λ (lambda) is a positive number which penalises the variability in growth rate of the flexible price equilibrium. Therefore, the lambda controls the smoothness of the trend growth path. If $\lambda = 0$, the variable is on the trend growth path and the trend growth path is allowed to

fluctuate a lot. If $\lambda = \infty$, the trend growth path approaches the linear trend. There is a trade off between how well the trend component fits the data and the smoothness of the trend. The lambda depends on the frequency of the observations. The shorter the periods between observations are, the larger the lambda is. This thesis uses a standard recommendation for quarterly data, where the lambda is 1600.

4.1 Inflation

Inflation is an annual change in prices. It is usually measured with the annual change in the Consumer Price Index (CPI), in which the weights of different products and services are taken from national accounts that rely on a household budget survey.

This thesis uses annual change in the CPI as a measure of inflation, since both Consensus Economics and Statistics Finland's survey data are expectations for an average annual change in consumer prices. Figure 1 shows an annual change in the CPI in Finland for the period 1990Q1–2012Q1. Statistics Finland publishes annual change in CPI monthly. In this thesis quarterly series are calculated using monthly average figures.

The New Keynesian Phillips curve estimations often use an annual change in GDP deflator as a measure of inflation (see e.g. Cogley and Spordone 2008). The GDP deflator is an implicit price deflator and is calculated dividing GDP at current prices by GDP at reference year prices. The GDP deflator takes into account final consumption expenditure, gross fixed capital formation and net of exports and imports of goods and services. The major difference between Consumer Price Index and GDP deflator is that Consumer Price Index takes into account the net imports of goods and services while GDP deflator takes into account the net exports of goods and services. The annual change in CPI does not fit the NKPC theory as well as an annual change in GDP deflator, since the CPI also includes the prices of imported items. The GDP deflator includes only items that are produced in Finland. However, the annual change in CPI is a close approximation to the monetary policy variable of euro area that is a year-on-year increase in consumer prices over the medium term.
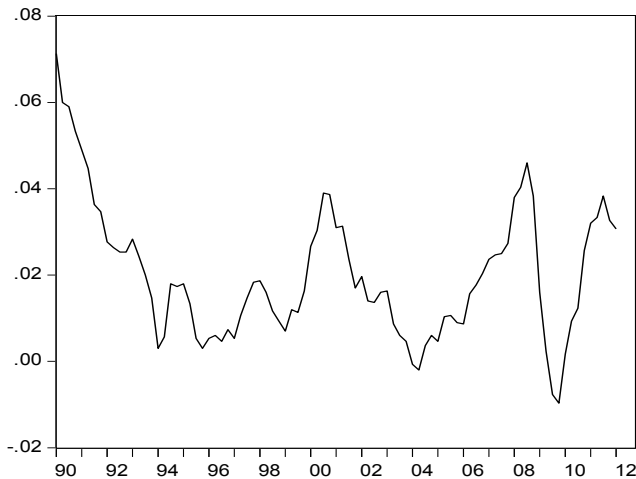
Figure 1. Inflation measured with annual change in Consumer Price Index in Finland 1990Q1–2012Q1.

Figure 1 shows that inflation has been quite volatile in period 1990Q1–2012Q1. However, in 1993 the Bank of Finland announced an explicit inflation target. The aim of the inflation target was to stabilise the rate of inflation permanently at a level of 2 per cent by the year 1995. In 1999 Finland joined the euro area, where the primary objective of monetary policy is to maintain price stability, aiming at year-on-year increase in consumer prices of below, but close to, 2 per cent over the medium term.

4.2 Inflation Expectations

The assumption of rational expectations is relaxed in this thesis and inflation expectations are measured with both Consensus Economics and Statistics Finland's survey data. Both of these inflation forecasts are published monthly.

Consensus Economics surveys financial and economic forecasters for their estimates of a range of variables including consumer price inflation. These forecasts are published in Consensus Forecasts publication. Consensus Economics inflation forecast is an average change in consumer prices on previous calendar year. This inflation forecast is made monthly for the current and following years and therefore there is need to construct a series of inflation forecast over the following 12 months. The series is constructed following Gerlach (2007). Inflation forecast over the following 12 months is a weighted average of forecasts for current and following years, where the weights depend on the month in which the forecast is made. Inflation forecast over the following 12 months is calculated as follows

$$E_m\{\pi_{m+12}\} = \left[\left(\frac{12-m}{12}\right)E_m\{\text{current year}\}\right] + \left[\left(\frac{m}{12}\right)E_m\{\text{following year}\}\right], \tag{4.05}$$

where m is the respective number of month in which inflation forecast is made, January being number 1, February number 2, March number 3 etc.

Statistics Finland has gathered Consumer Survey inflation forecast monthly since October 1995. In the survey expected inflation is measured by asking consumers the percentage change of consumer prices in the following 12 months.

Since both Consensus Economics and Statistics Finland's Consumer Survey inflation forecasts are now monthly series that forecast consumer price inflation over the following 12 months, the quarterly series can be calculated using monthly average figures. Figure 2 shows both Consensus Economics (CE) and Statistics Finland's Consumer Survey (CS) inflation forecasts made at time t for the following year.
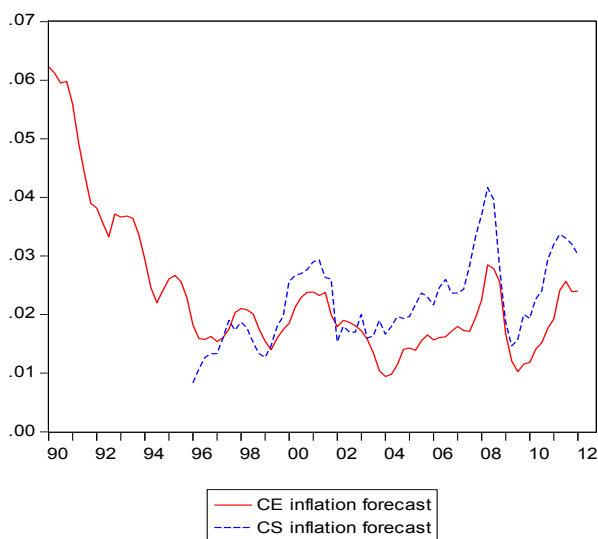
Figure 2. Inflation forecasts for the following year. Inflation forecasts of Consensus Economics (CE) 1990Q1–2012Q1 and Statistics Finland's Consumer Survey (CS) 1996Q1–2012Q1.

According to the rational expectations hypothesis, inflation expectations at time $t-n$ for period t cannot differ systematically from actual inflation at time t, if the model describing the economy is correct. Therefore, it is interesting to compare inflation forecasts made at time $t-4$ for period t and inflation at time t. Figure 3 shows that both inflation forecasts seem to

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be backward-looking and are less volatile than actual inflation. Hirvonen (2008) studied Statistics Finland's Consumer Survey data and concluded that inflation expectations seem to be determined by experienced current inflation. Consensus Economics inflation forecast seems to follow almost the same kind of pattern as Consumer Survey inflation forecast does. In other studies of Statistics Finland's Consumer Survey data, Kangassalo and Takala (2005) found that consumers emphasise prices of frequently bought commodities when forming inflation expectations. On the other hand, Lehtinen (2007) found that inflation in frequently bought commodities in Finland was greater than in other commodities between years 2000 and 2007. The studies of Kangassalo and Takala (2005) and Lehtinen (2007) may explain some part of the higher level of Consumer Survey inflation forecast compared to both Consensus Economics inflation forecast and actual inflation.

Figure 4 shows data as it is entered into the New Keynesian Phillips curve estimations. It compares inflation forecast made at time t for period t+4 and inflation at time t.
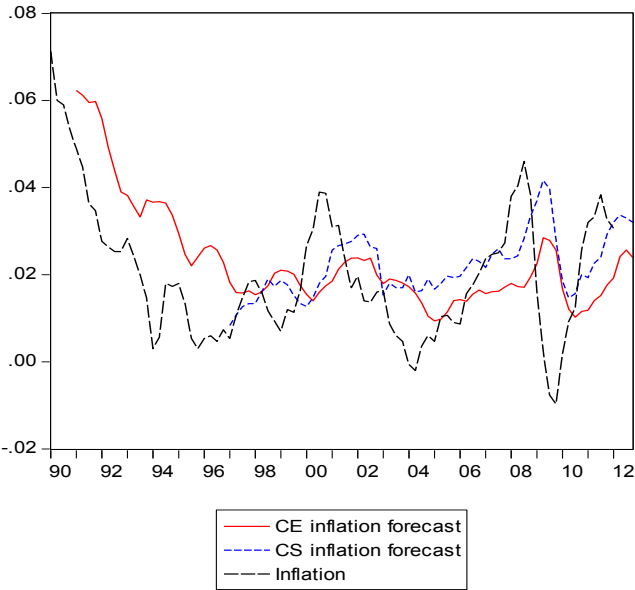
Figure 3. Inflation forecasts and inflation compared 1990Q1–2012Q1.
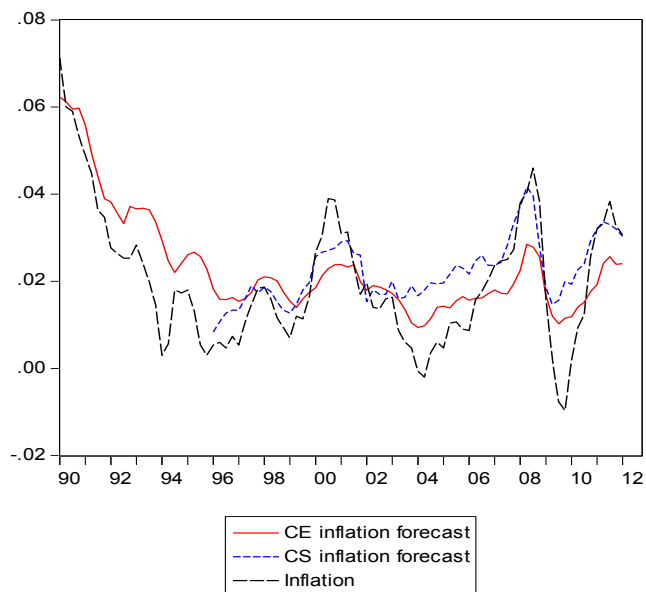
Figure 4. Inflation forecasts for the following year and inflation compared 1990Q1–2012Q1.

4.3 Real Marginal Cost

Real marginal cost is a change in real total cost that arises when the quantity produced increases by one unit. As was shown in chapter 2.1 the deviation of real marginal cost from its steady-state value has a linear relationship with output gap, if all output is consumed and perfect competition in the labour market is assumed. Therefore output gap is used as a proxy for real marginal cost. Output gap is calculated as the difference between log real GDP and its flexible price equilibrium at time t.

Figure 5 shows development of real GDP in Finland between 1990Q1 and 2012Q1. GDP is seasonally adjusted and expressed at reference year 2000 prices.
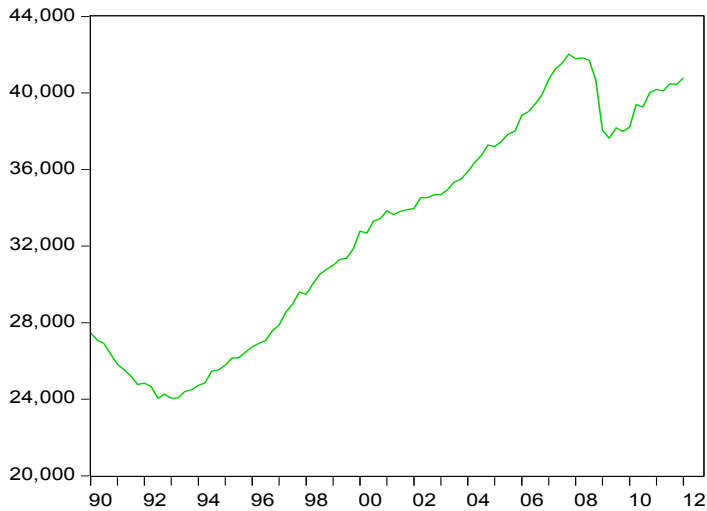
Figure 5. Seasonally adjusted GDP in millions of euros at reference year 2000 prices in Finland 1990Q1–2012Q1.

Figure 6 shows output gap for period 1990Q1–2012Q1. Output gap is a difference between log real GDP and its flexible price equilibrium at time t. It is calculated using the Hodrick–Prescott filter with a smoothing parameter of 1600.
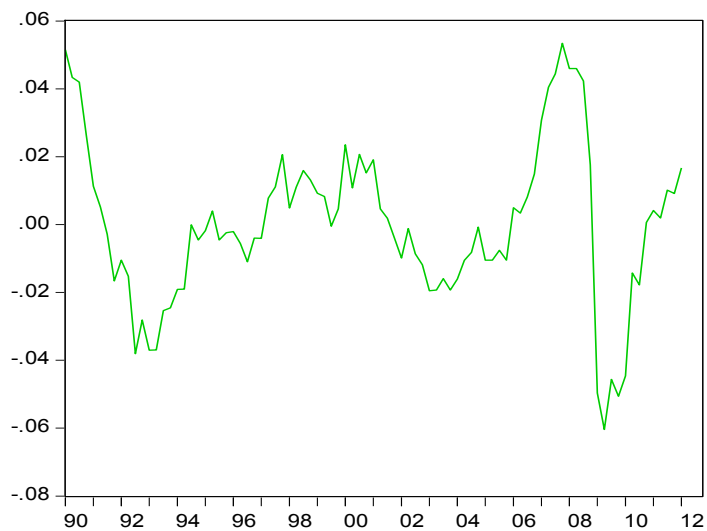
Figure 6. Output gap estimated using the Hodrick–Prescott filter for period 1990Q1–2012Q1.

Since output gap is used as a driving variable for inflation, it is interesting to see how output gap series is interacting with inflation. Figure 7 shows that inflation is a lagging variable to output gap.
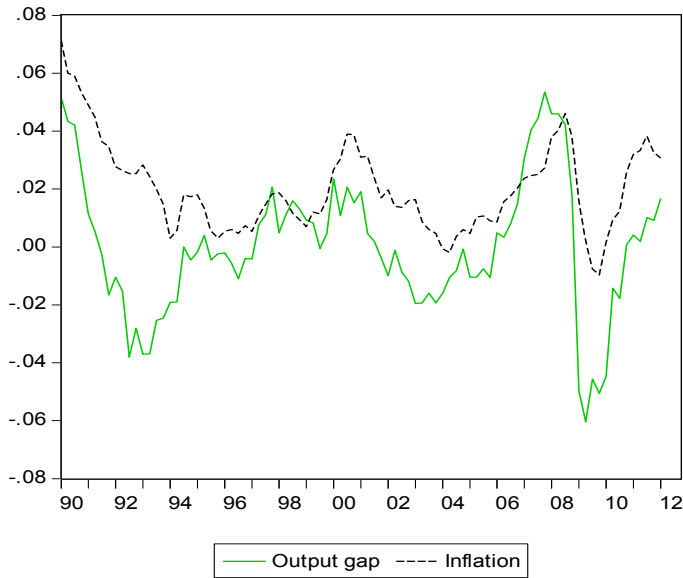
Figure 7. Output gap and inflation in Finland 1990Q1–2012Q1.

In addition to the above figures in this chapter, it is also necessary to analyse inflation and output gap in a scatter plot. Figure 8 shows that there is some evidence that output gap correlates with inflation. This correlation is an assumption behind NKPC theory.
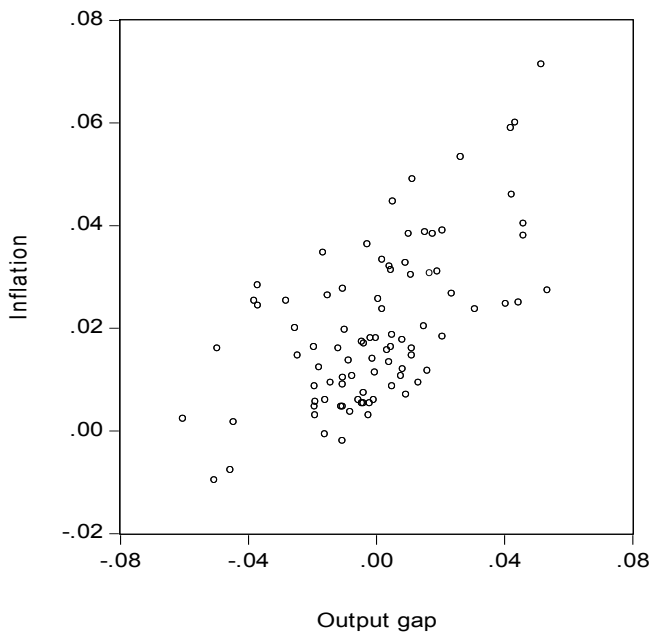
Figure 8. Scatter plot showing relationship between output gap and inflation in Finland 1990Q1–2012Q1.

5   THE DYNAMICS OF INFLATION, INFLATION EXPECTATIONS AND REAL MARGINAL COST

Before estimating the NKPC, the variables are analysed using the frequency domain method to gain understanding of inflation in Finland. The frequency domain method takes into account the dynamic nature of time series, since the variables can be analysed at different frequencies. It gives information on the dynamics of both correlations and lead-lag relationships of variables at different frequencies. The correlations and lead-lag relationships in the frequency domain are measured with coherence and phase of the cross spectrum respectively.

In a widely recognised book by Hamilton (1994) the coherence of the cross spectrum $h_{YX}(\omega)$ or population coherence between X and Y measures the joint effect the cycles of frequency ω have on X and Y. It combines the real $c_{YX}(\omega)$ and imaginary $q_{YX}(\omega)$ components of population cross spectrum $s_{YX}(\omega)$ from X to Y as follows

$$h_{YX}(\omega) = \frac{\left[c_{YX}(\omega)\right]^2 + \left[q_{YX}(\omega)\right]^2}{s_{YY}(\omega)s_{XX}(\omega)}, \tag{5.01}$$

where $0 \leq h_{YX}(\omega) \geq 1$ for all ω as long as the X and Y are covariance-stationary with absolutely summable autocovariance matrices. $s_{YY}(\omega)$ and $s_{XX}(\omega)$ represent the population spectrum of Y and X respectively. The coherence can be interpreted as a measure of correlation between the time series Y and X at different frequencies. If the coherence is close to one (zero), the series Y and X are highly (slightly) related at the frequency ω.

The phase of the cross spectrum $\theta(\omega)$ is the following

$$\theta(\omega) = \tan^{-1}\left[\frac{q_{YX}(\omega)}{c_{YX}(\omega)}\right]. \tag{5.02}$$

The slope of the phase function or diagram gives the delay in time periods. If the slope is zero there is no lead-lag relationship. In this thesis the positive (negative) slope means that inflation is a lagging (leading) variable at the frequency ω.

Each frequency ω corresponds to the time taken for variables to go through their complete sequence of values. In this thesis, frequency 0.5 corresponds to the period of two years, frequency 1.0 corresponds to the period of one year, frequency 1.5 corresponds to the period of 8 months and frequency 2.0 corresponds to the period of 6 months.

The following subchapter 5.1 concentrates on the correlations and lead-lag relationships between inflation and inflation expectations, while subchapter 5.2 concentrates on the correlations and lead-lag relationships between inflation and output gap.

5.1 Inflation and Inflation Expectations

In this chapter inflation is analysed with both Consensus Economics and Statistics Finland's Consumer Survey inflation forecast using frequency domain method. This analysis uses inflation at time t and inflation forecasts at time t for $t+4$. Inflation and Consensus Economics (CE) inflation forecast is studied for period 1990Q1–2012Q1 in figure 9 and for period 1996Q1–2012Q1 in figure 11. Figure 10 studies inflation and Statistics Finland's Consumer Survey (CS) inflation forecast in period 1996Q1–2012Q1. Both coherence and phase of the cross spectrum are seen in these figures. The coherence of the cross spectrum measures correlation between inflation and inflation forecasts at different frequencies. The phase of the cross spectrum shows which time series is leading and the extent of the lag.

Figures 9 and 11 show that there is correlation between inflation and the Consensus Economics inflation forecast at both high and low frequencies. However, the correlation is highest at low frequencies. This means that the highest correlation is at frequencies where it takes more than one year for the variables to go through their complete sequence of values. This correlation is 0.9 for period 1996Q1–2012Q1 and approximately 0.7 for period 1990Q1–2012Q1. Figure 10 shows that there is correlation between inflation and Consumer Survey inflation forecast only at frequencies where it takes more than one year for the variables to go through their complete sequence of values.

Figures 9, 10 and 11 show that inflation forecasts are leading inflation at medium frequencies, while at the highest frequencies inflation is a leading variable. A negative (positive) slope means that inflation is a leading (lagging) variable. If the slope is zero, there is no lead-lag

relationship. The major difference between the dynamics of different forecasts and inflation is that the Consumer Survey inflation forecast is lagging inflation at frequencies that correspond to a period of eight months, whereas the Consensus Economics inflation forecast is lagging inflation at frequencies that correspond to a period of six months. The degree of the slope signals the extent of the lag. At the highest frequencies the lag is large, meaning that it takes time for inflation to affect inflation expectations. The results that there are no lead-lag relationships at low frequencies are in accordance with the results that at low frequencies there is correlation between inflation and inflation forecasts.

Since the NKPC explains inflation in the short run, the high frequencies are the frequencies that are most important to concentrate on. The results above are interesting, because at the highest frequencies inflation forecasts for the following year are led by inflation while the lag is large, meaning that it takes time for inflation to affect inflation expectations for the following year. This confirms the inferences made in chapter 4.2 that inflation forecasts are backward-looking.
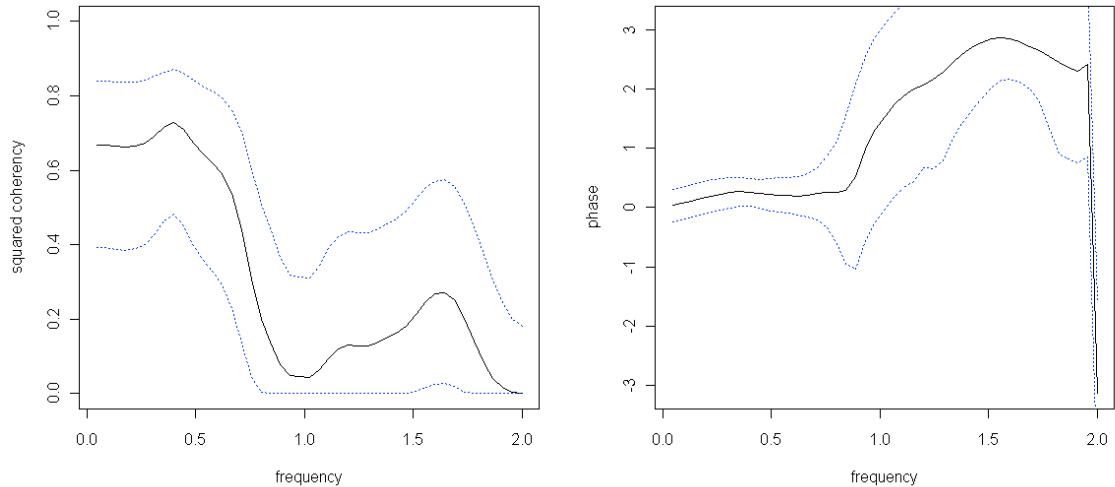
Figure 9. The coherence (left) and phase (right) of the cross spectrum between inflation and Consensus Economics inflation forecast for the following year in Finland 1990Q1–2012Q1.
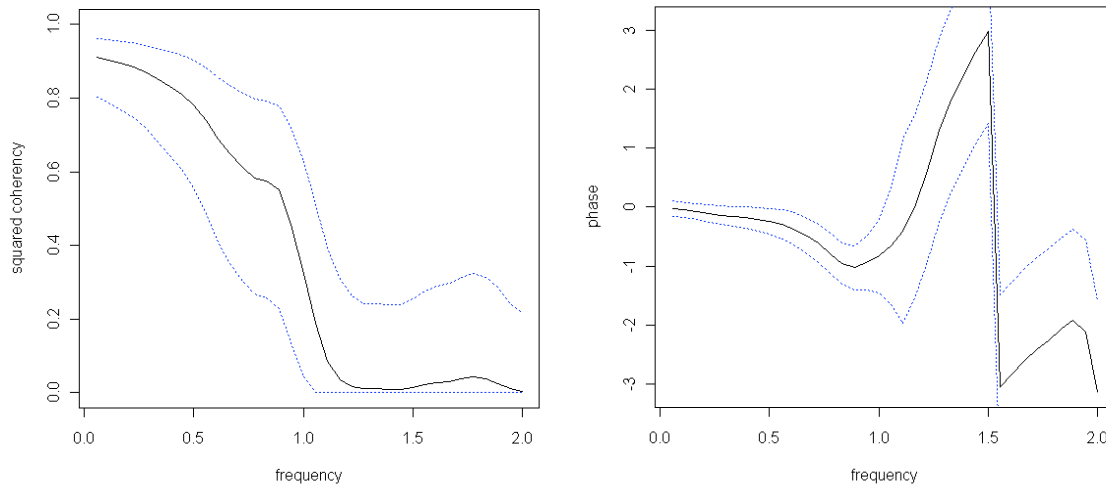
Figure 10. The coherence (left) and phase (right) of the cross spectrum between inflation and Statistics Finland's Consumer Survey inflation forecast for the following year in Finland 1996Q1–2012Q1.
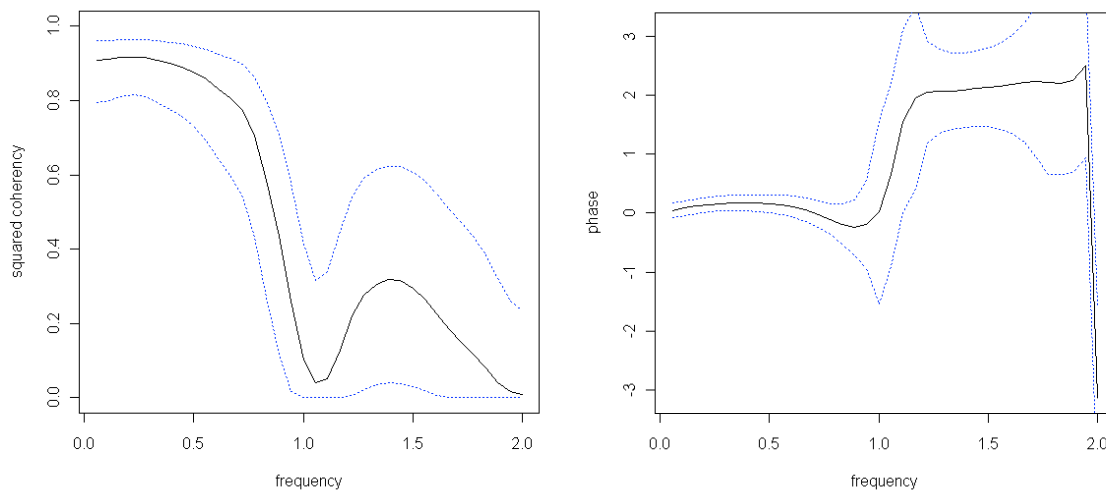
Figure 11. The coherence (left) and phase (right) of the cross spectrum between inflation and Consensus Economics inflation forecast for the following year in Finland 1996Q1–2012Q1.

5.2   Inflation and Real Marginal Cost

In this chapter inflation is analysed with output gap using the frequency domain method. This analysis uses inflation at time t and output gap at time t. Inflation and output gap is studied for period 1990Q1–2012Q1 in figure 12 and for period 1996Q1–2012Q1 in figure 13. Both coherence and phase of the cross spectrum are seen in these figures. The coherence of the cross spectrum measures correlation between inflation and output gap at different frequencies, while the phase of the cross spectrum shows which time series is leading and the extent of the lag.

Figures 12 and 13 show that there is correlation between inflation and output gap at both high and low frequencies. However, the correlation is highest at low frequencies. This means that the highest correlation is at frequencies where it takes around two years' time for the variables to go through their complete sequence of values. This correlation is approximately 0.8 for period 1996Q1–2012Q1, while it is just above 0.6 for period 1990Q1–2012Q1.

Figures 12 and 13 show that output gap is leading inflation at medium and high frequencies, while at the highest frequencies inflation is a leading variable. A negative (positive) slope means that inflation is a leading (lagging) variable. If the slope is zero, there is no lead-lag relationship. The degree of the slope shows the extent of the lag. At medium and the highest frequencies the lag is quite small, meaning that it only takes a little time for output gap to affect inflation and for inflation to affect output gap respectively. The results that there are no lead-lag relationships at low frequencies are in accordance with the results that at low frequencies there is correlation between inflation and output gap.

Since the NKPC explains inflation in the short run, the high frequencies are the frequencies that are most important to concentrate on. The results above are interesting, because at high frequencies inflation is both lagging and leading output gap. In NKPC output gap is used as a driving variable for inflation.

Figure 12. The coherence (left) and phase (right) of the cross spectrum between inflation and output gap in Finland 1990Q1–2012Q1. Output gap is the difference between log real GDP and its flexible price equilibrium, estimated using the Hodrick–Prescott filter.
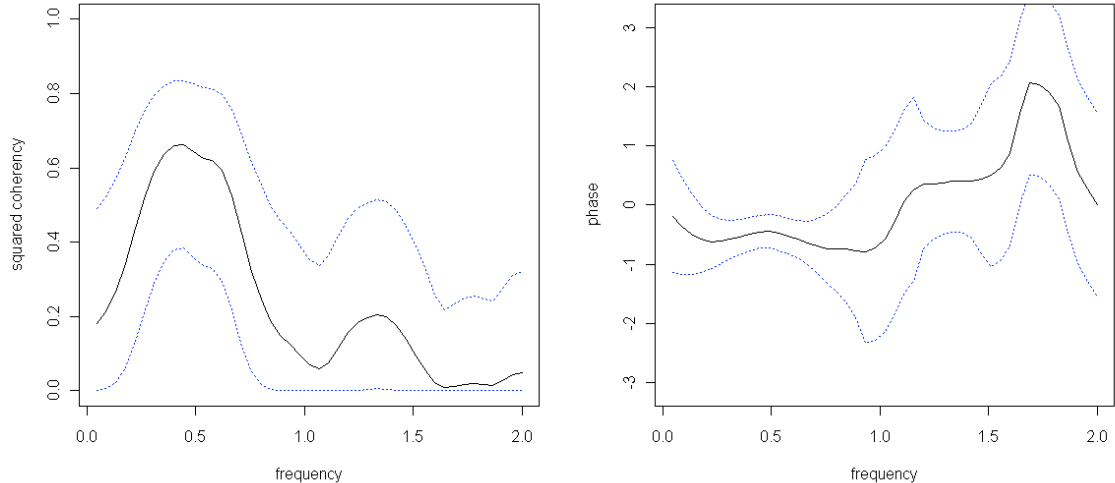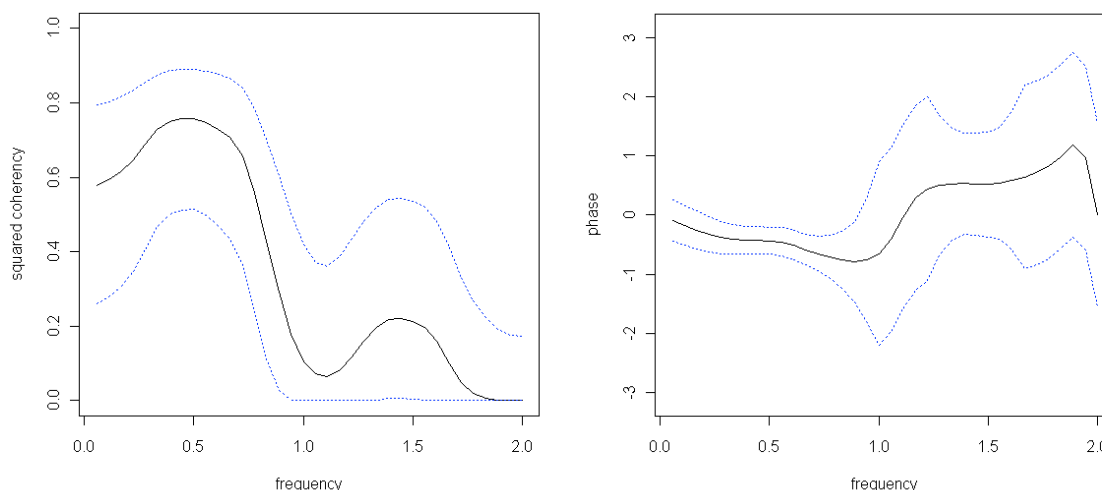
Figure 13. The coherence (left) and phase (right) of the cross spectrum between inflation and output gap in Finland 1996Q1–2012Q1. Output gap is the difference between log real GDP and its flexible price equilibrium, estimated using the Hodrick–Prescott filter.

6 ESTIMATION RESULTS

The NKPC is estimated with both Ordinary Least Squares (OLS) and Generalised Method of Moments (GMM). Estimations are run with both Consensus Economics (CE) and Statistics Finland's Consumer Survey (CS) inflation forecasts with a non-fixed and fixed discount factor. The fixed discount factor is 0.97. Estimations with Consensus Economics inflation forecast are done for both periods 1990Q1–2012Q1 and 1996Q1–2012Q1, while estimations with Consumer Survey inflation forecast are done only for period 1996Q1–2012Q1. In the first subchapter 6.1 NKPC is estimated with OLS and in the second subchapter 6.2 with GMM.

6.1 Ordinary Least Squares Estimations

The Ordinary Least Squares (OLS) estimation results for the NKPC are presented in table 1. According to the theory of NKPC the coefficient for real marginal cost is positive. The coefficient κ for output gap is correctly signed and significant in all estimations and gets values between 0.21–0.28. The Consumer Survey inflation forecast gives the lowest coefficients for output gap, while Consensus Economics inflation forecast gives the highest. These estimation results are robust, since they are largely not affected by the choice of period or measures for inflation expectations.

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In OLS estimations a non-fixed discount factor β gets values that are significant and between 0.77–0.97. As can be noticed, the values for discount factor are affected by both the choice of period and measures for inflation expectations. The lowest non-fixed discount factor is received when Consumer Survey inflation forecast is used as a measure of inflation expectations, whereas the highest is received with the Consensus Economics inflation forecast for the period 1996Q1–2012Q1. The highest non-fixed discount factor is approximately the same as the fixed discount factor used in this thesis and in studies of Paloviita (2006).

If the coefficient R^2 is used as a criterion for the estimation's goodness of fit the best estimations are received with non-fixed discount factor β. The highest coefficient is received when the Consensus Economics inflation forecast is used for the period 1990Q1–2012Q1.

Table 1. The New Keynesian Phillips curve estimation results using OLS.

$$\pi_t = \beta\pi_{t+4}^* + \kappa\hat{y}_t$$

Model	β	κ	DW	JB	R^2
NKPC with CE inflation forecast, 1990Q1–2012Q1	0.858 (0.029)***	0.281 (0.032)***	0.474	0.447	0.793
NKPC with CE inflation forecast and fixed discount factor β, 1990Q1–2012Q1	0.970	0.264 (0.035)***	0.402	0.271	0.352
NKPC with CS inflation forecast, 1996Q1–2012Q1	0.768 (0.036)***	0.256 (0.037)***	0.548	1.911	0.737
NKPC with CS inflation forecast and fixed discount factor β, 1996Q1–2012Q1	0.970	0.207 (0.043)***	0.367	0.453	0.020
NKPC with CE inflation forecast, 1996Q1–2012Q1	0.965 (0.046)***	0.269 (0.037)***	0.464	3.224	0.729
NKPC with CE inflation forecast and fixed discount factor β, 1996Q1–2012Q1	0.970	0.268 (0.036)***	0.464	3.207	0.465

Note: Numbers in parenthesis are standard errors

* Significance at 5% level

** Significance at 1% level

*** Significance at 0.1% level

In order to analyse the results presented in table 1 the possibility of a multicollinearity problem has to be considered. Multicollinearity is caused by highly correlated independent variables. In this case the relevant correlations are between inflation forecasts and output gap. Table 2 shows that the smallest correlation between inflation forecast and output gap is when the studied period is 1990Q1–2012Q1. If the period studied is only 1996Q1–2012Q1 both Consensus Economics and Consumer Survey inflation forecasts are highly correlated with output gap. The multicollinearity problem produces large standard errors but it does not cause biased results. The correlation measures suggests that the Consensus Economics inflation forecast is a better measure of expected inflation in NKPC, since it is available for a longer period than Statistics Finland's Consumer Survey inflation forecast. Estimations that use fixed discount factor β do not face the problem of multicollinearity since there is only one independent variable.

Table 2. Correlations between output gap and both Consensus Economics and Statistics Finland's Consumer Survey inflation forecast.

Correlations	Output gap
CE inflation forecast 1990Q1–2012Q1	0.284
CS inflation forecast 1996Q1–2012Q1	0.552
CE inflation forecast 1996Q1–2012Q1	0.637

Note: Output gap is the only independent variable if discount factor β is fixed.

In order to further evaluate OLS estimation results, the residuals need to be analysed. Figures 14 and 15 show residuals of the NKPC models with Consensus Economics inflation forecast for period 1990Q1–2012Q1 and Consumer Survey inflation forecast for period 1996Q1–2012Q1 respectively. Both figures show the residuals with a non-fixed and fixed discount factor β. The statistics of Durbin–Watson (DW) shown in table 1 are used to test autocorrelation of residuals. The better the model is, the less autocorrelated are the residuals. The statistics of Jarque–Bera (JB) shown in table 1 are used to test whether the residuals are normally distributed in a model.
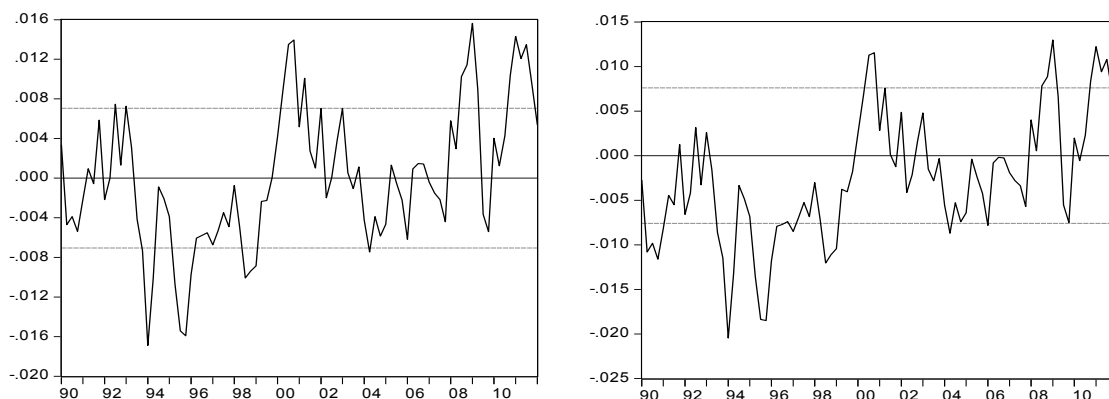
Figure 14. NKPC residuals. The model of NKPC with Consensus Economics inflation forecast for period 1990Q1–2012Q1 with a non-fixed (on left) and fixed (on right) discount factor.
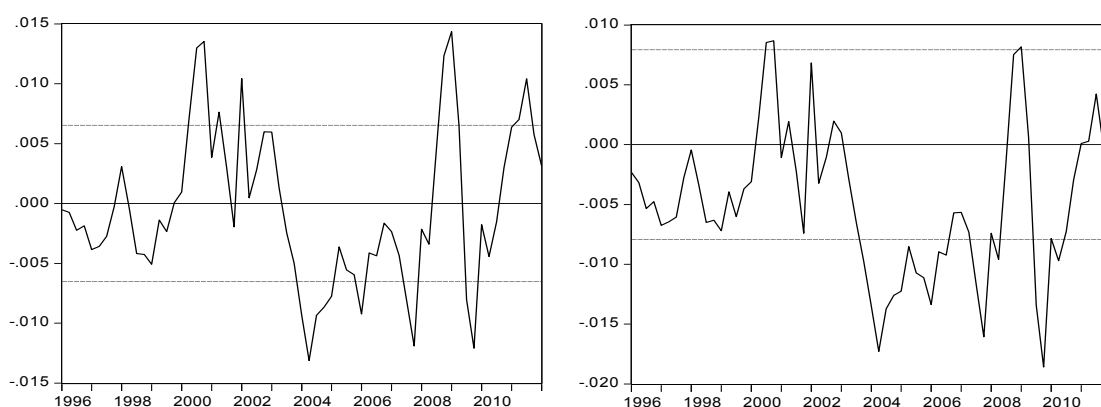
Figure 15. NKPC residuals. The model of NKPC with Statistics Finland's Consumer Survey inflation forecast for period 1996Q1–2012Q1 with a non-fixed (on left) and fixed (on right) discount factor.

The Durbin–Watson statistics measure the linear association between adjacent residuals in a regression model. If there is no serial correlation the DW is around 2. If the DW statistic is less than 2, it means that there is serial correlation and as the DW gets closer to zero, the serial correlation increases. If the DW statistic is greater than 2, there is negative correlation and as it gets closer to 4, the negative correlation increases. Table 1 shows that the Durbin–Watson (DW) statistic is around 0.5 in all OLS estimations, meaning that residuals are serially correlated.

The Jarque–Bera (JB) statistics measure whether residuals are normally distributed. Under the null hypothesis of normal distribution, the Jarque–Bera statistic is distributed as χ^2 with 2 degrees of freedom. It means that the normality assumption is rejected at the 5 per cent significance level if JB is greater than 5.991. The null hypothesis is not rejected at the 5 per

cent significance level in any estimation, meaning that residuals in all estimations are normally distributed at that significance level.

Based on the analysis above, the best NKPC model considered in this thesis using the OLS is the NKPC with Consensus Economics inflation forecast and non-fixed discount factor for period 1990Q1–2012Q1. A steepness of the NKPC can be seen in the value for coefficient κ that is 0.28. The smaller the value for coefficient κ, the more rigidity in price setting and the more quantities change in the economy as a result of an unanticipated shock. If prices are set flexibly, only the prices change, not quantities. The NKPC model with the Consensus Economics inflation forecast and non-fixed discount factor for period 1990Q1–2012Q1 shows that there was rigidity in price setting in Finland.

Even though there were significant and correctly signed coefficients in the OLS estimations, it cannot be overlooked that residuals were serially correlated. Therefore, it is necessary to estimate NKPC also with the GMM method.

6.2 Generalised Method of Moments Estimations

The Generalised Method of Moments (GMM) is an estimation method whereby GMM estimates are robust to heteroskedasticity and autocorrelation of unknown form. GMM method is also valuable if there are measurement errors in variables. In this thesis both inflation expectations variables and output gap as a real marginal cost proxy may contain measurement errors.

Tables 3 and 5 show the GMM estimation results for NKPC with Consensus Economics inflation forecast for periods 1990Q1–2012Q1 and 1996Q1–2012Q1 respectively. Table 4 shows GMM estimation results for NKPC with Statistics Finland's Consumer Survey inflation forecast for period 1996Q1–2012QQ1. In all three tables there are estimation results with a non-fixed and fixed discount factor β. The fixed discount factor is again 0.97.

In all estimations the standard errors of estimated parameters were modified using Bartlett or a quadratic kernel with variable Newey–West bandwidth. Prewhitening was also applied in some estimations. The choice between the use of Bartlett or quadratic kernel was made based

on the significance of estimated coefficients. The same was applied to decide whether prewhitening was necessary.

The variables that are independent are assumed to need an instrument. Here the instruments are lagged variables of both output gap and inflation. J-statistic tests the hypothesis that instruments are not correlated with an error term. In order to test the hypothesis, the model needs to be overidentified. This means that in the estimations there must be more instruments than variables that need instruments. The hypothesis that instruments are not correlated with an error term would be abandoned if p-value is 0.05 or less. In all GMM estimations in this thesis, the hypothesis is supported and therefore instruments are not correlated with an error term.

The coefficient κ for output gap is correctly signed and significant in all GMM estimations. In tables 3, 4 and 5 the coefficient κ for output gap is between 0.12–0.63. If lagged terms of inflation are not the only instruments included in estimations, then the coefficient for output gap is between 0.12–0.38. The estimations with Statistics Finland's Consumer Survey inflation forecast give both the lowest and highest values for output gap coefficients. These coefficients received from estimations using the Consumer Survey inflation forecast are the closest to the results of Paloviita and Mayes (2006). In their study, the coefficient for Finnish output gap was 0.229 when NKPC was estimated with GMM and inflation was measured with the private consumption deflator, and inflation expectations with OECD forecast for private consumption deflator. Even though there are differences in estimation results for coefficient κ depending on the inflation forecast and instruments used, the results are robust between periods and between modification methods of standard errors.

In GMM estimations, the non-fixed discount factor β gets values that are significant and between 0.61–0.93. As can be noticed, the value of discount factor is affected by both the choice of period and a measure of inflation expectations. The lowest discount factor is received when the Consumer Survey inflation forecast is used as a measure of inflation expectations, whereas the highest is received with the Consensus Economics inflation forecast for the period 1990Q1–2012Q1. In all estimations the non-fixed discount factor receives values that are lower than the fixed discount factor, 0.97.

Table 3. The New Keynesian Phillips curve estimation results using GMM and Consensus Economics inflation forecast as inflation expectations, Finnish data between 1990Q1 and 2012Q1.

$$\pi_t = \beta\pi_{t+4}^* + \kappa\hat{y}_t$$

Model	β	κ	J-statistic	Instruments	GMM	Obs
NKPC	0.842 (0.059)***	0.337 (0.035)***	0.013 [0.910]	$\hat{y}_{t-1}$, $\hat{y}_{t-2}$, $\hat{y}_{t-3}$	B, V, –	86
NKPC	0.925 (0.060)***	0.287 (0.035)***	0.045 [0.833]	$\hat{y}_{t-1}$, $\hat{y}_{t-2}$, π_{t-1}	B, V, –	87
NKPC	0.933 (0.061)***	0.312 (0.041)***	0.062 [0.804]	$\hat{y}_{t-1}$, π_{t-1}, π_{t-2}	B, V, –	87
NKPC	0.895 (0.084)***	0.611 (0.132)***	0.009 [0.923]	π_{t-1}, π_{t-2}, π_{t-3}	B, V, –	86
NKPC with fixed discount factor β	0.97	0.307 (0.041)***	0.020 [0.888]	$\hat{y}_{t-1}$, $\hat{y}_{t-2}$	Q, V, P	87
NKPC with fixed discount factor β	0.97	0.288 (0.050)***	0.033 [0.740]	$\hat{y}_{t-1}$, π_{t-1}	B, V, –	88
NKPC with fixed discount factor β	0.97	0.483 (0.128)***	0.018 [0.892]	π_{t-1}, π_{t-2}	B, V, –	87

Note: Numbers in parenthesis are standard errors

* Significance at 5% level

** Significance at 1% level

*** Significance at 0.1% level

J-statistic tests the hypothesis that instruments are not correlated with an error term. P-value is shown in brackets.

GMM options: B = Bartlett kernel, Q = Quadratic kernel, V = variable Newey–West bandwidth and P = prewhitening

Table 4. The New Keynesian Phillips curve estimation results using GMM and Statistics Finland's Consumer Survey inflation forecast as inflation expectations, Finnish data between 1996Q1 and 2012Q1.

$$\pi_t = \beta\pi_{t+4}^* + \kappa\hat{y}_t$$

Model	β	κ	J-statistic	Instruments	GMM	Obs
NKPC	0.725 (0.062)***	0.298 (0.047)***	0.030 [0.863]	$\hat{y}_{t-1}$, $\hat{y}_{t-2}$, $\hat{y}_{t-3}$	B, V, –	62
NKPC	0.631 (0.061)***	0.210 (0.026)***	0.081 [0.776]	$\hat{y}_{t-1}$, $\hat{y}_{t-2}$, π_{t-1}	Q, V, –	63
NKPC	0.607 (0.055)***	0.245 (0.040)***	0.080 [0.777]	$\hat{y}_{t-1}$, π_{t-1}, π_{t-2}	B, V, –	63
NKPC	0.640 (0.094)***	0.633 (0.129)***	0.022 [0.882]	π_{t-1}, π_{t-2}, π_{t-3}	B, V, –	62
NKPC with fixed discount factor β	0.97	0.124 (0.057)*	0.080 [0.777]	$\hat{y}_{t-1}$, $\hat{y}_{t-2}$	Q, V, –	63
NKPC with fixed discount factor β	0.97	0.380 (0.161)*	0.038 [0.846]	$\hat{y}_{t-1}$, π_{t-1}	Q, V, P	64
NKPC with fixed discount factor β	0.97	0.300 (0.071)***	0.096 [0.756]	π_{t-1}, π_{t-2}	Q, V, –	63

Note: Numbers in parenthesis are standard errors

Table 5. The New Keynesian Phillips curve estimation results using GMM and Consensus Economics inflation forecast as inflation expectations, Finnish data between 1996Q1 and 2012Q1.

$$\pi_t = \beta\pi_{t+4}^* + \kappa\hat{y}_t$$

Model	β	κ	J-statistic	Instruments	GMM	Obs
NKPC	0.882 (0.082)***	0.360 (0.030)***	0.023 [0.880]	$\hat{y}_{t-1}$, $\hat{y}_{t-2}$, $\hat{y}_{t-3}$	B, V, −	62
NKPC	0.836 (0.107)***	0.315 (0.033)***	0.016 [0.899]	$\hat{y}_{t-1}$, $\hat{y}_{t-2}$, π_{t-1}	Q, V, P	63
NKPC	0.842 (0.104)***	0.308 (0.030)***	0.018 [0.894]	$\hat{y}_{t-1}$, π_{t-1}, π_{t-2}	Q, V, P	63
NKPC	0.868 (0.148)***	0.614 (0.140)***	0.018 [0.892]	π_{t-1}, π_{t-2}, π_{t-3}	B, V, −	62
NKPC with fixed discount factor β	0.97	0.307 (0.033)***	0.013 [0.911]	$\hat{y}_{t-1}$, $\hat{y}_{t-2}$	Q, V, P	63
NKPC with fixed discount factor β	0.97	0.290 (0.036)***	0.119 [0.731]	$\hat{y}_{t-1}$, π_{t-1}	B, V, −	64
NKPC with fixed discount factor β	0.97	0.580 (0.109)***	0.026 [0.871]	π_{t-1}, π_{t-2}	B, V, −	63

6.3   Concluding Remarks from the Estimations

Estimations in chapters 6.1 and 6.2 show that current inflation can be explained with survey-based inflation expectations and the output gap in Finland between 1990Q1 and 2012Q1. The NKPC was estimated with both Ordinary Least Squares (OLS) and Generalised Method of Moments (GMM). In these estimations both Consensus Economics and Statistics Finland's Consumer Survey inflation forecasts were used as proxies for inflation expectations. Consensus Economics inflation forecast was used for both periods 1990Q1–2012Q1 and 1996Q1–2012Q1, while Statistics Finland's Consumer Survey inflation forecast was used for period 1996Q1–2012Q1. Since the estimations were based on quarterly data, the number of observations was sufficient.

Comparing the estimation results of OLS in table 1 and GMM in tables 3, 4 and 5 is interesting, because they show the same kind of results. In all NKPC estimations in this thesis the coefficient κ for output gap is correctly signed and significant. The non-fixed discount factor β is also significant in all estimations.

The coefficients for output gap get a wider range of values 0.12–0.63 in GMM estimations than 0.21–0.28 in OLS estimations. However, the coefficients received from GMM estimations are largely affected by the choice of instruments. If the instruments do not only include the lagged terms of inflation, then the coefficients for output gap are between 0.12–0.38. In both GMM and OLS estimations the lowest coefficient is received with Statistics Finland's Consumer survey inflation forecast. In GMM estimations Consumer Survey inflation forecast also gives the highest coefficients for output gap. The coefficients for output gap are largely not affected by the choice of period.

The steepness of the NKPC can be seen in the value of coefficient κ for output gap. The smaller the value for coefficient κ, the more rigidity in price setting and the more quantities change in the economy as a result of an unanticipated shock. Estimations with GMM show both higher and lower price rigidity than OLS estimations, since GMM gives a wider range of values for coefficients than OLS estimations. Since both inflation expectations variables and output gap as a real marginal cost proxy may contain measurement errors, the GMM method is more reliable.

The non-fixed discount factor β gets values 0.61–0.93 in GMM estimations and 0.77–0.97 in OLS estimations. In both GMM and OLS estimations the lowest values for discount factor are received when Statistics Finland's Consumer Survey inflation forecast is used as a measure of inflation expectations. The choice of period affected the values of discount factor in both GMM and OLS estimations. In GMM estimations the highest discount factor is received for the period 1990Q1–2012Q1, while in OLS estimations the highest is received for the period 1996Q1–2012Q1. In OLS estimations the highest discount factor is approximately the same as the fixed discount factor used in this thesis and in Paloviita (2006).

7 CONCLUSIONS

This thesis has looked at the New Keynesian Phillips curve from both a theoretical and empirical perspective. The NKPC theory explains current inflation with forward-looking inflation expectations and current real marginal cost. In this thesis the rational expectations hypothesis is relaxed and inflation expectations are measured with survey-based inflation expectations. The empirical part of this thesis showed that once the rational expectations hypothesis is relaxed and survey-based inflation expectations are used, inflation in Finland can be explained with the New Keynesian Phillips curve over the period 1990Q1–2012Q1.

In NKPC estimations the annual change in GDP deflator is the most frequently used measure of inflation. However, this thesis used an annual change in the Consumer Price Index as a measure of inflation, because inflation expectations that were available on a quarterly basis were expectations for the annual change in consumer prices. The annual change in consumer prices does not fit the NKPC theory as well as annual change in GDP deflator, because the annual change in consumer prices includes also the prices of imported items. The GDP deflator only includes items that are produced in Finland. However, the annual change in consumer price is a close approximation to the monetary policy variable of the euro area that is a year-on-year increase in consumer prices over the medium term.

The analysis of variables in this thesis showed that the dynamics of variables used in the NKPC estimations varied at different frequencies. Therefore the NKPC should be estimated for different frequencies separately. As the NKPC explains inflation in the short run, the main interest would be at the high frequencies.

The analysis of variables in this thesis also showed that inflation expectations are lagging variables for inflation in the short-run. Since inflation expectations are important in monetary policy decision-making processes, they should be studied even further. If inflation expectations are backward-looking, as the analysis in this thesis showed, monetary policy does not have as much power in the economy as it would if inflation expectations were forward-looking. Inflation expectations and inflation could also be further analysed with the frequency domain method. Both variables are available on a monthly basis, and therefore they could also be studied at even higher frequencies than studied in this thesis with quarterly data.

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