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The Monetary Policy in Korea with a Multi-sector Model

다섹터 모형으로 본 한국의 통화정책

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Abstract

This paper aims to investigate the conduct of monetary policy in Korea with respect to its target inflation index in a multi-sector framework. We develop a multi-sector New Keynesian model and construct an optimal price index (OPI) to assess the performance of the CPI inflation targeting adopted in Korea. From the normative analysis, we find that the OPI inflation targeting can reduce the welfare loss by 0.18 percent of the steady-state consumption in Korea. Furthermore, from the empirical analysis with data, we observe several results as follows: (1) The CPI inflation targeting in Korea is not far apart from the OPI inflation targeting, (2) However, there exist non-negligible differences between the policy rates under the two inflation targeting schemes since the OPI inflation is less volatile and more persistent than the CPI inflation, (3) The actual policy rate is relatively inertial and highly correlated with the policy rate under the OPI inflation targeting, which may provide justification for the Bank of Korea's tendency to adjust the policy rate slowly and cautiously.

Keywords: Korean monetary policy, Optimal monetary policy, Multi-sector New-Keynesian model, Heterogeneity in price stickiness, Inflation targeting

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1 Introduction

For several decades, a large number of central banks around the world have adopted inflation targeting as a framework for monetary policy. In such a regime, central bank has an explicit target inflation rate so that the price level is anchored. Apart from a quantitative target which a central bank sets, there have been considerable concerns on what measure of inflation rate it should target. Measures of the overall price level without consideration of sectoral heterogeneity, such as the consumer price index (CPI), are widely used to design target inflation rates. The Bank of Korea has committed to CPI inflation targeting in pursuit of price stability. That is, it sets a quantitative target in terms of the CPI inflation which is measured by the year-on-year change in CPI and conducts monetary policy to maintain the rate of CPI inflation near its target.

However, there is a growing interest in several properties of sectoral heterogeneity which play a pivotal role in promoting monetary policy transmission mechanisms. A recent stream of research focuses on sectoral heterogeneity in nominal rigidities and discusses how it affects the conduct of monetary policy in a multi-sector economy. Bils and Klenow (2004), and Nakamura and Steinsson (2008) find empirical facts of the heterogeneity in sectoral nominal rigidities based on micro data. Furthermore, Aoki (2001), Mankiw and Reis (2003), Benigno (2004), and Eusepi, Hobijn, and Tambalotti (2012) suggest a way to harmonize sectoral inflation rates based on the sectoral heterogeneity in nominal rigidities to approximate optimal monetary policy. This approach is rooted in the analysis of several sources of social welfare loss. As the central bank has only one instrument in performing monetary policy, the economy cannot cope with all the sources of welfare loss. Recognizing this intrinsic limitation, there have been considerable efforts to construct an optimal inflation index (OPI, hereafter) that generates the approximated optimal monetary policy.

The main contribution of this paper is that we investigate the conduct of monetary policy in Korea with respect to its target inflation index by considering sectoral heterogeneity in price stickiness across sectors. For the analysis, we adopt two inflation indices. First one is the OPI inflation which gives more weights to the sectoral inflation rates in stickier sectors. As shown in Benigno (2004), it is an optimally weighted average of sectoral inflation rates whose stabilization maximizes the social welfare. Another one

is the index that aggregates sectoral inflation rates by their normalized sector sizes. It is in contrast to the OPI inflation in that it only takes the sector sizes into consideration when determining the overall inflation level. In the case of Korea, by defining sectors as the twelve consumption categories in household consumption, the latter is same as the CPI inflation which is the target inflation index used in the Bank of Korea. Then, we are interested in the performance of the CPI inflation targeting compared to the OPI inflation targeting.

We use a multi-sector New Keynesian model with heterogeneity in nominal rigidities across sectors. There are two sources - sectoral inflation rates and relative price gaps across sectors - which induce welfare loss. As mentioned before, because of the intrinsic limitation of making the two sources in control, a central bank cannot achieve the perfect stabilization of both. The resulting optimal targeting strategy is to put higher weights on stickier sectors. Based on this mechanism, we numerically derive OPI inflation. First, we build a database with measures of nominal rigidities across sectors. We consider the twelve consumption categories in household consumption and estimate the sectoral nominal rigidities by taking a semi-structural approach. Then, we calibrate the model and construct the OPI inflation that minimizes the welfare loss in the model. In order to compare the OPI inflation targeting with the CPI inflation targeting, we compute the welfare gap between them.

Finally, we evaluate the current monetary policy in Korea based on the realized OPI inflation, CPI inflation and core inflation over the sample period 2003-2016. With the three forms of inflation rate, we use the Taylor rule and derive three different forms of the interest rates. From these, we observe several findings of the monetary policy in Korea. First, the CPI inflation targeting in Korea is not far apart from the OPI inflation targeting. This is based on the fact that all of the aforementioned inflation indices and the policy rates based on them behave in a quite similar way. Also, the series of OPI inflation lies closer to the series of CPI inflation than the series of core inflation which used to be the target inflation index in Korea before 2007. Second, there are non-negligible differences between the policy rates under the OPI inflation targeting and the CPI inflation targeting, which emerge from the ranking of volatility and persistence. From the realized series, we find that the policy rates derived with the OPI inflation exhibit lower volatility and

higher persistence than those with the CPI inflation. This is based on the fact that the OPI inflation is less volatile and more persistent than the CPI inflation in the case of Korea. Furthermore, examining the actual policy rate (call rate) series, we find that it is highly correlated with the policy rates under the OPI inflation targeting. Reflecting on it, we may justify the Bank of Korea's preference to adjust the policy rate slowly and cautiously.

The rest of the paper is organized as follows. Section 2 presents the multi-sector model, monetary policy and the welfare criterion. Section 3 depicts the characteristics of our multi-sector which is defined by the twelve consumption categories of household consumption in Korea and reports calibrations of model parameters. Section 4 discusses the main mechanism of deriving the OPI, calculates the weights that construct the OPI under several calibrations of the model, and presents the welfare analysis. Section 5 derives the inflation and policy rate paths based on the OPI inflation, CPI inflation and the core inflation, and presents some implications of the monetary policy in Korea through the comparison of them. Finally, section 6 concludes.

2 Model

In this section, we present a multi-sector New Keynesian model which is in line with Woodford (2003) and Benigno (2004). The model characterizes heterogeneity in sectoral price stickiness. The entire economy with a single central bank lies in the interval [0,1]. It is composed of subintervals $\mathcal{I}_j$ of a sector $j = 1, 2, \ldots, J$, of which size is n_j with $\sum_{j=1}^{J} n_j = 1$. We assume that a continuum of agents are populated on the interval [0,1], who are consuming composite goods and working in firm j in sector i. To simplify, we assume a representative agent in each sector.

2.1 Households

2.1.1 Households problem

The representative household in sector j who gains utility from consuming composite goods and disutility from working has the following lifetime utility:

$$U_{j,t} = \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t \left\{ U\left(C_{j,t}\right) - \frac{1}{n_j} \int_{\mathcal{I}_j} V\left(N_{j,t}\left(i\right)\right) di \right\} \right]$$

where the utility and disutility functions have the following functional forms:

$$U(C_{j,t}) = \frac{C_{j,t}^{1-\rho} - 1}{1-\rho} \quad \text{and} \quad V(N_{j,t}(i)) = \frac{N_{j,t}^{1+\eta}(i)}{1+\eta}$$

Here, $C_{j,t}$ is the composite consumption of sector j household and $N_{j,t}(i)$ is the agent's labor supply at firm i in sector j at period t. The parameter β is an intertemporal discount factor with $0 < \beta < 1$, ρ indicates the coefficient of relative risk aversion, and $\frac{1}{\eta}$ implies the Frisch elasticity of labor supply.

The household in sector j faces the budget constraint below:

$$P_t C_{j,t} + \mathbb{E}_t \left[Q_{t,t+1} B_{j,t+1} \right] = B_{j,t} + \frac{1}{n_j} \int_{\mathcal{I}_j} W_{j,t}(i) N_{j,t}(i) di + \frac{1}{n_j} \int_{\mathcal{I}_j} \Pi_{j,t}(i) di - P_t T_t$$

where P_t is the price of sector j household's composite consumption goods. We assume that a complete set of securities that completely spans all the states of nature is available within each sector. $B_{j,t}$ is the nominal payoffs of the portfolio held by the agent in region j at period t, $Q_{t,t+1}$ is the nominal stochastic factor, $W_{j,t}(i)$ refers to a nominal wage offered by firm i in sector j, $\Pi_{j,t}(i)$ is profit income earned from firm i in sector j, and $P_t T_t$ is net of lump-sum taxes.

2.1.2 Consumption aggregates and Price indices

The composite consumption goods is defined as a Cobb-Douglas aggregate of sectoral goods, which is in line with Obstfeld and Rogoff (1998, 2000):

$$C_{j,t} \equiv \prod_{k=1}^{J} \left(\frac{C_{j,k,t}}{n_k} \right)^{n_k}$$

where $C_{j,k,t}$ is sector j representative household's consumption of differentiated goods produced in sector k. It is defined as:

$$C_{j,k,t} \equiv \left[\left(\frac{1}{n_k} \right)^{\frac{1}{\sigma}} \int_{\mathcal{I}_k} C_{j,k,t}(i)^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}}$$

where σ refers to the elasticity of substitution among the continuum of goods produced within a sector.

From the standard expenditure minimization, the consumer price index (CPI), P_t, is obtained as follows:

$$P_t = \prod_{j=1}^{J} \left(P_{j,t} \right)^{n_j}$$

where $P_{j,t}$ is the sectoral (sector j) price index. Here, the demand for sectoral goods is given so that the representative household in sector j can optimally allocate its expenditure on sectoral goods. It is given as:

$$C_{j,k,t} = n_k \left(\frac{P_{k,t}}{P_t} \right)^{-1} C_{j,t}$$

The sectoral (sector j) price index, $P_{j,t}$, is also constructed by solving the standard expenditure minimization problem:

$$P_{j,t} = \left[\left(\frac{1}{n_j} \right) \int_{\mathcal{I}_j} P_{j,t}(i)^{1-\sigma} di \right]^{\frac{1}{1-\sigma}}$$

where $P_{j,t}(i)$ is the price of goods produced at firm i in sector j. Likewise, the demand

for individual goods is obtained by optimally allocating the expenditure on individual goods. It is followed by:

$$C_{j,k,t}(i) = \left(\frac{P_{k,t}(i)}{P_{k,t}}\right)^{-\sigma} \left(\frac{P_{k,t}}{P_t}\right)^{-1} C_{j,t}$$

Lastly, we define the aggregate consumption for the economy as:

$$C_t \equiv \sum_{j=1}^{J} n_j C_{j,t}$$

Then, the total demand for sectoral and individual goods can also be derived:

$$C_{k,t} = n_k \left(\frac{P_{k,t}}{P_t}\right)^{-1} C_t$$
$$C_{k,t}(i) = \left(\frac{P_{k,t}(i)}{P_{k,t}}\right)^{-\sigma} \left(\frac{P_{k,t}}{P_t}\right)^{-1} C_t$$

where $C_{k,t} = \sum_{j=1}^{J} n_j C_{j,k,t}$ and $C_{k,t}(i) = \sum_{j=1}^{J} n_j C_{j,k,t}(i)$.

2.1.3 First-order conditions

Back to the household problem of maximizing the utility under the budget constraint, the consumption of composite goods and the labor supply can be obtained from the inter-temporal and intra-temporal optimality conditions as follows:

$$\frac{1}{R_t} = \beta \mathbb{E}_t \left[\frac{C_{j,t}^{\rho} P_t}{C_{j,t+1}^{\rho} P_{t+1}}\right]$$
$$N_{j,t}(i)^{\eta} C_{j,t}^{\rho} = \frac{W_{j,t}(i)}{P_t}$$

where $\mathbb{E}_t Q_{t,t+1} \equiv \frac{1}{R_t}$.

2.2 Firms

A monopolistically competitive firm in each sector optimally sets prices as in Calvo (1983) and Yun (1983). Each producer in sector j (for $j = 1, 2, \ldots J$) updates his/her

price with a fixed per-period probability $(1-\alpha_j)$. Note that this probability is assumed to be sector-specific, which induces sectoral heterogeneity in nominal rigidities. A price-adjusting firm in sector j faces the pricing problem to maximize a discounted sum of expected profits as follows:

$$\max_{P_{j,t}(i)} \mathbb{E}_t \sum_{k=0}^{\infty} \left(\alpha_j^k Q_{t,t+k}\right) \left[P_{j,t}(i) Y_{j,t+k}(i) - (1-s) W_{j,t+k}(i) N_{j,t+k}(i)\right]$$

subject to the demand function for its product:

$$Y_{j,t+k}(i) = \left(\frac{P_{j,t}(i)}{P_{j,t+k}}\right)^{-\sigma} \left(\frac{P_{j,t+k}}{P_{t+k}}\right)^{-1} Y_{t+k}$$

where $Q_{t,t+k} = \beta^k \left(\frac{P_t}{P_{t+k}}\right) \left(\frac{C_{j,t}}{C_{j,t+k}}\right)^{\rho}$ comes from the household inter-temporal optimality condition, the term in the bracket is the expected profits for firm i, and s refers to a constant subsidy rate which is set to cancel out the mark-up charged by a firm over its marginal cost.

Since firms within a sector reset their prices at the same time, they choose a common price denoted by $P^*_{j,t}(i) = P^*_{j,t}$. Then, the law of motion for the sectoral price index is given by:

$$P_{j,t} = \left[\alpha_j P_{j,t-1}^{1-\sigma} + (1-\alpha_j) P_{j,t}^{*\,1-\sigma}\right]^{\frac{1}{1-\sigma}}$$

We assume a Cobb-Douglas production with sector-specific productivity for all firms.

$$Y_{j,t}(i) = A_{j,t} N_{j,t}(i)$$

where $A_{j,t}$ is the level of sectoral productivity, $N_{j,t}(i)$ is the labor hours hired by firm i in sector j. The sectoral productivity follows an AR(1) process in logs

$$\log A_{j,t} = \phi_j^A \log A_{j,t-1} + \varepsilon_{j,t} \tag{1}$$

$$\text{with } \varepsilon_{j,t} \sim_{i.i.d} N(0, \sigma_j^{A^2})$$

where ϕ_j^A, σ_j^A imply the persistence of the productivity and the standard deviation of the innovation, respectively.

The first-order condition with respect to the optimal price of firm i in sector j is given by:

$$\mathbb{E}_t \sum_{k=0}^{\infty} \left(\alpha_j^k Q_{t,t+k}\right) \left[\frac{P_{j,t}(i)}{P_{j,t+k}} - \frac{W_{j,t+k}(i)}{P_{j,t+k}} \frac{1}{A_{j,t+k}}\right] \left(\frac{P_{j,t}(i)}{P_{j,t+k}}\right)^{-\sigma} \left(\frac{Y_{t+k}^j}{n_j}\right) = 0$$

2.3 Government

The government collects lump-sum taxes, and finances its purchases and the total employment subsidy given to firms. The government budget constraint at period t is given by:

$$P_t G_t + s \sum_{j=1}^{J} \int_{\mathcal{I}_j} W_{j,t}(i) N_{j,t}(i) di = P_t T_t$$

Here, the left-hand side of the budget constraint describes government spending which is composed of the two terms, G_t and $s \sum_{j=1}^{J} \int_{\mathcal{I}_j} W_{j,t}(i) N_{j,t}(i) di$. First, G_t refers to government expenditure which is assumed to be zero, i.e. $G_t = 0$, for simplicity. Second, $s \sum_{j=1}^{J} \int_{\mathcal{I}_j} W_{j,t}(i) N_{j,t}(i) di$ is the aggregation of the subsidy handed out to firms for promoting their employment. The right-hand side of the budget constraint shows government revenue with lumpsum tax, T_t.

2.4 Market clearing conditions

The goods market clears so that the condition is imposed as follows:

$$C_{k,t}(i) = Y_{k,t}(i), \ \forall i$$

This implies that the total demand equals the production of final goods at the aggregate

level. Thus, the resource constraint holds as follows:

$$\sum_{j=1}^{J} n_j C_{j,t} = C_t = Y_t$$

We assume that one-period-ahead contingent assets must have zero net-supply. Then, the financial market clearing is set to:

$$\sum_{j=1}^{J} n_j B_{j,t+1} = 0$$

Furthermore, since asset markets are complete, it can be shown that

$$C_{j,t} = C_t = Y_t, \ \forall j$$

with an appropriate initial wealth condition.

2.5 Monetary policy

In this subsection, we specify a central bank's welfare criterion and a class of targeting rules. Here, we confine monetary policy to the class of inflation targeting policies since inflation targeting has been used by many central banks to promote price stability over the past decades. We consider two different targeting rules: (1) OPI inflation targeting and (2) Strict inflation targeting. The OPI inflation targeting is the monetary policy that targets the optimally weighted average of sectoral inflation rates. On the other hand, we call the monetary policy that targets the growth rate of an aggregate price index the strict inflation targeting. Before we look into these, we first define a central bank's welfare criterion.

2.5.1 Central bank's welfare criterion

In order to perform normative analysis of the two targeting schemes, we primarily have to adopt a welfare criterion. And then, we compute the welfare gap between the two targeting schemes to investigate when the welfare loss is reduced, and evaluate how

costly the strict inflation targeting is in terms of the welfare.

In our framework, we define the welfare of a sector (at t period) as the average utility flow among all the households belonging to a sector:

$$w_t^j = U(C_{j,t}) - \frac{1}{n_j}\int_{\mathcal{I}_j} V(N_{j,t}(i))di$$

And the welfare of economy (at t period) is defined as a weighted average of the average utility flows of the sectors.

$$W_t = \sum_{j=1}^{J} n_j w_t^j = \sum_{j=1}^{J}\left[n_j U(C_{j,t}) - \int_0^1 V(N_{j,t}(i))di\right]$$

Following the standards, we compute the second-order approximation of W_t and get:

$$\frac{W_t - \bar{W}}{W_C \bar{C}} \approx -\frac{1}{2}L_t + t.i.p. + o\left(\|\xi\|^3\right)$$

with

$$L_t = (\rho+\eta)\left(\hat{Y}_t - \tilde{Y}_t\right)^2 + (1+\eta)\sum_{j=1}^{J}\left(\hat{P}_{j,t}^R - \tilde{P}_{j,t}^R\right)^2 + (1+\eta\sigma)\sigma\sum_{j=1}^{J}\frac{n_j\alpha_j}{(1-\alpha_j)(1-\alpha_j\beta)}\pi_{j,t}^2.$$ [1]

A welfare-maximizing central bank will minimize the following welfare loss function:

$$\mathcal{L} = -\mathbb{E}_0\sum_{t=0}^{\infty}\beta^t\left(\frac{W_t - \bar{W}}{W_C\bar{C}}\right) = \frac{1}{2}\mathbb{E}_0\sum_{t=0}^{\infty}\beta^t L_t \tag{2}$$

which is a fraction of the steady-state consumption. The loss function features three main sources of welfare loss. The first one is the deviation of the level of consumption from its efficient value, which is equivalent to the deviation of the level of output. The second source is the gap between the relative price in sticky price regime and that in flexible price regime. Lastly, sectoral inflation rates with nominal rigidities across sectors increase the welfare loss. We will investigate these sources more in detail in 4.1.

In order to evaluate the welfare loss normatively, we focus on the ex-ante value

[1]For a variable X_t, $\hat{X}_t$ denotes the log-deviation of X_t from its steady-state value ($\bar{X}_t$), and $\tilde{X}_t$ denotes the same but under flexible prices. In addition, $\hat{X}_{j,t}^R \equiv \hat{X}_{j,t} - \hat{X}_t$ denotes the log-deviation of sector j variable ($X_{j,t}$) from the aggregate counterpart (X_t), and $\tilde{X}_{j,t}^R \equiv \tilde{X}_{j,t} - \tilde{X}_t$ denotes the same but under flexible prices.

of it with unconditional expectation of (2). It is given by:

$$\mathbb{E}\mathcal{L} = \frac{1}{2}\mathbb{E}\sum_{t=0}^{\infty}\beta^t L_t \tag{3}$$

2.5.2 Inflation targeting rules

We define monetary policy as a class of inflation targeting, which is along the lines of the monetary policy adopted by many central banks in current days. There are two targeting rules that we describe in this paper.

Following Benigno (2004), we suppose that the central bank perfectly stabilizes a weighted average of sectoral inflation rates at each period t. The form is given by:

$$\pi_t^{target} = \sum_{j=1}^{J}\delta_j\pi_{j,t} = 0$$

$$\text{where } \delta_j \geq 0 \text{ and } \textstyle\sum_{j=1}^{J}\delta_j = 1$$

The central bank chooses the sets of weight $\{\delta_j\}_j$ to maximize the social welfare. Here, the weight δ_j multiplied to $\pi_{j,t}$ implies the degree of concerns on sector j inflation rate when stabilizing the overall inflation level. $\{\delta_j^*\}_j$ denotes this chosen set of weights. Then, the OPI inflation targeting can be depicted with the weight:

$$\delta_j = \delta_j^*$$

Another targeting rule, the strict inflation targeting, uses a normalized sector size for the weight of sectoral inflation. It is given as:

$$\delta_j = n_j$$

where n_j refers to a normalized sector size. One good example for this is the Harmonized Index of Consumption Prices (HICP)[2] targeting rule used in the European Central Bank. Also, the CPI inflation[3] targeting rule adopted in the Bank of Korea is another example

[2]HICP has the weights that equal each country's share of total consumption.

[3]The CPI inflation is defined by the year-one-year change in the Consumer Price Index (CPI).

of the strict inflation targeting.

2.6 Equilibrium

Along the system of equations which consist of the households' optimality conditions and budget constraint, the firms' optimality conditions, the monetary policy rule, and the market clearing conditions, we derive the equilibrium of the model. We solve the model by log-linearizing the equilibrium conditions around a deterministic steady state. The full set of log-linearized equations is provided in the Appendix.

3 Calibration

In this section, we calibrate model parameters implied by the Korean economy. We first estimate heterogeneous parameters (the sector size $\{n_j\}_j$ and the sectoral infrequency of price adjustment $\{\alpha_j\}_j$), using the time series data on sectoral prices and quantities. Also, we choose other homogeneous parameters following the standards. Beforehand, we first describe sectors that correspond to the model sectors $j = 1, 2, \ldots, J$.

3.1 Sector description

We calibrate the model by mapping the model sectors into the twelve consumption categories in household consumption. The twelve sectors are the second-level disaggregation of the aggregate consumption. Period t is measured in quarters. More detailed characteristics of the twelve sectors will be discussed when we estimate heterogeneous parameters in 3.2.

3.2 Heterogeneous parameters

We calibrate values for the parameters that characterize the degree of sectoral heterogeneity. There are two heterogeneous parameters in this model. The first one is the size of sectors, $\{n_j\}_j$. We calibrate the parameters so that they match the average expenditure share of each consumption category over our sample period 2003-2016. It is presented in

the third column of table 1. The second parameter governing the degree of sectoral heterogeneity is the sectoral infrequency of price adjustments, $\{\alpha_j\}_j$. Implied by the Calvo pricing scheme, the dynamics of the sectoral inflation rate $\pi_{j,t}$ can be approximated by:

$$\pi_{j,t} = \alpha_j \pi_{j,t-1} + \varepsilon_{j,t}$$

where $\varepsilon_{j,t}$ is a serially uncorrelated exogenous term. Using the quarterly data on sectoral price indices from the Bank of Korea and the Korean Statistical Information Service, we estimate the parameters $\{\alpha_j\}_j$ by ordinary least square method. The estimation results are described in the fourth column of table 1. We also compute the average duration of price in quarters, $1/(1-\alpha_j)$, which is shown in the last column in table 1.

Table 1: Twelve sectors

	Twelve consumption categories	n_j(%)	α_j	Duration
1	Food and non-alcoholic beverages	14.15	0.1943	1.24
2	Alcoholic beverages and tobacco	1.30	0.0435	1.05
3	Clothing and footwear	6.44	0.7234	3.62
4	Housing, water, electricity and other fuels	10.13	0.6180	2.62
5	Furnishings, household equipment and routine household maintenance	3.73	0.4679	1.88
6	Health	6.36	0.4690	1.88
7	Transport	12.28	0.3613	1.57
8	Communication	6.41	0.0583	1.06
9	Recreation and culture	5.51	0.2497	1.33
10	Education	11.77	0.5578	2.26
11	Restaurants and hotels	13.27	0.7720	4.39
12	Miscellaneous goods and services	8.65	0.4231	1.73

Among the twelve sectors, the two largest sectors are “Food and non-alcoholic beverages” and “Restaurants and hotels”, and the two smallest sectors are “Alcoholic beverages and tobacco” and “Furnishings, household equipment and routine household maintenance”. The two stickiest sectors are “Restaurants and hotels” and “Clothing and footwear”, which take about thirteen months and eleven months, respectively, to adjust its price on average. The most flexible sector is “Alcoholic beverages and tobacco”, which takes only about three months to change its price on average.

3.3 Homogeneous parameters

Other model parameters are chosen following the standards. The time discount factor, β, is set so that the steady-state annual real interest rate is around 4 percent. The risk aversion parameter, ρ, and the inverse of Frisch elasticity of labor supply, η, are set to 1.3 and 1, respectively. Lastly, the within-sector elasticity of substitution, σ, is set to 6. We take these values from Bae (2013) which analyzes the Korean economy in a DSGE model.

We assume that the sectoral productivity $A_{j,t}$ follows the AR(1) process and calibrate the parameters of the distribution, the autocorrelation coefficient, ϕ_j^A, and the standard deviation of the shock innovation, σ_j^A. We also assume that the shock is symmetric across sectors since disaggregate labor hour data is not available for the sectors we consider. However, it enables us to shut down other sources of sectoral heterogeneity. We use the real seasonally-adjusted quarterly data on real output and total hours worked from the Korean Statistical Information Service, and measure the productivity by the Solow residual. Then, we estimate (1) by ordinary least square method. The estimated shock process is described in table 3. Our estimate of ϕ^A is 0.34, which is smaller than the values in previous studies. In the Appendix, we take different values and repeat the same process for robustness checks. We find that our numerical results are not significantly affected by these variations.

Table 2: Model parameter values

β	0.99	Time discount factor
ρ	1.3	Risk aversion
η	1	Inverse of Frisch elasticity
σ	6	Within-sector elasticity of substitution

Table 3: Shock process

ϕ^A	0.34	Persistence of the productivity
σ^A	0.0138	Standard deviation of the shock innovation

4 Numerical results

In this section, we obtain numerical results from the twelve-sector model and discuss several properties of the OPI inflation targeting in comparison to the CPI inflation targeting. We first investigate the main mechanism of deriving the OPI which is constructed by a weighted sum of sectoral inflation rates.

4.1 Main mechanism

As shown in Benigno (2004), there are two main sources that generate the welfare loss in this model. First one is the sectoral inflation which induces the inefficient price dispersion within a sector. The other one is the relative price gap across sectors, which creates inefficient paths of the terms of trade when hit by sectoral shocks. We find these two factors in the loss function in our model.

$$L_t = (\rho + \eta)(\hat{Y}_t - \tilde{Y}_t)^2 + (1 + \eta) \sum_{j=1}^{J} (\hat{P}^R_{j,t} - \tilde{P}^R_{j,t})^2 + (1 + \eta\sigma)\sigma \sum_{j=1}^{J} \frac{n_j \alpha_j}{(1 - \alpha_j)(1 - \alpha_j \beta)} \pi^2_{j,t}$$

Regarding the effect of sectoral inflation rates on the welfare loss, it depends on the sectoral nominal rigidities and the sector sizes. We can see this from the coefficient of each sectoral inflation, $\frac{n_j \alpha_j}{(1-\alpha_j)(1-\alpha_j \beta)}$. In other words, as a sector gets stickier or larger, the effect of the given sectoral inflation on the welfare loss gets more amplified. This is because there are more firms with old prices in stickier sectors. Relative price gap also accounts for the welfare loss since the efficient relative price allocates resources across sectors with response to sectoral disturbances. Therefore, bigger relative price gap implies that the relative prices cannot respond appropriately to sectoral shocks.

Even though both the sectoral inflation and the relative price gap are included as main sources of the loss function, a central bank cannot cope with all the distortions because of the lack of instruments. Given the definition of the relative price gap, there exists a trade-off between the sectoral inflation and the relative price gap:

$$\hat{P}^R_{j,t} - \hat{P}^R_{j,t-1} = \pi_{j,t} - \sum_{j=1}^{J} n_j \pi_{j,t}$$

If the central bank aims to stabilize the sectoral inflation rates, it can eliminate the inefficiency of the price dispersion within sectors. Nevertheless, it can never reduce the relative price gap, precluding it from adjusting properly toward disturbances. On the other hand, if the central bank manages to close the relative price gap, it cannot control the sectoral inflation. Therefore, both of the factors cannot be simultaneously controlled to minimize the welfare loss. This is known as the nonfeasibility of the efficient outcome in Benigno (2004).

New Keynesian Philips curve (NKPC) also shows the relation between the sectoral inflation and relative price gap. Specifically, it describes the effect of the relative price gap on the sectoral inflation.

$$\pi_{j,t} = \frac{(1-\alpha_j)(1-\alpha_j\beta)}{\alpha_j(1+\eta\sigma)}\left[-(\eta+1)(\hat{P}^R_{j,t} - \tilde{P}^R_{j,t}) + (\eta+\rho)(\hat{Y}_t - \tilde{Y}_t)\right] + \beta\mathbb{E}_t\pi_{j,t+1}$$

With the intrinsic limitation, targeting the inflation index that places larger weight on stickier sectors leads to welfare improvement. This is due to the fact that the sectoral inflation rates in stickier sectors make more significant amounts of the welfare loss. Thus, when constructing a target inflation index, it is optimal to place higher weights on stickier sectors. On the other hands, the simple CPI inflation disregards the heterogeneity in nominal rigidities across sectors. In this case, the normalized sector size becomes the weight on each sectoral inflation. Therefore, the CPI inflation gives more weights on flexible sectors but less on stickier sectors compared to the OPI inflation, making sectoral inflation in stickier sectors not stabilized enough to optimize the welfare.

Therefore, depending on the central bank's inflation targeting strategy, the implemented policy effects on social welfare are different. In the following subsections, we compute the OPI inflation in the case of Korea, and conduct welfare analysis by calculating the welfare gap between the OPI inflation targeting and the CPI inflation targeting.

4.2 Optimal inflation index for Korean economy

The optimal weights on each sectoral inflation in a target inflation index, $\{\delta^*_j\}_j$, are chosen from the welfare loss minimization. It is presented in the fifth column of table 4. With the

optimal weights, we construct the OPI inflation, i.e. $\pi_t^{OPI} \equiv \sum_{j=1}^{J=12} \delta_j^* \pi_{j,t}$. Also, the third column shows the average expenditure share of each consumption category, which is same as the weight given for the CPI inflation, i.e. $\pi_t^{CPI} \equiv \sum_{j=1}^{J=12} n_j \pi_{j,t}$. Thus, observing the third and fifth columns in table 4, we can easily compare these two inflation indices.

Table 4: Optimal weights for the twelve sectors

	Twelve consumption categories	n_j(%)	α_j	δ_j^*(%)
1	Food and non-alcoholic beverages	14.15	0.1943	3.46
2	Alcoholic beverages and tobacco	1.30	0.0435	0.15
3	Clothing and footwear	6.44	0.7234	15.91
4	Housing, water, electricity and other fuels	10.13	0.6180	15.90
5	Furnishings, household equipment and routine household maintenance	3.73	0.4679	2.50
6	Health	6.36	0.4690	5.78
7	Transport	12.28	0.3613	6.04
8	Communication	6.41	0.0583	0.47
9	Recreation and culture	5.51	0.2497	1.69
10	Education	11.77	0.5578	11.25
11	Restaurants and hotels	13.27	0.7720	31.64
12	Miscellaneous goods and services	8.65	0.4231	5.20

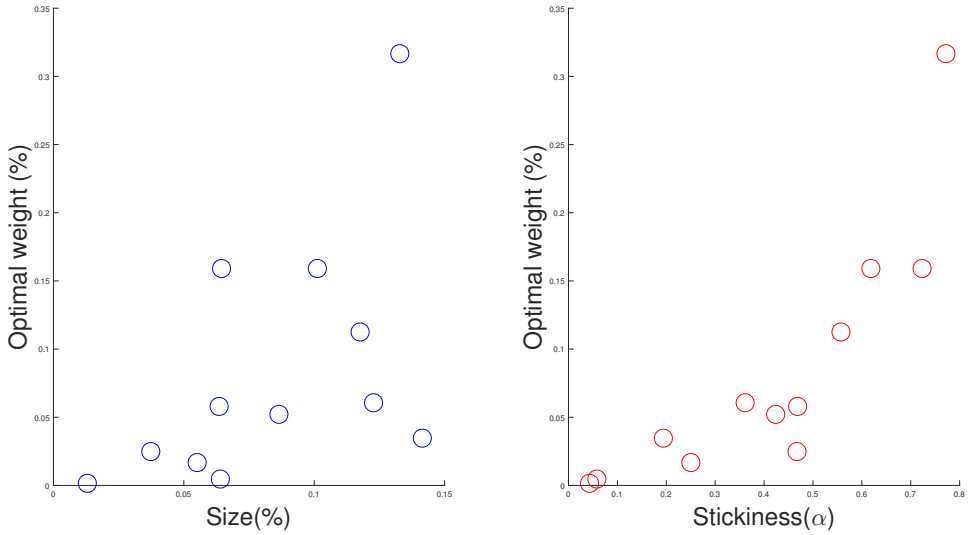
In table 4, we find several significant implications of the twelve sectors. First of all, "Restaurants and hotels" which is the stickiest sector with $\alpha_j = 0.7720$ gets the highest weight. Its weight expands from 13.27 percent to 31.64 percent, which is two times more than its initial size. On the other hand, "Alcoholic beverages and tobacco" which is the most flexible sector with $\alpha_j = 0.0435$ gets the lowest weight, 0.15 percent.

Table 5: Four sectors

	Twelve consumption categories	n_j(%)	α_j	δ_j^*(%)
1	Food and non-alcoholic beverages	14.15(1st)	0.1943(10th)	3.46(8th)
3	Clothing and footwear	6.44(7th)	0.7234(2nd)	15.91(2nd)
7	Transport	12.28(3rd)	0.3613(8th)	6.04(5th)
8	Communication	6.41(8th)	0.0583(11th)	0.47(11th)

There are four sectors that stand out in terms of the variations of their weights. The first one is "Food and non-alcoholic beverages" of which share was initially 14.15 percent and ranked the first. However, its optimal weight drastically drops to 3.46 percent

Figure 1: Optimal weights and Sector characteristics



and ranks the eighth. This might arise from its nominal rigidity which is the tenth highest among those of other sectors. The second one is "Clothing and footwear". Even though its initial expenditure share was 6.44 percent, its optimal weight gets inflated to 15.91 percent. Consequently, its initial weight was the seventh rank but it becomes the second rank. This might be due to the fact that its nominal rigidity is the second highest. Furthermore, "Transport" receives its weight deflated to 6.04 percent from 12.28 percent. In the same manner, "Communication" has its initial weight of 6.41 percent. However, its optimal weight declines to 0.47 percent. Same as the aforementioned mechanism, their nominal rigidities are not significantly high enough (the eighth and eleventh rank among the twelve sectors, respectively) to maintain their initial shares.

We can conclude from these facts that the optimal weights are positively correlated with the heterogeneous parameters, the sector sizes and the nominal rigidities. Noticeably, higher weights are given to the sectors with higher degree of price rigidities, which is in line with Benigno (2004). The weights are also affected by the initial sector sizes, although it is not as much as the effect of the nominal rigidities on the weights. Numerically, the correlation of the optimal weights, $\{\delta_j^*\}_j$, with the nominal rigidities, $\{\alpha_j\}_j$, is 0.8403, while that with the sector sizes, $\{n_j\}_j$, is 0.5164. Figure 1 illustrates these results.

Table 6: Correlation with the optimal weights

	$\{n_j\}_j$	$\{\alpha_j\}_j$
Correlation with $\{\delta_j^*\}_j$	0.5164	0.8403

4.3 Welfare analysis

In this subsection, we numerically compute the welfare of the OPI inflation and CPI inflation targeting rules, and compare them in welfare dimension. To begin with, we first define a welfare gap expressed in units of a percentage shift in the steady-state consumption. It is obtained by the difference between the unconditionally expected welfare losses (given as (3)) which are associated with the two inflation targeting schemes:

$$(\mathbb{E}\mathcal{L}_{CPI} - \mathbb{E}\mathcal{L}_{OPI}) \times 100(\%) \tag{4}$$

Our numerical simulation shows that the welfare gap (calculated by (4)) appears to be 0.18 percent. This implies that if we conduct the CPI inflation targeting instead of the OPI inflation targeting, the welfare loss is generated as 0.18 percent of the steady-state consumption. In other words, by adopting the OPI inflation targeting, we can reduce the welfare loss by 0.18 percent of the steady-state consumption. This number is fairly significant. By way of comparison, Eusepi, Hobijn, and Tambalotti (2011) find that welfare loss of targeting core inflation is 0.16 percent of the steady-state consumption, and suggest that moving from core to OPI inflation targeting generates substantial amount of improvement in the U.S. economy. Thus, our result of welfare improvement by 0.18 percent of the steady-state consumption captures significant progress by targeting the OPI inflation rather than the CPI inflation. This is obvious from the fact that the CPI inflation targeting does not consider the sectoral heterogeneity in nominal rigidities across sectors, rendering the welfare loss not to be minimized.

5 Monetary policy in Korea

In this section, we compare the OPI inflation, CPI inflation and core inflation by using the Korean data. Assuming that a simple Taylor rule[4] approximates the Korean monetary policy well, we obtain another three types of policy rate under the three inflation indices. Then, we address the properties of the three inflation indices and how the implied interest rates under each inflation targeting would look different.

5.1 Implications for target inflation rate

We modify the OPI inflation index on an annual basis as follows:

$$\pi_t^{OPI,yr} \equiv \sum_{j=1}^{J=12} \delta_j^* \pi_{j,t}^{yr}$$

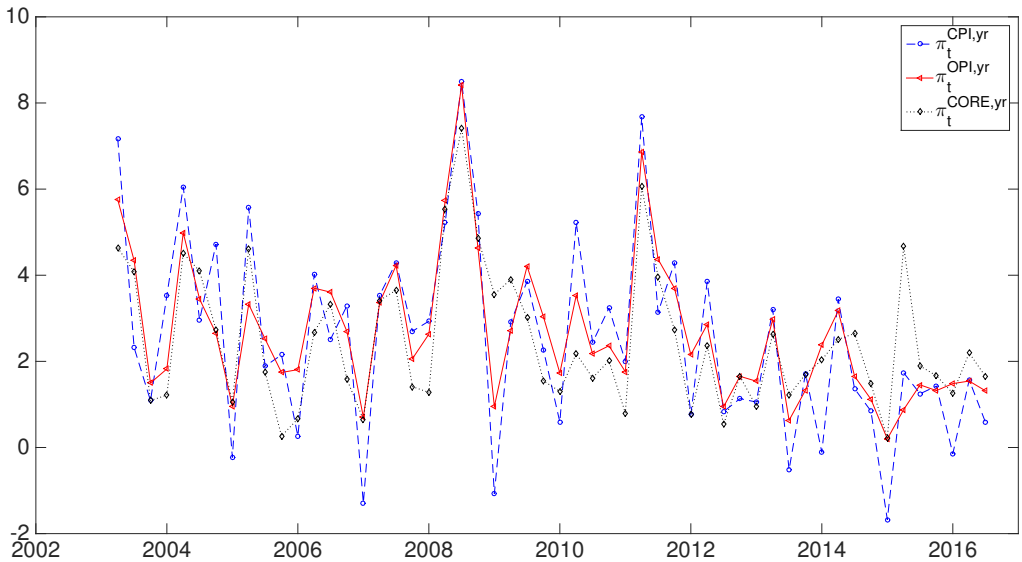
where $\{\delta_j^*\}_j$ are the optimal weights computed as in table 4 and $\{\pi_{j,t}^{yr}\}_j$ are sectoral inflation rates which are the annualized log-price changes in the price of the twelve consumption categories ($j = 1, 2, \ldots, 12$). The quarterly data on sectoral price indices is used from the Bank of Korea.

In figure 2, we plot the annualized OPI inflation rate ($\pi_t^{OPI,yr}$), CPI inflation rate ($\pi_t^{CPI,yr}$), and core inflation rate ($\pi_t^{CORE,yr}$) in Korea over the sample period 2003-2016. Here, the CPI inflation ($\pi_t^{CPI,yr}$) is made by the annualized log-difference of CPI data, and the core inflation ($\pi_t^{CORE,yr}$) is formed by the annualized log-difference of core CPI data which takes out agricultural products and oils from the original CPI. This time-series view presents several properties of the three forms of inflation rate in the case of Korea.

First of all, we can observe from figure 2 that the three inflation indices behave quite similarly, but not exactly in a same way. Considering the fact that the Bank of Korea used to have the inflation target measured by the core inflation rate in previous years and currently adopt the CPI inflation rate, the Bank of Korea has not made a big mistake in choosing its inflation targeting scheme. Nonetheless, our theoretical welfare analysis suggests that there exists non-negligible welfare gain by targeting the OPI inflation that places more weights on stickier sectors.

[4]It depicts how the central bank adjusts its policy rate in response to changes in inflation and output.

Figure 2: Inflation rates 2003-2016



Secondly, the series of OPI inflation lies between the series of CPI inflation and core inflation. Perhaps, it is not surprising in that the core inflation does not consider the two flexible sectors but focuses on relatively sticky sectors, while the CPI inflation disregards the sectoral heterogeneity in nominal rigidities. We may expect that the core inflation would be closer to the OPI inflation since the core inflation puts more concerns on stabilizing stickier sectors. However, the realized result shows that the OPI inflation is more similar to the CPI inflation and more apart from the core inflation than we expected. This may provide a basis for the switch of the Bank of Korea's target inflation index from the core inflation to the CPI inflation in 2007.

Thirdly, there are noticeable differences between the three forms of inflation rate. We focus on the volatility of each inflation rate. We find that the CPI inflation exhibits higher volatility, while the core inflation has lower volatility than others. By calculating the standard deviation of each inflation rate over the sample period, the CPI inflation shows a standard deviation of 2.2215 which is the highest value, while the core inflation has the lowest value of a standard deviation, which is 1.5841. The volatility of the OPI inflation is not as much as that of the CPI inflation, but it is only slightly higher than that of the core inflation. The standard deviation of the OPI inflation is 1.6419 which is between those of the CPI inflation and core inflation.

Furthermore, we compute the persistence of each inflation rate. Similar to the ranking of volatility, the OPI inflation is the most persistent while the CPI inflation is the least persistent. To be specific, the autocorrelation of the former is 0.3780 which is the highest, while that of the latter is only 0.0626. The autocorrelation of the core inflation is 0.2756 which lies in the middle of them. Thus, these rankings of volatility and persistence exhibit the major differences between the OPI inflation and the other two indices. These results are mainly due to the fact that the OPI inflation places disproportionately more weights on stickier sectors.

Table 7: Volatility and Persistence of the inflation rates

Inflation rate index	$\pi^{OPI,yr}$	$\pi^{CPI,yr}$	$\pi^{CORE,yr}$
Standard deviation	1.6419	2.2215	1.5841
Autocorrelation	0.3780	0.0626	0.2756

5.2 Implications for policy instrument

Assuming that the monetary policy in Korea is characterized by a simple Taylor rule, we derive the series of policy rates under the aforementioned three forms of target inflation index. We find several important features of the realized policy rates that convey the conduct of the monetary policy in Korea. We first define a standard Taylor rule for the Korean monetary policy.

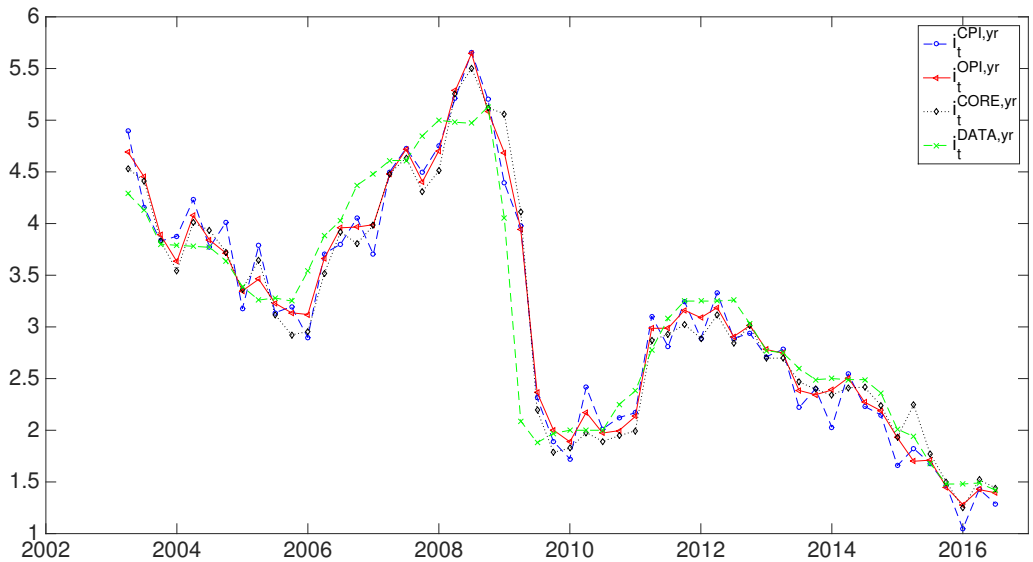
We adopt a Taylor rule with an interest rate smoothing term in a form of:

$$i_t = \rho_i i_{t-1} + (1 - \rho_i) \left\{ \bar{i}_t + \rho_\pi (\pi_t - \bar{\pi}_t) + \rho_y \tilde{y}_t \right\}$$

where i_t is the nominal interest rate, $\bar{i}_t$ is the target (natural) rate of interest, π_t is the inflation rate, $\bar{\pi}_t$ is the target rate of inflation, and $\tilde{y}_t$ is the output gap. The parameter ρ_i is the smoothing parameter which measures the persistence of the interest rates, while ρ_π and ρ_y measures how much the interest rate responses to the inflation rate gap and the output gap, respectively.

Following Bae (2013), we calibrate the parameters to imply the monetary policy in Korea. We set the smoothing parameter ρ_i to 0.913, the coefficient of the inflation

Figure 3: Interest rates 2003-2016



gap ρ_π to 1.66, and the coefficient of the output gap ρ_y to 0.024. In addition, we use the one-period ahead uncollateralized call rates (on an annual basis) for i_{t-1}, the HP filtered uncollateralized call rates (on an annual basis) for $\bar{i}_t$, the target rate of the annualized inflation announced by the Bank of Korea for $\bar{\pi}_t$, and the HP-filtered log(GDP) for $\tilde{y}_t$. Finally, we use three alternative annualized inflation rates (the OPI inflation, $\pi_t^{OPI,yr}$, CPI inflation, $\pi_t^{CPI,yr}$, and core inflation, $\pi_t^{CORE,yr}$) in place of π_t to compare the implied policy rates under each inflation targeting.

In figure 3, we plot the interest rates, $i_t = i_t^{OPI,yr}$, $i_t = i_t^{CPI,yr}$, and $i_t = i_t^{CORE,yr}$, implied by the Taylor rule with the three inflation rates over the period 2003-2016. In addition, the actual time series data of the uncollateralized call rate, $i_t^{DATA,yr}$, is also presented. In the figure, we have several meaningful findings.

To begin with, the model implied interest rates, $i_t^{OPI,yr}$,$i_t^{CPI,yr}$, and $i_t^{CORE,yr}$, are not significantly different from each other, but rather move together. This implies that it would not be a big mistake even if the central bank did not adopt the OPI inflation index in Korea.

However, there exist non-negligible differences between the three interest rates. $i_t^{CPI,yr}$ shows the highest volatility, which has a standard deviation of 1.1399, while

$i_t^{CORE,yr}$ exhibits the lowest volatility with a standard deviation of 1.1012. Meanwhile, $i_t^{OPI,yr}$ has a standard deviation of 1.1105 which is in the middle of the other values. In addition, observing the persistence of each interest rate, $i_t^{OPI,yr}$ is the most persistent, while $i_t^{CPI,yr}$ is the least persistent. The rankings of volatility and persistence in the implied interest rates are also in line with those in inflation rates ($\pi_t^{OPI,yr}$ is more inertial and less volatile than $\pi_t^{CPI,yr}$).

Table 8: Volatility and Persistence of the interest rates

Interest rate	$i^{OPI,yr}$	$i^{CPI,yr}$	$i^{CORE,yr}$
Standard deviation	1.1105	1.1399	1.1012
Autocorrelation	0.9015	0.8610	0.8886

Furthermore, we observe that the simple Taylor rule approximates the actual monetary policy in Korea well. The overall movements of the model implied interest rates and the actual policy rate behave in a similar way although the actual policy rate is more inertial and less volatile than any other types of the model implied interest rate. It is also noticeable that the actual policy rate looks more similar to the implied interest rate under the OPI inflation targeting. Table 9 shows that $i^{DATA,yr}$ has the highest correlation with i_t^{OPI}, which is 0.9475. This result may capture the Bank of Korea's reluctance to change the policy rate.

Table 9: Correlation of the data with the model implied interest rates

Correlation of $i^{DATA,yr}$ with	$i^{OPI,yr}$	$i^{CPI,yr}$	$i^{CORE,yr}$
Correlation	0.9475	0.9365	0.9305

6 Conclusion

This paper documents several implications of the monetary policy in Korea with respect to its target inflation index. In a multi-sector framework, we calibrate parameters for sectoral heterogeneity and construct the OPI inflation index that minimizes the welfare loss numerically. We find that the optimal weights placed on stickier sectors depend on sector-specific characteristics (the sectoral nominal rigidities and the sector sizes), and

that the OPI inflation targeting closely approximates the optimal monetary policy by minimizing the welfare loss. In the case of Korea, the OPI inflation targeting reduces the welfare loss by 0.18 percent of the steady-state consumption compared to the CPI inflation targeting, which is a significant amount of welfare improvement.

From the empirical analysis, we also observe several findings. First of all, the CPI targeting in Korea is not far apart from the OPI inflation targeting. Second, in terms of volatility and persistence, there still exist non-negligible differences between the OPI inflation rate and the CPI inflation rate, and also between the implied policy rates with the respective inflation rate. Since the OPI inflation is less volatile and more persistent than the CPI inflation, the model implied interest rate under the OPI inflation targeting smoothly moves compared to the one under the CPI inflation targeting. Lastly, the actual policy rate is relatively inertial and highly correlated with the model implied policy rate under the OPI inflation targeting. This may provide justification for the Bank of Korea's preference to adjust the policy rate slowly and cautiously.

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Appendix

A System of log-linearized equations

In this section, we log-linearize our model around the steady states of each variable. Here, $\bar{X}_t$ denotes the steady-state value of the variable X_t. In the log-linearized version of the model, we use the following notations:

$$
\begin{aligned}
X_t &\equiv \sum_{j=1}^{J} n_j X_{j,t}, \\
X_{j,t}^R &\equiv X_{j,t} - X_t, \\
\hat{X}_t &\equiv \log(X_t) - \log(\bar{X}_t), \\
\tilde{X}_t &\equiv \log(X_t) - \log(\bar{X}_t)
\end{aligned}
$$

which refer to aggregate variable, relative variable and a log-linearized variable under sticky and flexible prices, respectively.

- Household's optimality conditions:

$$
\begin{aligned}
\hat{Y}_t &= \mathbb{E}_t \hat{Y}_{t+1} + \frac{1}{\rho}\left(\mathbb{E}_t \pi_{t+1} - \hat{R}_t\right) \\
\eta \hat{N}_{j,t}(i) + \rho \hat{Y}_t &= \hat{W}_{j,t}(i) - \hat{P}_t
\end{aligned}
$$

- Definition of the relative price:

$$
\begin{aligned}
\hat{P}_{j,t}^R &= \hat{P}_{j,t} - \hat{P}_t \\
\tilde{P}_{j,t}^R &= \tilde{P}_{j,t} - \tilde{P}_t
\end{aligned}
$$

• Flexible price allocation:

$$\tilde{P}^R_{j,t} = \frac{(\eta+\rho)}{(\eta+1)}\tilde{Y}_t - \hat{A}_{j,t}$$
$$\tilde{Y}_t = \frac{(\eta+1)}{(\eta+\rho)}\sum_{j=1}^{J} n_j \hat{A}_{j,t}$$

• Production function:

$$\hat{Y}_{j,t}(i) = \hat{A}_{j,t} + \hat{N}_{j,t}(i)$$

• Demand function:

$$\hat{Y}_{j,t} = -\left(\hat{P}_{j,t} - \hat{P}_t\right) + \hat{Y}_t = -\hat{P}^R_{j,t} + \hat{Y}_t$$

• Identities:

$$\mathbb{E}_t \hat{Q}_{t,t+1} = -\hat{R}_t$$
$$\pi_{j,t} = \hat{P}_{j,t} - \hat{P}_{j,t-1}$$
$$\pi_t = \hat{P}_t - \hat{P}_{t-1}$$
$$\hat{P}^R_{j,t} - \hat{P}^R_{j,t-1} = \pi_{j,t} - \pi_t$$

- New Keynesian Phillips Curve (NKPC) from the firm's optimality condition:

$$\pi_{j,t} = \frac{(1-\alpha_j)(1-\alpha_j\beta)}{\alpha_j(1+\eta\sigma)}\left[-(\eta+1)\left(\hat{P}^R_{j,t} - \tilde{P}^R_{j,t}\right) + (\eta+\rho)\left(\hat{Y}_t - \tilde{Y}_t\right)\right] + \beta\mathbb{E}_t\pi_{j,t+1}$$

B Derivation of the welfare loss function

Following Woodford (2003), we derive the utility-based loss function. We take the second-order Taylor expansion of the utility function $U(C_{j,t})$ around the steady state $\bar{C}$. It is given by:

$$U\left(C_{j,t}\right) = U\left(\bar{C}\right) + U_C\left(C_{j,t} - \bar{C}\right) + \frac{1}{2}U_{CC}\left(C_{j,t} - \bar{C}\right)^2 + o\left(\|\xi\|^3\right) \tag{5}$$

where $o(\|\xi\|^3)$ denotes all the terms that are of third or higher order in the deviations of variables from their steady-state values. We also expand $C_{j,t}$ with the second-order Taylor approximation and then it is obtained as follows:

$$C_{j,t} = \bar{C}\left(1 + \hat{C}_{j,t} + \frac{1}{2}\hat{C}_{j,t}^2\right) + o\left(\|\xi\|^3\right) \tag{6}$$

where $\hat{C}_{j,t} = \log\left(C_{j,t}\right) - \log\left(\bar{C}\right)$. Then, the deviation of $C_{j,t}$ from its steady-state value $\bar{C}$ can be rewritten as:

$$C_{j,t} - \bar{C} = \bar{C}\hat{C}_{j,t} + \frac{1}{2}\bar{C}\hat{C}_{j,t}^2 + o\left(\|\xi\|^3\right) \tag{7}$$

Substituting (7) into (5), we obtain

$$U\left(C_{j,t}\right) = U\left(\bar{C}\right) + U_C\bar{C}\hat{C}_{j,t} + \frac{1}{2}U_C\bar{C}\hat{C}_{j,t}^2 + \frac{1}{2}U_{CC}\bar{C}^2\hat{C}_{j,t}^2 + o\left(\|\xi\|^3\right) \tag{8}$$

Here, since $U\left(\bar{C}\right)$ is independent of monetary policy, we include it in $t.i.p.$ which describes all the terms independent of monetary policy. Then, (8) becomes

$$U\left(C_{j,t}\right) = U_C\bar{C}\hat{C}_{j,t} + \frac{1}{2}U_C\bar{C}\hat{C}_{j,t}^2 + \frac{1}{2}U_{CC}\bar{C}^2\hat{C}_{j,t}^2 + t.i.p. + o\left(\|\xi\|^3\right), \tag{9}$$

which can be reorganized as

$$U\left(C_{j,t}\right) = U_C\bar{C}\hat{C}_{j,t} + \frac{1}{2}U_C\bar{C}\left(1 + \frac{U_{CC}}{U_C}\bar{C}\right)\hat{C}_{j,t}^2 + t.i.p. + o\left(\|\xi\|^3\right)$$

Note that $\rho \equiv -\frac{U_{CC}\bar{C}}{U_C}$ is defined from the utility function. Thus, we have

$$U\left(C_{j,t}\right) = U_C\bar{C}\left(\hat{C}_{j,t} + \frac{1}{2}(1-\rho)\hat{C}_{j,t}^2\right) + t.i.p. + o\left(\|\xi\|^3\right) \tag{10}$$

Similarly, we take the second-order Taylor expansion of $V\left(N_{j,t}(i)\right)$ around the steady state $\bar{N}$. Then, we obtain

$$V\left(N_{j,t}(i)\right) = V\left(\bar{N}\right) + V_N\left(N_{j,t}(i) - \bar{N}\right) + \frac{1}{2}V_{NN}\left(N_{j,t}(i) - \bar{N}\right)^2 + o\left(\|\xi\|^3\right) \tag{11}$$

Also, the second order approximation of $N_{j,t}(i)$ is derived as follows:

$$N_{j,t}(i) = \bar{N}\left(1 + \hat{N}_{j,t}(i) + \frac{1}{2}\hat{N}_{j,t}(i)^2\right) + o\left(\|\xi\|^3\right) \tag{12}$$

The deviation of $N_{j,t}(i)$ from its steady-state value $\bar{N}$ is written as:

$$N_{j,t}(i) - \bar{N} = \bar{N}\hat{N}_{j,t}(i) + \frac{1}{2}\bar{N}\hat{N}_{j,t}(i)^2 + o\left(\|\xi\|^3\right) \tag{13}$$

By substituting (13) into (11), it is given by:

$$V\left(N_{j,t}(i)\right) = V\left(\bar{N}\right) + V_N\left(\bar{N}\hat{N}_{j,t}(i) + \frac{1}{2}\bar{N}\hat{N}_{j,t}(i)^2\right) + \frac{1}{2}V_{NN}\left(\bar{N}\hat{N}_{j,t}(i) + \frac{1}{2}\bar{N}\hat{N}_{j,t}(i)^2\right)^2 + o\left(\|\xi\|^3\right)$$

Using the definition of $o\left(\|\xi\|^3\right)$ and $t.i.p.$, we obtain

$$V\left(N_{j,t}(i)\right) = V_N\bar{N}\hat{N}_{j,t}(i) + \frac{1}{2}V_N\bar{N}\hat{N}_{j,t}(i)^2 + \frac{1}{2}V_{NN}\bar{N}^2\hat{N}_{j,t}(i)^2 + t.i.p. + o\left(\|\xi\|^3\right),$$

which can be rewritten as:

$$V\left(N_{j,t}(i)\right) = V_N\bar{N}\hat{N}_{j,t}(i) + \frac{1}{2}V_N\bar{N}\left(1 + \frac{V_{NN}}{V_N}\bar{N}\right)\hat{N}_{j,t}(i)^2 + t.i.p. + o\left(\|\xi\|^3\right)$$

Since $\eta \equiv \frac{V_{NN}\bar{N}}{V_N}$, it becomes

$$V\left(N_{j,t}(i)\right) = V_N\bar{N}\left(\hat{N}_{j,t}(i) + \frac{1}{2}(1+\eta)\hat{N}_{j,t}(i)^2\right) + t.i.p. + o\left(\|\xi\|^3\right) \tag{14}$$

From the production function, we obtain

$$\hat{Y}_{j,t}(i) = \hat{A}_{j,t} + \hat{N}_{j,t}(i), \tag{15}$$

which can be rewritten as:

$$\hat{N}_{j,t}(i) = \hat{Y}_{j,t}(i) - \hat{A}_{j,t} \tag{16}$$

Substituting (16) into (14), we have

$$V\left(N_{j,t}(i)\right) = V_N \bar{N}\left\{\left(\hat{Y}_{j,t}(i) - \hat{A}_{j,t}\right) + \frac{1}{2}(1+\eta)\left(\hat{Y}_{j,t}(i) - \hat{A}_{j,t}\right)^2\right\} + t.i.p. + o\left(\|\xi\|^3\right) \tag{17}$$

It can be rewritten as:

$$V\left(N_{j,t}(i)\right) = V_N \bar{N}\left\{\hat{Y}_{j,t}(i) + (1+\eta)\left(\frac{1}{2}\hat{Y}_{j,t}(i)^2 - \hat{A}_{j,t}\hat{Y}_{j,t}(i)\right)\right\} + t.i.p. + o\left(\|\xi\|^3\right) \tag{18}$$

By integrating (18) over the range of $\mathcal{I}_j$, we have

$$\begin{aligned}\frac{1}{n_j}\int_{\mathcal{I}_j} V\left(N_{j,t}(i)\right) di =& V_N \bar{N}\left\{\mathbb{E}\left(\hat{Y}_{j,t}(i)\right) + \frac{1}{2}(1+\eta)\mathbb{E}\left(\hat{Y}_{j,t}(i)^2\right) - (1+\eta)\hat{A}_{j,t}\mathbb{E}\left(\hat{Y}_{j,t}(i)\right)\right\} \\ &+ t.i.p. + o\left(\|\xi\|^3\right)\end{aligned} \tag{19}$$

This implies that

$$\begin{aligned}&\frac{1}{n_j}\int_{\mathcal{I}_j} V\left(N_{j,t}(i)\right) di \\ &\quad = V_N \bar{N}\left\{\mathbb{E}\left(\hat{Y}_{j,t}(i)\right) + \frac{1}{2}(1+\eta)Var\left(\hat{Y}_{j,t}(i)\right) + \frac{1}{2}(1+\eta)\mathbb{E}\left(\hat{Y}_{j,t}(i)\right)^2 - (1+\eta)\hat{A}_{j,t}\mathbb{E}\left(\hat{Y}_{j,t}(i)\right)\right\} \\ &\quad + t.i.p. + o\left(\|\xi\|^3\right)\end{aligned} \tag{20}$$

Taking the second-order Taylor expansion of the aggregate output, we obtain

$$\hat{Y}_{j,t} = \mathbb{E}\left(\hat{Y}_{j,t}(i)\right) + \frac{1}{2}\left(\frac{\sigma-1}{\sigma}\right)Var\left(\hat{Y}_{j,t}(i)\right) + o\left(\|\xi\|^3\right)$$

It implies that:

$$\mathbb{E}\left(\hat{Y}_{j,t}(i)\right) = \hat{Y}_{j,t} - \frac{1}{2}\left(\frac{\sigma-1}{\sigma}\right) Var\left(\hat{Y}_{j,t}(i)\right) + o\left(\|\xi\|^3\right) \tag{21}$$

and

$$\mathbb{E}\left(\hat{Y}_{j,t}(i)\right)^2 = \hat{Y}_{j,t}^2 + +o\left(\|\xi\|^3\right) \tag{22}$$

By substituting (21) and (22) into (20), we get

$$\begin{aligned}
&\frac{1}{n_j}\int_{\mathcal{I}_j} V\left(N_{j,t}(i)\right) di \\
&\quad = V_N \bar{N}\left\{\hat{Y}_{j,t} + \frac{1}{2}(1+\eta)\hat{Y}_{j,t}^2 - (1+\eta)\hat{A}_{j,t}\hat{Y}_{j,t} + \frac{1}{2}\left(\eta + \frac{1}{\sigma}\right) Var\left(\hat{Y}_{j,t}(i)\right)\right\} \\
&\quad\quad + t.i.p. + o\left(\|\xi\|^3\right)
\end{aligned}$$

Recall that we have

$$\bar{N} = \frac{\bar{Y}}{\bar{A}_j} = \bar{Y}$$

Also, from the household's intra-temporal optimality condition, we have

$$-\frac{V_N}{U_C} = \frac{\bar{W}}{\bar{P}} = \bar{A}_j = 1$$

Thus, this implies

$$-V_N = U_C \Longrightarrow -V_N\bar{N} = U_C\bar{Y} = U_C\bar{C}$$

Combining these altogether, the household j's utility function is given by:

$$\begin{aligned}
w_t^j &= U\left(C_{j,t}\right) - \frac{1}{n_j}\int_{\mathcal{I}_j} V\left(N_{j,t}(i)\right) di \\
&= U_C\bar{C}\left\{\hat{C}_{j,t} + \frac{1}{2}(1-\rho)\hat{C}_{j,t}^2\right\} \\
&\quad - U_C\bar{C}\left\{\hat{Y}_{j,t} + \frac{1}{2}(1+\eta)\hat{Y}_{j,t}^2 - (1+\eta)\hat{A}_{j,t}\hat{Y}_{j,t} + \frac{1}{2}\left(\eta + \frac{1}{\sigma}\right) Var\left(\hat{Y}_{j,t}(i)\right)\right\} + t.i.p. + o\left(\|\xi\|^3\right)
\end{aligned}$$

Then, it is rearranged by:

$$w_t^j = U_C\bar{C}\left\{\hat{C}_{j,t} + \frac{1}{2}(1-\rho)\hat{C}_{j,t}^2 - \hat{Y}_{j,t} - \frac{1}{2}(1+\eta)\hat{Y}_{j,t}^2 + (1+\eta)\hat{A}_{j,t}\hat{Y}_{j,t} - \frac{1}{2}\left(\eta + \frac{1}{\sigma}\right)Var\left(\hat{Y}_{j,t}(i)\right)\right\}$$
$$+ t.i.p. + o\left(\|\xi\|^3\right) \tag{23}$$

From (23), the weighted sum of the utility is

$$\sum_{j=1}^{J} n_j w_t^j = \sum_{j=1}^{J}\left[n_j U\left(C_{j,t}\right) - \int_0^1 V\left(N_{j,t}(i)\right)di\right]$$
$$= U_C\bar{C}\left[\begin{array}{l} \sum_{j=1}^{J} n_j\hat{C}_{j,t} + \frac{1}{2}(1-\rho)\sum_{j=1}^{J} n_j\hat{C}_{j,t}^2 - \sum_{j=1}^{J} n_j\hat{Y}_{j,t} - \frac{1}{2}(1+\eta)\sum_{j=1}^{J} n_j\hat{Y}_{j,t}^2 \\ (1+\eta)\sum_{j=1}^{J} n_j\hat{A}_{j,t}\hat{Y}_{j,t} - \frac{1}{2}\left(\eta + \frac{1}{\sigma}\right)\sum_{j=1}^{J} n_j Var\left(\hat{Y}_{j,t}(i)\right) \end{array}\right]$$
$$+ t.i.p. + o\left(\|\xi\|^3\right) \tag{24}$$

Recall that the resource constraint is given by:

$$Y_t = \sum_{j=1}^{J} n_j C_{j,t},$$

which implies

$$\hat{Y}_t = \sum_{j=1}^{J} n_j\hat{C}_{j,t} \tag{25}$$

Also, from the sectoral goods demand function, we have

$$\hat{Y}_{j,t} = -\hat{P}_{j,t}^R + \hat{Y}_t,$$

from which we get:

$$\sum_{j=1}^{J} n_j\hat{Y}_{j,t} = \hat{Y}_t \tag{26}$$

$$\sum_{j=1}^{J} n_j\hat{Y}_{j,t}^2 = \sum_{j=1}^{J} n_j\left(\hat{P}_{j,t}^R\right)^2 + \left(\hat{Y}_t\right)^2 \tag{27}$$

since $\sum_{j=1}^{J} n_j\hat{P}_{j,t}^R = \sum_{j=1}^{J} n_j\left(\hat{P}_{j,t} - \hat{P}_t\right) = 0$.

Meanwhile, from the flexible allocation, we obtain

$$\hat{A}_{j,t} = -\tilde{P}^R_{j,t} + \left(\frac{\eta+\rho}{\eta+1}\right)\tilde{Y}_t$$

Then, it is rewritten as:

$$(1+\eta)\hat{A}_{j,t} = -(1+\eta)\tilde{P}^R_{j,t} + (\eta+\rho)\tilde{Y}_t \tag{28}$$

Substituting (25),(26),(27), and (28) into (24), we have

$$\begin{aligned}
\sum_{j=1}^{J} n_j w_t^j &= U_C\bar{C}\left[\begin{array}{l} \hat{Y}_t + \frac{1}{2}(1-\rho)\left(\hat{Y}_t\right)^2 - \hat{Y}_t - \frac{1}{2}(1+\eta)\left\{\sum_{j=1}^{J} n_j\left(\hat{P}^R_{j,t}\right)^2 + \left(\hat{Y}_t\right)^2\right\} \\ + \sum_{j=1}^{J} n_j\left\{-(1+\eta)\tilde{P}^R_{j,t} + (\eta+\rho)\tilde{Y}_t\right\}\left(-\hat{P}^R_{j,t} + \hat{Y}_t\right) \\ -\frac{1}{2}\left(\eta+\frac{1}{\sigma}\right)\sum_{j=1}^{J} n_j Var\left(\hat{Y}_{j,t}(i)\right) \end{array}\right] \\
&\quad + t.i.p. + o\left(\|\xi\|^3\right) \\
&= U_C\bar{C}\left[\begin{array}{l} -\frac{1}{2}(\rho+\eta)\left(\hat{Y}_t\right)^2 - \frac{1}{2}(1+\eta)\sum_{j=1}^{J} n_j\left(\hat{P}^R_{j,t}\right)^2 + (1+\eta)\sum_{j=1}^{J} n_j\tilde{P}^R_{j,t}\hat{P}^R_{j,t} \\ +(\rho+\eta)\tilde{Y}_t\hat{Y}_t - \frac{1}{2}(\eta+\frac{1}{\sigma})\sum_{j=1}^{J} n_j Var\left(\hat{Y}_{j,t}(i)\right) \end{array}\right] \\
&\quad + t.i.p. + o\left(\|\xi\|^3\right) \\
&= U_C\bar{C}\left[\begin{array}{l} -\frac{1}{2}(\rho+\eta)\left\{\left(\hat{Y}_t\right)^2 - 2\tilde{Y}_t\hat{Y}_t + \left(\tilde{Y}_t\right)^2 - \left(\tilde{Y}_t\right)^2\right\} \\ -\frac{1}{2}(1+\eta)\sum_{j=1}^{J} n_j\left\{\left(\hat{P}^R_{j,t}\right)^2 - 2\tilde{P}^R_{j,t}\hat{P}^R_{j,t} + \left(\tilde{P}^R_{j,t}\right)^2 - \left(\tilde{P}^R_{j,t}\right)^2\right\} \\ -\frac{1}{2}\left(\eta+\frac{1}{\sigma}\right)\sum_{j=1}^{J} n_j Var\left(\hat{Y}_{j,t}(i)\right) \end{array}\right] \\
&\quad + t.i.p. + o\left(\|\xi\|^3\right)
\end{aligned} \tag{29}$$

Here, since $\left(\tilde{Y}_t\right)^2$ and $\left(\tilde{P}^R_{j,t}\right)^2$ belong to $t.i.p.$, we can rewrite (29) by:

$$\begin{aligned}
\sum_{j=1}^{J} n_j w_t^j &= -\frac{1}{2}U_C\bar{C}\left\{\begin{array}{l} (\rho+\eta)\left(\hat{Y}_t - \tilde{Y}_t\right)^2 + (1+\eta)\sum_{j=1}^{J} n_j\left(\hat{P}^R_{j,t} - \tilde{P}^R_{j,t}\right)^2 \\ + \left(\eta+\frac{1}{\sigma}\right)\sum_{j=1}^{J} n_j Var\left(\hat{Y}_{j,t}(i)\right) \end{array}\right\} \\
&\quad + t.i.p. + o\left(\|\xi\|^3\right)
\end{aligned} \tag{30}$$

Note that the demand for individual goods is given by:

$$Y_{j,t}(i) = \left(\frac{P_{j,t}(i)}{P_{j,t}}\right)^{-\sigma}\left(\frac{P_{j,t}}{P_t}\right)^{-1} Y_t$$

By log-linearization, it becomes

$$\hat{Y}_{j,t}(i) = -\sigma\left(\hat{P}_{j,t}(i) - \hat{P}_{j,t}\right) - \left(\hat{P}_{j,t} - \hat{P}_t\right) + \hat{Y}_t$$

Then, we have that

$$Var\left(\hat{Y}_{j,t}(i)\right) = \sigma^2 Var\left(\hat{P}_{j,t}(i)\right) \tag{31}$$

Here, $Var\left(\hat{P}_{j,t}(i)\right)$ describes price dispersion within a sector. Defining $\bar{P}_t \equiv \mathbb{E}_i\left\{\log(P_{j,t}(i))\right\}$, we obtain

$$\begin{aligned}
Var\left(\hat{P}_{j,t}(i)\right) &= Var\left(\log(P_{j,t}(i)) - \bar{P}_{t-1}\right) \\
&= \mathbb{E}\left((\log(P_{j,t}(i)) - \bar{P}_{t-1})^2\right) - \left(\mathbb{E}(\log(P_{j,t}(i)) - \bar{P}_{t-1})\right)^2 \\
&= \left\{\alpha_j \mathbb{E}\left((\log(P_{j,t-1}(i)) - \bar{P}_{t-1})^2\right) + (1-\alpha_j)\left(\log(\tilde{P}_{j,t}(i)) - \bar{P}_{t-1}\right)^2\right\} \\
&\quad - \left(\mathbb{E}(\log(P_{j,t}(i)) - \bar{P}_{t-1})\right)^2 \\
&= \left\{\alpha_j Var\left(P_{j,t-1}(i)\right) + (1-\alpha_j)\left(\log(\tilde{P}_{j,t}(i)) - \bar{P}_{t-1}\right)^2\right\} - \left(\mathbb{E}(\log(P_{j,t}(i)) - \bar{P}_{t-1})\right)^2 \\
&= \left\{\alpha_j Var\left(P_{j,t-1}(i)\right) + (1-\alpha_j)\left(\log(\tilde{P}_{j,t}(i)) - \bar{P}_{t-1}\right)^2\right\} - \left(\triangle\bar{P}_t\right)^2
\end{aligned} \tag{32}$$

by defining $\triangle\bar{P}_t = \bar{P}_t - \bar{P}_{t-1} = \log(P_{j,t}(i)) - \bar{P}_{t-1}$.
Here, note that

$$\begin{aligned}
\triangle\bar{P}_t &= \left\{\alpha_j \bar{P}_{t-1} + (1-\alpha_j)\log(\tilde{P}_t(i))\right\} - \bar{P}_{t-1} \\
&= (1-\alpha_j)\left(\log(\tilde{P}_t(i)) - \bar{P}_{t-1}\right)
\end{aligned}$$

Then, (32) is written

$$\begin{aligned}
Var\left(\hat{P}_{j,t}(i)\right) &= \alpha_j Var\left(\hat{P}_{j,t-1}(i)\right) + \frac{1}{1-\alpha_j}\left(\triangle\bar{P}_t\right)^2 - \left(\triangle\bar{P}_t\right)^2 \\
&= \alpha_j Var\left(\hat{P}_{j,t-1}(i)\right) + \frac{\alpha_j}{1-\alpha_j}\left(\triangle\bar{P}_t\right)^2
\end{aligned}$$

Note that

$$\bar{P}_t = \log(P_{j,t}) + o\left(\|\xi\|^3\right),$$

which implies

$$\triangle \bar{P}_t = \pi_{j,t} + o\left(\|\xi\|^3\right)$$

Thus, we obtain

$$Var\left(\hat{P}_{j,t}(i)\right) = \alpha_j Var\left(\hat{P}_{j,t-1}(i)\right) + \frac{\alpha_j}{1-\alpha_j}(\pi_{j,t})^2 + o\left(\|\xi\|^3\right),$$

and by backward iteration we have

$$\begin{aligned} Var\left(\hat{P}_{j,t}(i)\right) &= \alpha_j^{t+1} Var\left(P_{j,-1}(i)\right) + \sum_{s=0}^{t} \alpha_j^{t-s} \frac{\alpha_j}{1-\alpha_j}(\pi_{j,s})^2 + o(\|\xi\|^3) \\ &= \sum_{s=0}^{t} \alpha_j^{t-s} \frac{\alpha_j}{1-\alpha_j}(\pi_{j,s})^2 + t.i.p. + o\left(\|\xi\|^3\right) \end{aligned}$$

since $\alpha_j^{t+1} Var\left(P_{j,-1}(i)\right)$ is independent of the policy conducted from $t \geq 0$.
Then, we take the discounted value over time, we obtain

$$\sum_{t=0}^{\infty} \beta^t Var\left(\hat{P}_{j,t}(i)\right) = \frac{\alpha_j}{(1-\alpha_j)(1-\alpha_j\beta)} \sum_{t=0}^{\infty} \beta^t \pi_{j,t}^2 + t.i.p. + o\left(\|\xi\|^3\right) \tag{33}$$

By substituting (33) into (31),

$$\sum_{t=0}^{\infty} \beta^t Var\left(\hat{Y}_{j,t}(i)\right) = \sigma^2 \frac{\alpha_j}{(1-\alpha_j)(1-\alpha_j\beta)} \sum_{t=0}^{\infty} \beta^t \pi_{j,t}^2 + t.i.p. + o\left(\|\xi\|^3\right) \tag{34}$$

Now, we take the discounted sum of (30) with (34)

$$
\begin{aligned}
\sum_{t=0}^{\infty}\beta^t\sum_{j=1}^{J}n_j w_t^j &= -\frac{1}{2}U_C\bar{C}\sum_{t=0}^{\infty}\beta^t\left\{\begin{array}{l}(\rho+\eta)\left(\hat{Y}_t-\tilde{Y}_t\right)^2+(1+\eta)\sum_{j=1}^{J}n_j\left(\hat{P}_{j,t}^R-\tilde{P}_{j,t}^R\right)^2\\ +\left(\eta+\frac{1}{\sigma}\right)\sum_{j=1}^{J}n_j Var\left(\hat{Y}_{j,t}(i)\right)\end{array}\right\}\\
&\quad + t.i.p. + o\left(\|\xi\|^3\right)\\
&= -\frac{1}{2}U_C\bar{C}\sum_{t=0}^{\infty}\beta^t\left\{(\rho+\eta)\left(\hat{Y}_t-\tilde{Y}_t\right)^2+(1+\eta)\sum_{j=1}^{J}n_j\left(\hat{P}_{j,t}^R-\tilde{P}_{j,t}^R\right)^2\right\}\\
&\quad -\frac{1}{2}U_C\bar{C}\left(\eta+\frac{1}{\sigma}\right)\sum_{j=1}^{J}n_j\sum_{t=0}^{\infty}\beta^t Var\left(\hat{Y}_{j,t}(i)\right)+t.i.p.+o\left(\|\xi\|^3\right)\\
&= -\frac{1}{2}U_C\bar{C}\sum_{t=0}^{\infty}\beta^t\left\{(\rho+\eta)\left(\hat{Y}_t-\tilde{Y}_t\right)^2+(1+\eta)\sum_{j=1}^{J}n_j\left(\hat{P}_{j,t}^R-\tilde{P}_{j,t}^R\right)^2\right\}\\
&\quad -\frac{1}{2}U_C\bar{C}\left(\eta+\frac{1}{\sigma}\right)\sum_{j=1}^{J}n_j\left\{\sigma^2\frac{\alpha_j}{(1-\alpha_j)(1-\alpha_j\beta)}\sum_{t=0}^{\infty}\beta^t\pi_{j,t}^2\right\}+t.i.p.+o\left(\|\xi\|^3\right)\\
&= -\frac{1}{2}U_C\bar{C}\sum_{t=0}^{\infty}\beta^t\left\{\begin{array}{l}(\rho+\eta)\left(\hat{Y}_t-\tilde{Y}_t\right)^2+(1+\eta)\sum_{j=1}^{J}n_j\left(\hat{P}_{j,t}^R-\tilde{P}_{j,t}^R\right)^2\\ +\left(\eta+\frac{1}{\sigma}\right)\sigma^2\sum_{j=1}^{J}n_j\frac{\alpha_j}{(1-\alpha_j)(1-\alpha_j\beta)}\pi_{j,t}^2\end{array}\right\}\\
&\quad + t.i.p. + o\left(\|\xi\|^3\right)\\
&= -\frac{1}{2}U_C\bar{C}\sum_{t=0}^{\infty}\beta^t\left\{\begin{array}{l}(\rho+\eta)\left(\hat{Y}_t-\tilde{Y}_t\right)^2+(1+\eta)\sum_{j=1}^{J}n_j\left(\hat{P}_{j,t}^R-\tilde{P}_{j,t}^R\right)^2\\ +(1+\eta\sigma)\,\sigma\sum_{j=1}^{J}n_j\frac{\alpha_j}{(1-\alpha_j)(1-\alpha_j\beta)}\pi_{j,t}^2\end{array}\right\}\\
&\quad + t.i.p. + o\left(\|\xi\|^3\right)
\end{aligned}
$$

By taking expectation on it, we obtain

$$
\begin{aligned}
\mathbb{E}_0\sum_{t=0}^{\infty}\beta^t\sum_{j=1}^{J}n_j w_t^j &= -\frac{1}{2}U_C\bar{C}\mathbb{E}_0\sum_{t=0}^{\infty}\beta^t\left\{\begin{array}{l}(\rho+\eta)\left(\hat{Y}_t-\tilde{Y}_t\right)^2+(1+\eta)\sum_{j=1}^{J}n_j\left(\hat{P}_{j,t}^R-\tilde{P}_{j,t}^R\right)^2\\ +(1+\eta\sigma)\sigma\sum_{j=1}^{J}n_j\frac{\alpha_j}{(1-\alpha_j)(1-\alpha_j\beta)}\pi_{j,t}^2\end{array}\right\}\\
&\quad + t.i.p. + o\left(\|\xi\|^3\right)
\end{aligned}
$$

Thus, we derive

$$
L_t = (\rho+\eta)\left(\hat{Y}_t-\tilde{Y}_t\right)^2+(1+\eta)\sum_{j=1}^{J}n_j\left(\hat{P}_{j,t}^R-\tilde{P}_{j,t}^R\right)^2+(1+\eta\sigma)\sigma\sum_{j=1}^{J}n_j\frac{\alpha_j}{(1-\alpha_j)(1-\alpha_j\beta)}\pi_{j,t}^2
$$

C Robustness checks

For robustness checks, we obtain the OPI inflation and the implied nominal interest rates in the case of $\phi^A = 0.84$ and $\sigma^A = 0.0084$ taken from Bae (2013). We observe here that taking different parameter values for the shock process does not significantly affect the numerical results in baseline case ($\phi^A = 0.34$ and $\sigma^A = 0.0138$). Furthermore, by taking different values of ρ and η, we repeat the same process to obtain the optimal weights. These variations also do not impact greatly on the original numerical results.

C.1 Numerical results when $\phi^A = 0.84$ and $\sigma^A = 0.0084$

Table 10: Optimal weights for the twelve sectors (when $\phi^A = 0.84$ and $\sigma^A = 0.0084$)

	Twelve consumption categories	n_j(%)	α_j	δ_j^*(%)
1	Food and non-alcoholic beverages	14.15	0.1943	2.95
2	Alcoholic beverages and tobacco	1.30	0.0435	0.04
3	Clothing and footwear	6.44	0.7234	15.03
4	Housing, water, electricity and other fuels	10.13	0.6180	13.42
5	Furnishings, household equipment and routine household maintenance	3.73	0.4679	2.52
6	Health	6.36	0.4690	4.36
7	Transport	12.28	0.3613	5.15
8	Communication	6.41	0.0583	0.45
9	Recreation and culture	5.51	0.2497	1.46
10	Education	11.77	0.5578	10.84
11	Restaurants and hotels	13.27	0.7720	38.77
12	Miscellaneous goods and services	8.65	0.4231	5.01

Table 11: Four sectors (when $\phi^A = 0.84$ and $\sigma^A = 0.0084$)

	Twelve consumption categories	n_j(%)	α_j	δ_j^*(%)
1	Food and non-alcoholic beverages	14.15(1st)	0.1943(10th)	2.95(8th)
3	Clothing and footwear	6.44(7th)	0.7234(2nd)	15.03(2nd)
7	Transport	12.28(3rd)	0.3613(8th)	5.15(5th)
8	Communication	6.41(8th)	0.0583(11th)	0.45(11th)

Figure 4: Inflation rates 2003-2016 (when $\phi^A = 0.84$ and $\sigma^A = 0.0084$)

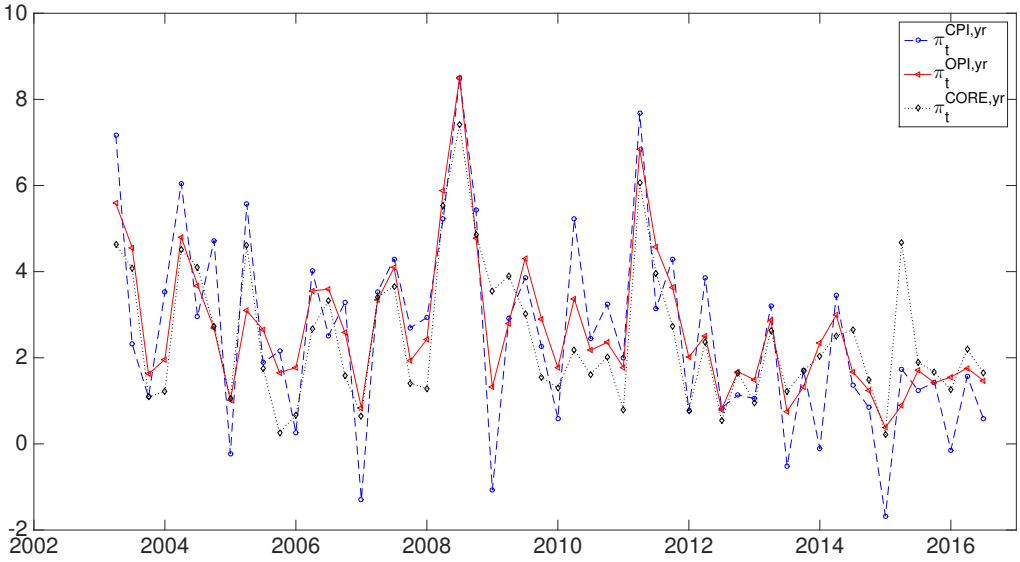

Table 12: Volatility and Persistence of the inflation rates (when $\phi^A = 0.84$ and $\sigma^A = 0.0084$)

Inflation rate index	$\pi^{OPI,yr}$	$\pi^{CPI,yr}$	$\pi^{CORE,yr}$
Standard deviation	1.6211	2.2215	1.5841
Autocorrelation	0.4107	0.0626	0.2756

Figure 5: Interest rates 2003-2016 (when $\phi^A = 0.84$ and $\sigma^A = 0.0084$)

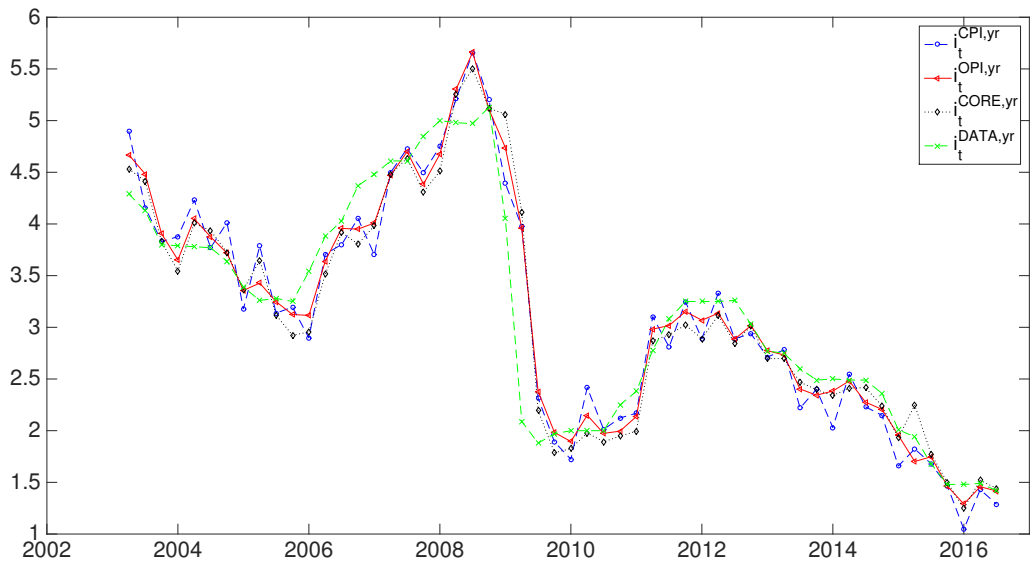

Table 13: Volatility and Persistence of the interest rates (when $\phi^A = 0.84$ and $\sigma^A = 0.0084$)

Interest rate	$i^{OPI,yr}$	$i^{CPI,yr}$	$i^{CORE,yr}$
Standard deviation	1.1094	1.1399	1.1012
Autocorrelation	0.9031	0.8610	0.8886

Table 14: Correlation of the data with the model implied interest rates (when $\phi^A = 0.84$ and $\sigma^A = 0.0084$)

Correlation of $i^{DATA,yr}$ with	$i^{OPI,yr}$	$i^{CPI,yr}$	$i^{CORE,yr}$
Correlation	0.9460	0.9365	0.9305

C.2 Numerical results with different values of ρ

Table 15: Optimal weights for the twelve sectors (when $\rho = 1$)

	Twelve consumption categories	n_j(%)	α_j	δ_j^*(%)
1	Food and non-alcoholic beverages	14.15	0.1943	3.89
2	Alcoholic beverages and tobacco	1.30	0.0435	0.15
3	Clothing and footwear	6.44	0.7234	13.84
4	Housing, water, electricity and other fuels	10.13	0.6180	16.14
5	Furnishings, household equipment and routine household maintenance	3.73	0.4679	4.30
6	Health	6.36	0.4690	5.93
7	Transport	12.28	0.3613	6.87
8	Communication	6.41	0.0583	0.64
9	Recreation and culture	5.51	0.2497	2.29
10	Education	11.77	0.5578	12.84
11	Restaurants and hotels	13.27	0.7720	26.64
12	Miscellaneous goods and services	8.65	0.4231	6.47

Table 16: Four sectors (when $\rho = 1$)

	Twelve consumption categories	n_j(%)	α_j	δ_j^*(%)
1	Food and non-alcoholic beverages	14.15(1st)	0.1943(10th)	3.89(9th)
3	Clothing and footwear	6.44(7th)	0.7234(2nd)	13.84(3rd)
7	Transport	12.28(3rd)	0.3613(8th)	6.87(5th)
8	Communication	6.41(8th)	0.0583(11th)	0.64(11th)

Table 17: Optimal weights for the twelve sectors (when $\rho = 2.5$)

	Twelve consumption categories	n_j(%)	α_j	δ_j^*(%)
1	Food and non-alcoholic beverages	14.15	0.1943	4.73
2	Alcoholic beverages and tobacco	1.30	0.0435	0.18
3	Clothing and footwear	6.44	0.7234	12.27
4	Housing, water, electricity and other fuels	10.13	0.6180	18.90
5	Furnishings, household equipment and routine household maintenance	3.73	0.4679	3.24
6	Health	6.36	0.4690	6.35
7	Transport	12.28	0.3613	7.64
8	Communication	6.41	0.0583	0.85
9	Recreation and culture	5.51	0.2497	2.29
10	Education	11.77	0.5578	15.98
11	Restaurants and hotels	13.27	0.7720	20.72
12	Miscellaneous goods and services	8.65	0.4231	6.85

Table 18: Four sectors (when $\rho = 2.5$)

	Twelve consumption categories	n_j(%)	α_j	δ_j^*(%)
1	Food and non-alcoholic beverages	14.15(1st)	0.1943(10th)	4.73(8th)
3	Clothing and footwear	6.44(7th)	0.7234(2nd)	12.27(4th)
7	Transport	12.28(3rd)	0.3613(8th)	7.64(5th)
8	Communication	6.41(8th)	0.0583(11th)	0.85(11th)

Table 19: Optimal weights for the twelve sectors (when $\rho = 3.5$)

	Twelve consumption categories	n_j(%)	α_j	δ_j^*(%)
1	Food and non-alcoholic beverages	14.15	0.1943	4.88
2	Alcoholic beverages and tobacco	1.30	0.0435	0.20
3	Clothing and footwear	6.44	0.7234	14.82
4	Housing, water, electricity and other fuels	10.13	0.6180	18.12
5	Furnishings, household equipment and routine household maintenance	3.73	0.4679	3.59
6	Health	6.36	0.4690	5.56
7	Transport	12.28	0.3613	7.87
8	Communication	6.41	0.0583	0.89
9	Recreation and culture	5.51	0.2497	2.36
10	Education	11.77	0.5578	16.00
11	Restaurants and hotels	13.27	0.7720	19.08
12	Miscellaneous goods and services	8.65	0.4231	6.63

Table 20: Four sectors (when $\rho = 3.5$)

	Twelve consumption categories	n_j(%)	α_j	δ_j^*(%)
1	Food and non-alcoholic beverages	14.15(1st)	0.1943(10th)	4.88(8th)
3	Clothing and footwear	6.44(7th)	0.7234(2nd)	14.82(4th)
7	Transport	12.28(3rd)	0.3613(8th)	7.87(5th)
8	Communication	6.41(8th)	0.0583(11th)	0.89(11th)

C.3 Numerical results with different values of η

Table 21: Optimal weights for the twelve sectors (when $\eta = 0.5$)

	Twelve consumption categories	n_j(%)	α_j	δ_j^*(%)
1	Food and non-alcoholic beverages	14.15	0.1943	3.52
2	Alcoholic beverages and tobacco	1.30	0.0435	0.08
3	Clothing and footwear	6.44	0.7234	15.81
4	Housing, water, electricity and other fuels	10.13	0.6180	13.47
5	Furnishings, household equipment and routine household maintenance	3.73	0.4679	2.70
6	Health	6.36	0.4690	4.70
7	Transport	12.28	0.3613	6.42
8	Communication	6.41	0.0583	0.55
9	Recreation and culture	5.51	0.2497	1.85
10	Education	11.77	0.5578	11.89
11	Restaurants and hotels	13.27	0.7720	34.32
12	Miscellaneous goods and services	8.65	0.4231	4.69

Table 22: Four sectors (when $\eta = 0.5$)

	Twelve consumption categories	n_j(%)	α_j	δ_j^*(%)
1	Food and non-alcoholic beverages	14.15(1st)	0.1943(10th)	3.52(8th)
3	Clothing and footwear	6.44(7th)	0.7234(2nd)	15.81(2nd)
7	Transport	12.28(3rd)	0.3613(8th)	6.42(5th)
8	Communication	6.41(8th)	0.0583(11th)	0.55(11th)

Table 23: Optimal weights for the twelve sectors (when $\eta = 2$)

	Twelve consumption categories	n_j(%)	α_j	δ_j^*(%)
1	Food and non-alcoholic beverages	14.15	0.1943	3.23
2	Alcoholic beverages and tobacco	1.30	0.0435	0.10
3	Clothing and footwear	6.44	0.7234	17.63
4	Housing, water, electricity and other fuels	10.13	0.6180	14.99
5	Furnishings, household equipment and routine household maintenance	3.73	0.4679	3.00
6	Health	6.36	0.4690	4.52
7	Transport	12.28	0.3613	5.44
8	Communication	6.41	0.0583	0.54
9	Recreation and culture	5.51	0.2497	1.65
10	Education	11.77	0.5578	11.95
11	Restaurants and hotels	13.27	0.7720	31.72
12	Miscellaneous goods and services	8.65	0.4231	5.23

Table 24: Four sectors (when $\eta = 2$)

	Twelve consumption categories	n_j(%)	α_j	δ_j^*(%)
1	Food and non-alcoholic beverages	14.15(1st)	0.1943(10th)	3.23(8th)
3	Clothing and footwear	6.44(7th)	0.7234(2nd)	17.63(2nd)
7	Transport	12.28(3rd)	0.3613(8th)	5.44(5th)
8	Communication	6.41(8th)	0.0583(11th)	0.54(11th)

Table 25: Optimal weights for the twelve sectors (when $\eta = 3$)

	Twelve consumption categories	n_j(%)	α_j	δ_j^*(%)
1	Food and non-alcoholic beverages	14.15	0.1943	3.68
2	Alcoholic beverages and tobacco	1.30	0.0435	0.13
3	Clothing and footwear	6.44	0.7234	15.61
4	Housing, water, electricity and other fuels	10.13	0.6180	16.23
5	Furnishings, household equipment and routine household maintenance	3.73	0.4679	2.85
6	Health	6.36	0.4690	5.79
7	Transport	12.28	0.3613	6.47
8	Communication	6.41	0.0583	0.65
9	Recreation and culture	5.51	0.2497	1.89
10	Education	11.77	0.5578	13.60
11	Restaurants and hotels	13.27	0.7720	26.76
12	Miscellaneous goods and services	8.65	0.4231	6.35

Table 26: Four sectors (when $\eta = 3$)

	Twelve consumption categories	n_j(%)	α_j	δ_j^*(%)
1	Food and non-alcoholic beverages	14.15(1st)	0.1943(10th)	3.68(8th)
3	Clothing and footwear	6.44(7th)	0.7234(2nd)	15.61(3rd)
7	Transport	12.28(3rd)	0.3613(8th)	6.47(5th)
8	Communication	6.41(8th)	0.0583(11th)	0.65(11th)

국문초록

다섹터 모형으로 본 한국의 통화정책

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본 연구는 소비자물가지수를 대상지표로 사용하고 있는 한국의 통화정책을 물가안정목표제에서의 대상지표 관점에서 분석하였다. 우선, 다섹터 신케인지언 모형을 활용하여 한국 경제를 모형화한 후 사회후생을 극대화하는 최적 물가지수를 구안하였다. 이를 통하여 한국에서는 최적 물가지수를 대상지표로 사용하는 경우, 사회 후생 손실을 총소비 균제값의 0.18 퍼센트 정도 줄일 수 있다는 사실을 발견하였다. 나아가 실증 분석을 통하여 한국의 통화정책에 대해 다음과 같은 결론을 도출하였다.

한국의 물가안정목표제는 본 연구에서 구안한 최적 물가지수를 대상지표로 사용하는 경우와 크게 벗어나지는 않지만, 최적 물가지수가 소비자물가지수에 비하여 덜 변동적이고 더 지속적인 특성을 보인다는 측면에서 확연한 차이가 존재함을 밝혔다. 또한 한국은행 정책금리가 최적 물가지수 사용시의 금리와 비슷한 양상을 보이고 있음을 확인하였다. 이는 곧 한국은행이 정책금리를 신중하게 조정하고 있음

을 반증하는 것으로 해석된다.

주요어 : 한국의 통화정책, 최적 통화정책, 다섹터 신케인지언 모형, 섹터간 명목 가격 경직도의 이질성, 물가안정목표제

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