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PRICE-LEVEL TARGETING VERSUS INFLATION TARGETING IN A NEW KEYNESIAN MODEL WITH INFLATION PERSISTENCE

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We compare Price-Level Targeting (PLT) versus Inflation Targeting (IT) using a New Keynesian model, which exhibits inflation persistence (as a result of partial indexation to lagged inflation). We find that, for standard values of the underlying parameters, (i) the loss associated to macroeconomic volatility may decrease about 29% by switching to PLT, (ii) a wide range of values for the weight given by the PLT central bank to output stabilisation allows to attain higher levels of social welfare, (iii) the higher the price rigidity the wider the range over which PLT outperforms IT, but the lower the welfare gain, and (iv) only when the level of indexation is higher than 65% it becomes better not to switch to PLT.

JEL classification codes: E52, E58
Key words: inflation targeting, price-level targeting, indexation, macroeconomic stability

I. Introduction

Since the adoption of Inflation Targeting (IT) by New Zealand in 1990, a growing number of countries have implemented this regime to conduct monetary policy (27 countries according to Hammond 2012). However, in recent years the financial

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crisis and the new challenges facing monetary policy have led to a re-examination of IT (Walsh 2011).

In 2006, the Bank of Canada, one of the IT countries, focused part of its research efforts on the exploration of an alternative regime known as Price Level Targeting (PLT), which intends to stabilise the economy's price level (rather than inflation) around a predetermined path.[1] In 2011, the Bank of Canada finally decided to stick with IT. An important reason was that IT has served Canadians well (Ragan 2011), and therefore the decision was in the spirit of the idea that 'one should not fix something that does not appear to be broken.'

The fact that IT works well does not imply that an alternative regime cannot work better. PLT is a good candidate to replace IT due to its potential benefits: decreasing long-term price level uncertainty, increasing short-term macroeconomic stability and reducing the probability and impact of Zero Lower Bound events.

Vestin (2006) and Roisland (2006) have shown that the optimal policy under commitment (also known as the timeless-perspective policy) can be implemented by assigning a price-level target and the appropriate weight on the output target to a central bank that acts under discretion. Consequently, at least from a theoretical perspective, PLT can outperform IT under discretion.

However, as the Bank of Canada remarks, there is uncertainty about the possibility of realising these theoretical advantages in practice (Bank of Canada 2011). The benefits of PLT stem from its ability to provide an anchor for the level of prices such that inflation expectations help to stabilise the economy, and therefore this regime requires a high degree of credibility and a significant proportion of agents with forward-looking expectations.

In the recent academic literature there is still an ongoing debate on whether or not PLT has possibilities to replace IT. Ambler (2014), for instance, considers that the problem with PLT is that while it entails a certain degree of commitment to the future course of monetary policy, central banks strongly prefer to

[1] This path may have a positive slope, and hence PLT does not necessarily imply a zero-inflation target. In many PLT models (including those of the present paper), as is common in IT models as well, it is assumed that there is a long-run zero-inflation target for the sake of simplicity, without trying to suggest that this is the optimal target. As some previous works have pointed out, a target of zero inflation may impose high costs in terms of social welfare (e.g. Akerlof, Dickens and Williams 1996; Caraballo and Dabús 2013).

exercise discretion.[2] In contrast, others like Hatcher and Minford (2016) argue that policymakers should keep paying attention to PLT since there is empirical evidence in favour of some assumptions in which the PLT benefits lie, i.e. the New-Keynesian structure of the economy and rational expectations.

The present paper analyses the performance of PLT versus IT in terms of social wellbeing, using a similar model to that used by Gaspar et al. (2010a), with a New Keynesian Phillips curve and a loss function, both of which include partial indexation to lagged inflation as derived by Woodford (2003).

It has been common to use indexation as a mechanism to incorporate inflation persistence into macroeconomic models (e.g., Christiano et al. 2005; Smets and Wouters 2007; Benati 2008; Fernández-Villaverde and Rubio-Ramírez 2008; Gaspar et al. 2010a, 2010b; Guerron-Quintana 2011; Bhattarai et al. 2014; among many others). However, as shown by Cogley and Sbordone (2008), inflation persistence may result from variation in the long-run trend component of inflation. When drift in trend inflation is taken into account in the Phillips curve, a forward-looking version of the New Keynesian model fits the data well with no need for backward-looking components.[3] From this perspective, incorporating partial indexation can be interpreted as a proxy for variable trend inflation rather than directly as the mechanism that generates persistence.

Our main results are as follows. First, using standard values of parameters we find that the social loss associated to macroeconomic volatility may decrease about 29% by switching to PLT (from IT) when the weight assigned to output stabilisation, in each regime, is optimally chosen (i.e., the weight is chosen so as to minimise the social loss). In practice, however, it may be difficult to be certain about the optimal value of this weight. Even if it were known, there is no guarantee that the monetary policy committee preferences coincide with such value.

[2] Ambler (2014) mentions, as an example of an increase in the use of discretion, the Fed's experiments with unconventional monetary policies since 2008. Nevertheless, at least one of the unconventional policies, Forward Guidance (FG), was used to communicate a temporary change in the approach to the conduct of monetary policy by committing to a future policy path. Femia et al. (2013) and Raskin (2013) find evidence that FG led to a change in the perception of the FOMC's reaction function.

[3] It is important to remark that although Cogley and Sbordone (2008) made a significant contribution to the analysis of inflation persistence by taking into account the concept of moving trend inflation; their empirical finding with regard to the absence of inflation lags in the Phillips curve may not be robust due to the fact that these results depend on the form of the estimated Euler equation. See Barnes et al. (2011) and Gumbau-Brisa and Lie (2015).

Our second result is obtained by comparing PLT versus IT when the weight on output stabilisation, in the former regime, deviates from the optimal value while that of the latter regime is always optimal. We find that, even under such circumstances, PLT outperforms IT at any value of the weight on output stabilisation between 0.22 and 30 times the optimal weight.

The above results are obtained for the benchmark parameter values. For our third result, we explore robustness of these results to variations in the underlying parameters and find that, in general, there are no significant changes except for variations of the parameter related to price rigidities (the probability of no adjustment in prices). In this case we find that that the higher the price rigidity the wider the range (of values of the output stabilisation weight) over which PLT outperforms IT, but the lower the welfare gain.

In the model of the present paper, the micro-founded social loss is based on the assumption that there is partial indexation to lagged inflation. If, accordingly, the loss function assigned to the central bank in a PLT or an IT regime incorporates this feature (by including a stabilisation objective expressed in terms of the quasi-difference of prices or inflation, respectively) the performance of these regimes does not depend on the degree of indexation because their effects on expected macroeconomic volatility are neutralised in both cases (this can be seen in sections A and C). In other words, our first three results are independent of the level of indexation and, consequently, they can be obtained in a purely forward-looking New Keynesian model.

In practice, however, it is more common to think of IT or PLT as the monetary regimes in which the central bank stabilises inflation or the price level, respectively, (rather than its quasi-difference) around its target. In this case the degree of indexation becomes essential for the comparison of PLT versus IT. Since the benefits of PLT are based on the effect of future price targets on expectations, it has been remarked by the previous literature that inflation inertia reduces its benefits.[4] This is why (in section E) we compare more practical forms[5] of both PLT and IT in order to determine the critical level of indexation to lagged inflation over which it is better not to switch to PLT. Using standard parameter values again, our

[4] Nonetheless, there is evidence that during the inflation-targeting era inflation persistence has been quite low or even nil (Benati 2008). See also section E.

[5] By ‘more practical forms’ we refer to functional forms that have been commonly used in previous literature to represent the central bank’s objective function, which do not incorporate the level of indexation.

fourth result is that the level of indexation has to be larger than 65% to make IT better than PLT in terms of social welfare.

The above-mentioned value (65%) is similar to those found by the previous literature. In a New Keynesian model with an ad hoc hybrid Phillips curve, Walsh (2003) shows that IT outperforms PLT when the weight on lagged inflation is greater than about 55%. Nessén and Vestin (2005), using a model derived by Steinson (2003), in which a fraction of agents follows a rule of thumb to change their prices, find that IT is better than PLT when this fraction is greater than about 60%.

Since none of these papers (including ours) endogenise the weight on lagged inflation, this critical value (65%) should be regarded as a lower bound because PLT may increase the weight of forward-looking expectations in the economy by reducing uncertainty about the future level of prices.

In the next section we present the model and our main findings. Conclusions are detailed in Section III. Some technical details are left to an online appendix.

II. Theoretical framework and results

Our setup is based on the same model used by Gaspar et al. (2010a) to analyse arguments in favour of PLT. It is composed of two aggregate equations (both derived and explained in detail by Woodford 2003): a New Keynesian Phillips curve with partial indexation to lagged inflation and its corresponding loss function. The Phillips curve takes the form

$$\pi_t - \gamma\pi_{t-1} = \beta\left(E_t\pi_{t+1} - \gamma\pi_t\right) + \kappa y_t + \varepsilon_t, \tag{1}$$

where $\pi_t = p_t - p_{t-1}$ is inflation, p_t is the log of the aggregate price, y_t is the log of the output gap, $\varepsilon_t \sim iid\ (0, \sigma^2)$ is a supply shock which is assumed to be observed in t and $E_t[.]$ corresponds to the expectations operator. $\beta \in (0,1)$ is the discount factor. There is Calvo pricing and $1-\omega$ is the probability that the firm can adjust its price. The parameter κ is equal to $[(1-\omega)(1-\omega\beta)/\omega][(\vartheta^{-1}+\varphi)/(1+\varphi\theta)]$ where θ, ϑ and φ are underlying structural parameters representing the elasticity of substitution between goods, the intertemporal elasticity of substitution of households and the elasticity of the real marginal cost with respect to the output level, respectively. The parameter $\gamma \in (0,1)$ captures the degree of indexation so that at the micro level the non-optimising firm j sets its price following $p_{jt} = p_{jt-1} + \gamma\pi_{t-1}$.

The period loss function for this model is derived as a quadratic approximation of the negative of the representative agent's period utility:

$$L_t = (\pi_t - \gamma\pi_{t-1})^2 + \lambda y_t^2, \tag{2}$$

where $\lambda = \kappa/\theta$. The central bank sets the output gap directly.[6]

A. Inflation targeting under discretion

By defining a variable $z_t = \pi_t - \gamma\pi_{t-1}$, equations (1) and (2) can be rewritten as

$$z_t = \beta E_t z_{t+1} + \kappa y_t + \varepsilon_t, \tag{3}$$

$$L_t^{IT} = z_t^2 + \lambda y_t^2. \tag{4}$$

To solve this model for IT, under discretion, it is easy to see that we can focus on the one-period problem. Since the central bank does not commit to future policy decisions, the shock ε_t is white noise and we assume rational expectations, it follows that $E_t z_{t+1} = 0$. Then, by substituting equation (3) into (4) and minimising the loss function with respect to y we obtain

$$y_t^{IT} = -\frac{\kappa}{\kappa^2+\lambda}\varepsilon_t. \tag{5}$$

This is a standard result which shows that, under discretion, the optimal policy is to tighten (loosen) monetary policy when facing a positive (negative) supply shock. Using equations (3)-(5) we can express the period loss function as $L_t = (\lambda/(\kappa^2+\lambda))\varepsilon_t^2$ and hence the discounted loss is

[6] Note that we use a very standard linear-quadratic framework, which is also highly tractable. However, the presence of monopolistically competitive firms in the New Keynesian model distorts the steady state and hence the welfare analysis has to rely on a strong assumption (that there is some mechanism, — e.g., a subsidy — that makes the zero-inflation steady state an efficient level of output). Higher accuracy and more general results can be obtained by using higher-order approximations of the structural equations or some other methods. With regard to this topic and methods see, for instance, Kim and Kim (2003), Schmitt-Grohé and Uribe (2004), Benigno and Woodford (2005).

$$V_t^{IT} = \sum_{i=0}^{\infty} \beta^i E_t L_{t+i}^{IT} = \frac{\lambda}{\kappa^2+\lambda}\left(\varepsilon_t^2 + \frac{\beta}{1-\beta}\sigma^2\right), \tag{6}$$

where V_t^{IT} is the value function for the IT case.

B. Inflation targeting under commitment

Details about how to find a solution for IT under commitment (ITC) are provided by the previous literature (e.g., Vestin 2000). In particular, minimising (4) subject to (3) under the timeless perspective leads to

$$z_t^{ITC} = \frac{\lambda}{\kappa}(y_{t-1}^{ITC} - y_t^{ITC}), \tag{7}$$

$$y_t^{ITC} = \eta\left(y_{t-1}^{ITC} - \frac{\kappa}{\lambda}\varepsilon_t\right), \tag{8}$$

where $\eta = \left(\tau - \sqrt{\tau^2 - 4\beta}\right)/2\beta$ and $\tau = 1 + \beta + \kappa^2/\lambda$. Using the above equations we can express $V_t^{ITC} = \sum_{i=0}^{\infty} \beta^i E_t[(z_{t+i+1}^{ITC})^2 + \lambda(y_{t+i+1}^{ITC})^2]$ as[7]

$$(z_t^{ITC})^2 + \lambda(y_t^{ITC})^2 + \frac{[(1-2\eta)\beta\lambda+\kappa^2+\lambda]\eta^2}{(1-\beta)(1-\beta\eta^2)\lambda}\beta\sigma^2 + \frac{[(1-2\eta)\lambda+(\kappa^2+\lambda)\eta^2]\lambda}{(1-\beta\eta^2)\kappa^2}\beta(y_t^{ITC})^2. \tag{9}$$

As mentioned in the introduction, Vestin (2006) and Roisland (2006) show that the ITC solution can be fully replicated under discretion by assigning a price level target and a specific weight on output in the central bank loss function. Consequently, the solution of ITC becomes a benchmark to measure the relative performance of PLT.

As we will see in the next subsection, similarly to the ITC solution (but unlike the IT solution) the PLT regime introduces a history-dependent policy response.

[7] See the online appendix.

C. Price level targeting

Let us now focus on the solution for PLT (under discretion). In this case, although the social loss is still the same, the central bank minimises a period loss function of the form

$$L_t^{PLT} = (p_t - \gamma p_{t-1})^2 + \mu y_t^2, \tag{10}$$

where μ is the weight given by the monetary policymaker to output stabilisation. In this case the central bank is interested in stabilising the path of prices rather than that of inflation. Notice that by defining a variable $w_t = p_t - \gamma p_{t-1}$ and taking into account that $\pi_t - \gamma\pi_{t-1} = w_t - w_{t-1}$, equations (1) and (10) can be rewritten as

$$w_t - w_{t-1} = \beta(E_t w_{t+1} - w_t) + \kappa y_t + \varepsilon_t, \tag{11}$$

$$L_t^{PLT} = w_t^2 + \mu y_t^2, \tag{12}$$

and we can state the problem of the central bank as

$$Min_{y_t}\, L_t^{PLT} + \beta E_t V_{t+1}^{PLT}. \tag{13}$$

It can be verified (see the online appendix) that by solving this problem we obtain the following functional forms, for the law of motion of w_t and y_t^{PLT} and for the value function V_{t+1}^{PLT}:

$$w_t = \phi(w_{t-1} + \varepsilon_t), \tag{14}$$

$$y_t^{PLT} = -\frac{(1+\beta\delta_w)(1+\beta\phi^2)\kappa}{(1+\beta\delta_w)\kappa^2+(1+\beta)^2\mu}(w_{t-1} + \varepsilon_t), \tag{15}$$

$$V_{t+1}^{PLT} = \delta_0 + \delta_w w_t^2, \tag{16}$$

where

$$\phi = \frac{(1+\beta)(1+\beta\phi^2)\mu}{(1+\beta\delta_w)\kappa^2+(1+\beta)^2\mu},\ \delta_w = \frac{(1+\beta\delta_w)(1+\beta\phi^2)^2\mu}{(1+\beta\delta_w)\kappa^2+(1+\beta)^2\mu},\ \delta_0 = \beta\delta_0 + \delta_w\sigma^2. \tag{17}$$

Remember, however, that social preferences remain the same, and hence we are not interested in comparing V_t^{IT} versus V_t^{PLT} but V_t^{IT} versus the discounted loss for society when the central bank minimises a PLT loss function, i.e., the loss obtained by substituting the solution for PLT into loss function (2) (or, equivalently, into loss function (4)), that is,

$$V_t^{IT|PLT} \equiv \sum_{i=0}^{\infty} \beta^i E_t((z_{t+i}^{PLT})^2 + \lambda(y_{t+i}^{PLT})^2). \tag{18}$$

Using equations (14), (15) and (17) we can express

$$y_{t+i}^{PLT} = \phi y_{t+i-1}^{PLT} - \frac{\kappa\delta_w}{(1+\beta\phi^2)\mu} \varepsilon_{t+i}, \tag{19}$$

and therefore the policy response is history-dependent, unlike the response for IT under discretion (equation (5)). Using equation (19), the fact that $z_{t+i} = w_{t+i} - w_{t+i-1}$ and that $E_t w_{t+i}^2 = \phi^{2i} w_t^2 + \phi^2\sigma(1-\phi^{2i})(1-\phi^2)^{-1}$, after some algebra we can express equation (18) in the following way:[8]

$$(z_t^{PLT})^2 + \lambda(y_t^{PLT})^2 + \frac{(1+\beta(1-2\phi))(1+\beta\phi^2)^2\phi^2\mu^2+\lambda\kappa^2\delta_w^2}{(1-\beta)(1-\beta\phi^2)(1+\beta\phi^2)^2\mu^2}\beta\sigma^2 + \frac{\left((1-\phi)^2(1+\beta\phi^2)^2\mu^2+\lambda\kappa^2\delta_w^2\right)\kappa^2\delta_w^2}{(1-\beta\phi^2)(1+\beta\phi^2)^4\phi^2\mu^4}\beta(y_t^{PLT})^2. \tag{20}$$

In the next subsection we compare equation (20) with (6) for different parameter values and use (9) as the point of reference for the maximum performance that PLT can attain.

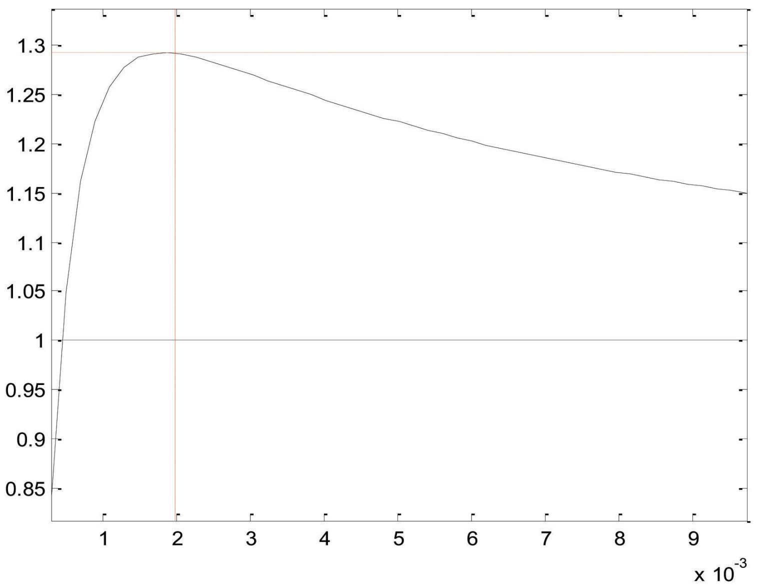
D. Parameter values and results

Notice we need to set values to $\beta, \omega, \theta, \sigma, \vartheta$ and φ in order to compare equations (6) and (20). The values for our benchmark case ($\beta = 0.99$, $\omega = 0.66$, $\theta = 10$, $\sigma = 0.004$, $\vartheta^{-1} = 0.16$ and $\varphi = 0.47$) are taken from Gaspar et al. (2010a, 2010b).[9]
Figure 1 shows the relation between the ratio $V_t^{IT}/V_t^{IT|PLT}$ (y-axis) and μ (x-axis). For the benchmark values $\kappa \simeq 2.0 \times 10^{-2}$, $\lambda \simeq 2.0 \times 10^{-3}$, (represented by the vertical

[8] See the online appendix for more details.
[9] Since Gaspar et al. (2010a, 2010b) do not provide specific values for ϑ^{-1} and φ, we take them from Woodford (2003, Table 6.1).

dotted line in the figure), $V_t^{IT}/V_t^{ITC} \simeq 1.29$ (represented by the horizontal dotted line in the figure), therefore the social loss is about 29% greater under discretion compared with the commitment solution. Since the latter can be implemented by assigning the appropriate PLT function to the central bank, this result basically says that, for the benchmark case, switching from the optimal IT regime to the optimal PLT regime (both under discretion) may increase social welfare by 29%.

Figure 1. $V_t^{IT}/V_t^{IT|PLT}$ **versus** μ **(benchmark case)**



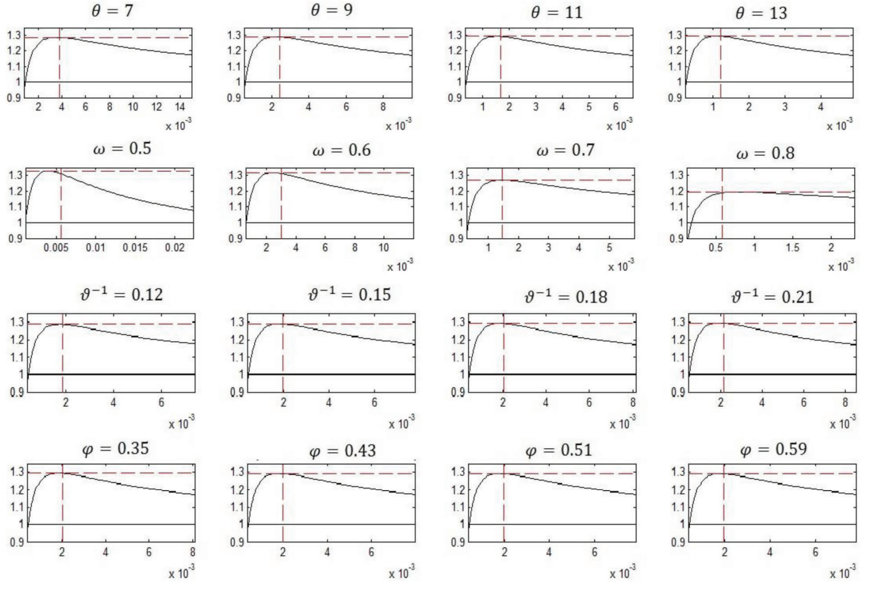
Whether or not PLT outperforms IT (and how much) depends on the weight given by the central bank to output stabilisation in the PLT loss function. The maximum is reached at $\mu \simeq 1.85 \times 10^{-3}$ (where $V_t^{IT|PLT} \approx V_t^{ITC}$); then for the benchmark case we can conclude that PLT gets closer to the ITC solution when the weight given to output stabilisation (relative to prices stabilisation) is about 1.85×10^{-3}, and therefore slightly lower than λ, the weight given to the same objective (but relative to inflation stabilisation) in the social loss.

Figure 1 also shows that the ratio $V_t^{IT}/V_t^{IT|PLT}$ is lower than one only for either small (lower than 4.5×10^{-4}, which represents about 22% of the value of λ) or very large (greater than 5.8×10^{-2} –not shown in the figure-, that is, almost thirty times λ) values of μ, and hence there is a wide range of values which allows the central bank to attain a higher level of social wellbeing under PLT, relative to IT. Only significant deviations of μ from λ can make it possible that IT can do better than PLT.

So far, our results support PLT against IT for the benchmark parameter values. We then explore the robustness of the aforementioned results to changes in four parameters, namely θ, ω, ϑ and φ.[10] Figure 2 shows the ratio $V_t^{IT}/V_t^{IT|PLT}$ for different parameter values (we change only one parameter at a time while the others remain constant and equal to their benchmark values). Since λ varies with each change, we consider values for μ between 20% and 400% of the corresponding λ.

We find that neither the range width (of values μ of as a proportion of λ) for which PLT outperforms IT nor the maximum value of the ratio $V_t^{IT}/V_t^{IT|PLT}$ change significantly for different values of θ, ϑ, or φ. However, they change significantly with ω. From Figure 2, note that the higher the price rigidity the wider the range over which PLT outperforms IT, but the lower the maximum ratio $V_t^{IT}/V_t^{IT|PLT}$.

Figure 2. $V_t^{IT}/V_t^{IT|PLT}$ **versus** μ



[10] It is not usual to allow for variation in β so we keep it constant for the analysis in this section. Changes in σ do not have a significant impact on the ratio $V_t^{IT}/V_t^{IT|PLT}$.

E. More practical versions of IT and PLT

Note that in the previous sections we do not have to set a specific value to the degree of indexation because all the above results are independent of γ. However, since the stabilising benefits of PLT crucially depend on the (partially) neutralising effect of forward-looking expectations, it could be the case that under some circumstances, high inflation persistence makes PLT ineffective or unappealing when compared to IT.

In this subsection, we modify the model to assign more practical and standard forms (as explained below) of the social loss function to the central bank. Under this change, the degree of indexation becomes relevant for the comparison between PLT and IT.

Before performing this modification, it is worth mentioning the fact that previous literature finds evidence that during the inflation-targeting era inflation persistence has been quite low. Benati (2008) shows that high inflation persistence arises when using a data sample that includes both high-inflation and low-inflation regimes while, in contrast, under the inflation-targeting regime inflation is close to being pure random noise around a constant. This result is in line with that of Cogley and Sbordone (2008) (see the introduction): to measure persistence it is relevant to control for shifts in the slow-moving trend inflation.

Although a current low level of inflation inertia is an advantage for PLT and weakens the need to incorporate inertia into the analysis, we think it is still interesting to try to determine the level of persistence (or, in the specific case of our model, the level of indexation to lagged inflation) over which it would be better for monetary policymakers not to switch to PLT. Furthermore, as Benati (2008) shows, although for Canada, New Zealand and some European countries recent inflation persistence is almost nil, there are still countries, such as the US and Japan, for which it is still relatively high (see also Fuhrer 2010 for the case of the US).

We modify the initial model in the following way. Note that equations (2) and (10) incorporate quasi-differences of inflation and prices, respectively. In practice, however, it is more common to think of IT as the monetary regime in which the central bank stabilises inflation (rather than its quasi-difference) around its target. For the same reason it seems more common to represent the central bank loss function for the IT regime as

$$L_t^{IT'} = \pi_t^2 + \mu y_t^2, \tag{21}$$

where we have assumed (as in the previous subsections) that the inflation target is zero. Similarly, if a central bank that wants to implement PLT is interested in stabilising prices (rather than their quasi-difference) around a targeted path[11], then the most appropriate loss function to represent such a regime is

$$L_t^{PLT'} = p_t^2 + \mu y_t^2. \tag{22}$$

In this subsection we want to compare these versions of IT and PLT, which are the ones that have been mainly studied by previous literature. As before, the social loss is still the same (equation 2).

As mentioned above, the ITC solution can be implemented by assigning the loss function (10) with the appropriate weight on output (e.g. $\mu \simeq 1.85 \times 10^{-3}$ for the benchmark case presented in the previous subsection). A corollary of that result is the fact that when the level of indexation is too high ($\gamma \to 1$) the optimal policy under commitment can be implemented by minimising a function of the form (21). In contrast, if the level of indexation is very low ($\gamma \to 0$) the ITC solution can be implemented by minimising a function of the form (22). This is also the reason why it is argued that a high level of indexation reduces the benefits of PLT. While indexation had no relevance in the analysis of the previous subsections, for the analysis of more practical versions of IT and PLT it becomes crucial.

The question that we intend to answer is how high the level of indexation has to be so as to make IT' better than PLT'. To that purpose we compare the discounted loss for society in both cases, that is,

$$V_t^{IT/IT'} \equiv \sum_{i=0}^{\infty} \beta^i E_t \left(\left(\pi_{t+i}^{IT'} - \gamma \pi_{t+i-1}^{IT'} \right)^2 + \lambda \left(y_{t+i}^{IT'} \right)^2 \right), \tag{23}$$

versus

$$V_t^{IT/PLT'} \equiv \sum_{i=0}^{\infty} \beta^i E_t \left(\left(\pi_{t+i}^{PLT'} - \gamma \pi_{t+i-1}^{PLT'} \right)^2 + \lambda \left(y_{t+i}^{PLT'} \right)^2 \right). \tag{24}$$

[11] Zero in our case. Remember that p is expressed in logs.

For these cases it is more difficult to derive an analytical expression so we obtain numerical approximations taking into account that when the central bank minimises a function of the form (21), the expressions for inflation and output take the following form:[12]

$$\pi_t^{IT'} = \psi_1^{IT'} \pi_{t-1}^{IT'} + \psi_2^{IT'} \varepsilon_t, \tag{25}$$

$$y_t^{IT'} = \psi_3^{IT'} \pi_{t-1}^{IT'} + \psi_4^{IT'} \varepsilon_t, \tag{26}$$

and when the central bank minimises a function of the form (22), the expressions for the aggregate price level and output take the following form:[13]

$$p_t^{PLT'} = \psi_1^{PLT'} p_{t-1}^{PLT'} + \psi_2^{PLT'} p_{t-2}^{PLT'} + \psi_3^{PLT'} \varepsilon_t, \tag{27}$$

$$y_t^{PLT'} = \psi_4^{PLT'} p_{t-1}^{PLT'} + \psi_5^{PLT'} p_{t-2}^{PLT'} + \psi_6^{PLT'} \varepsilon_t, \tag{28}$$

where coefficients ψ in equations (25)–(28) are constants that are determined (numerically) by postulating functional forms, solving the corresponding central bank problems (IT' and PLT') and solving systems of equations in a similar way we did for PLT (see the online appendix).

We consider again the benchmark case ($\beta = 0.99$, $\omega = 0.66$, $\theta = 10$, $\sigma = 0.004$, $\vartheta^{-1} = 0.16$ and $\varphi = 0.47$) and allow for variation in γ. We set values for μ between 20% and 300% of $\lambda \simeq 2.0 \times 10^{-3}$.

[12] See more details in the online appendix.

[13] See more details in the online appendix.

Figure 3. $V_t^{IT|IT'}/V_t^{ITC}$ **and** $V_t^{IT|PLT'}/V_t^{ITC}$ **versus** μ

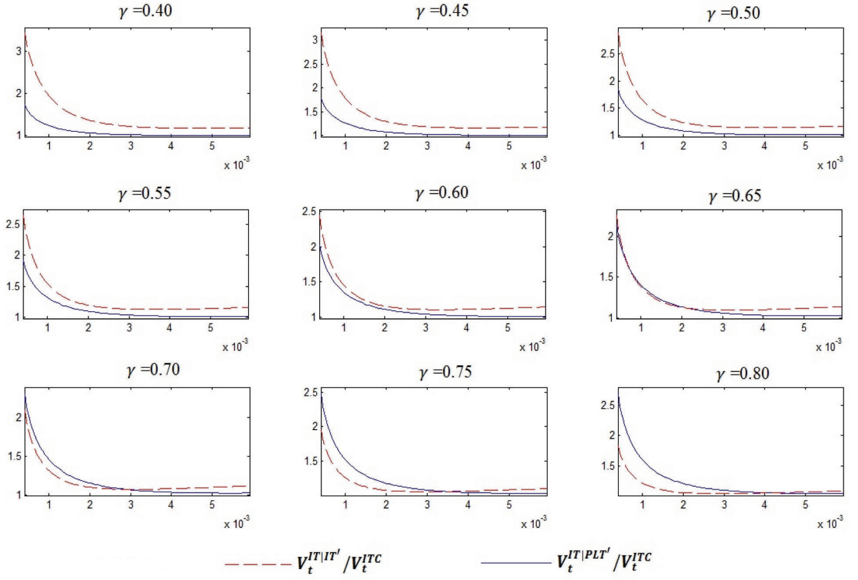


Figure 3 shows the ratios $V_t^{IT|IT'}/V_t^{ITC}$ (dotted line) and $V_t^{IT|PLT'}/V_t^{ITC}$ (solid line) for different values of γ from 0.4 to 0.8. Since ITC is the point of reference for the optimal performance, the closer is the line to one the better the performance of the corresponding regime. The fact that these ratios are never equal to 1 illustrates that equations (21) and (22) are optimal only for the extreme values of the indexation level (γ= 1 or γ= 0, respectively). However, for the appropriate values of μ, the performance of these regimes can be relatively good when compared to IT under commitment. It can also be seen that IT' starts to outperform PLT' with levels of indexation to past inflation higher than 65% (for values of μ close to γ). We denote this critical level by γ^*.

Since our benchmark scenario is based on values that have been used for the case of the US economy it is worth mentioning that 65% of indexation to lagged inflation is a little greater than the estimated value by Benati (2008) for the US (62%), since 1983.

We also allow for variation of parameters $\omega, \theta, \vartheta$ and φ. Table 1 shows the values of γ^* for the benchmark and four extreme cases. These results illustrate the fact that significant changes stem from variation in ω. We can also see that, even for the cases with high price rigidities, the level of indexation to past inflation over which IT' starts to outperform PLT' is greater than 50%, well above the values estimated by Benati (2008) for Canada, the Euro area, New Zealand, Sweden, Switzerland and the UK, during their recent monetary regimes (the highest estimated value is 19%, for Canada) and also greater than the value estimated for Japan (46% since 1983).

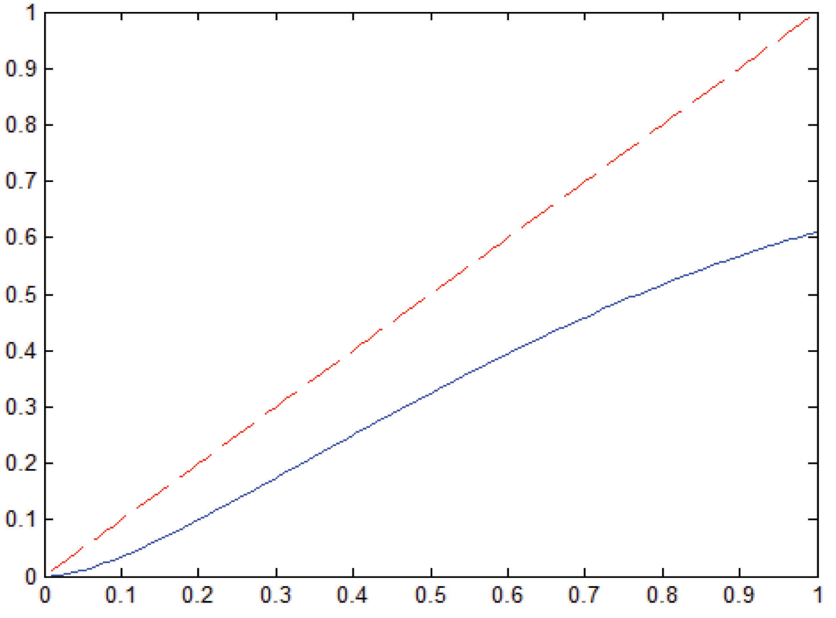
Table 1. Critical values of indexation

Parameter values[a]	γ^*
$\omega = 0.80,\ \theta = 7,\ \vartheta^{-1} = 0.12,\ \varphi = 0.59$	0.52
$\omega = 0.80,\ \theta = 10,\ \vartheta^{-1} = 0.16,\ \varphi = 0.47$	0.54
$\omega = 0.66,\ \theta = 10,\ \vartheta^{-1} = 0.16,\ \varphi = 0.47$	0.65
$\omega = 0.50,\ \theta = 10,\ \vartheta^{-1} = 0.16,\ \varphi = 0.47$	0.66
$\omega = 0.50,\ \theta = 13,\ \vartheta^{-1} = 0.21,\ \varphi = 0.35$	0.66

Note: [a] β= 0.99, σ= 0.004

Furthermore, the foregoing critical values should be regarded as lower bounds if we take into consideration that the model in this paper does not endogenise the indexation level. Even in cases where indexation to lagged inflation is initially higher, it could be beneficial to implement PLT because, as mentioned above, this regime may increase the proportion of forward-looking expectations in the economy (and therefore reduce the influence of backward-looking expectations) by reducing uncertainty about the future level of prices.

Figure 4. $\psi_1^{IT'}$ versus γ



As stated in the introduction we use indexation, as some previous literature does, with the intention of incorporating inflation persistence into our framework. As a result, these two variables are closely related in the model, and therefore we have mainly focused on only one of them, indexation. It is easy to see that for IT under discretion (Section A), inflation persistence can be directly represented by the indexation parameter (i.e. inflation follows an AR(1) process whose coefficient on past inflation is γ). For the case of the 'practical' version of IT, the level of persistence ($\psi_1^{IT'}$in equation (25)) depends on the indexation parameter. Figure 4 depicts how the former changes as a function of the latter (i.e. the solid line. The dotted one corresponds to the 45-degree line), for the benchmark parameter values. Setting $\gamma = 0.62$, i.e. the value estimated by Benati (2008) for the US economy for the period 1983-2005, the above function predicts a level of persistence of 0.41, a little smaller than the one calculated by Benati (2008) using the seasonally adjusted CPI series for the same period (0.49).

III. Conclusion

In recent years the new challenges facing monetary policy have led to a re-examination of Inflation Targeting (IT). Price-Level Targeting (PLT), a monetary policy strategy in which the central bank aims to stabilise the aggregate price level (rather than inflation) around a target path, has been considered a good candidate to replace IT due to its potential benefits: decreasing long-term price level uncertainty, increasing short-term macroeconomic stability and reducing the probability of facing a zero lower bound problem. However, since these benefits become effective through the expectations channel, PLT requires a high degree of credibility. Moreover, there is little and rather outdated practical experience with PLT and there might be significant costs of moving from one regime to another (e.g., due to some communication issues).

The previous literature has shown that PLT can be used to implement the IT solution under commitment, and therefore it is known that a credible PLT regime can outperform IT under discretion. The present paper analyses the performance of PLT versus IT, in terms of social wellbeing, using a New Keynesian model which includes partial indexation to lagged inflation.

We find that, for standard parameter values, the social loss associated to macroeconomic volatility may decrease about 29% by implementing a credible PLT regime when the weight assigned to output stabilisation, in each regime, is optimally chosen. Even if such weight is not optimally chosen by the PLT central bank, there is a wide range of values that allows attaining higher levels of social welfare. We also find that the higher the price rigidity the wider the range over which PLT outperforms IT, but the lower the welfare gain.

In a second analysis, we compare more practical forms of both PLT and IT in order to determine the critical level of indexation to lagged inflation over which it is better not to switch to PLT. Using standard parameter values again, we find that this level is 65%, which is a little higher than the one estimated by Benati (2008) for the US (for the period 1983-2005), and much higher than those estimated by the same author for Canada, the Euro area, Japan, New Zealand, Sweden, Switzerland and the UK (for periods related to their recent monetary regimes, e.g. inflation targeting).

Additionally, this critical value (65%) should be regarded as a lower bound since our model does not endogenise the indexation level. In cases where indexation is initially higher, it would still be worth switching to PLT because this regime may increase the influence of forward-looking expectations in the economy by reducing uncertainty about the future level of prices.

References

Akerlof, George, Dickens, William and George Perry (1996). The macroeconomics of low inflation. *Brookings Papers on Economic Activity* 1: 1-76.

Ambler, Steven (2014). Price-level targeting: a post mortem.? Commentary 400. C.D Howe Institute.

Bank of Canada (2011). Renewal of the inflation-control target: Background information November 2011. Bank of Canada.

Barnes, Michelle, Gumbau-Brisa, Fabià, Lie, Denny and Giovanni Olivei (2011). Estimation of forward-looking relationships in closed form: An application to the new Keynesian Phillips curve. Working Papers 11-3. Federal Reserve Bank of Boston.

Benati, Luca (2008). Investigating inflation persistence across monetary regimes. *Quarterly Journal of Economics*, 123(3): 1005-1060.

Benigno, Pierpaolo and Michael Woodford (2005). Inflation stabilization and welfare: The case of a distorted steady state. *Journal of the European Economic Association*, 3(6): 1185-1236.

Bhattarai, Saroj, Lee, Jae Won and Woong Yong Park (2014). Price indexation, habit formation, and the generalized Taylor principle. *Journal of Economic Dynamics and Control*, 48(C): 218-225.

Caraballo, Ma. Ángeles and Carlos Dabús (2013). Price dispersion and optimal inflation: The Spanish case. *Journal of Applied Economics* 16: 49-70.

Christiano, Lawrence, Eichenbaum, Martin and Charles Evans (2005). Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy*, 113(1): 1-45.

Cogley, Timothy and Argia Sbordone (2008). Trend inflation, indexation, and inflation persistence in the new Keynesian Phillips curve. *American Economic Review*, 98(5): 2101-26.

Femia, Katherine, Friedman, Steven, and Brian Sack (2013). The effects of policy guidance on perceptions of the Fed's reaction function. Federal Reserve Bank of New York, Staff Report No. 652.

Fernández-Villaverde, Jesús and Juan Rubio-Ramírez (2008). How structural are structural parameters.? In *National Bureau of Economic Research (NBER) Macroeconomics Annual 2007*, Volume 22: 83-137.

Fuhrer, Jeffrey (2010). Inflation persistence. In B. M. Friedman and M. Woodford, editors, *Handbook of monetary economics*, Edition 1, Volume 3, Chapter 9: 423-486.

Gaspar, Vítor, Smets, Frank and David Vestin (2010a). Is the time for price-level path stability.? In P., Siklos, M., Bohl and M. Wohar, editors, *Challenges in central banking: The current institutional environment and forces affecting monetary policy*, Cambridge University Press.

Gaspar, Vítor, Smets, Frank and David Vestin (2010b). Inflation expectations, adaptive learning and optimal monetary policy. In B., Friedman and M. Woodford, *Handbook of monetary economics*, 3: 1055-1095.

Guerron-Quintana, Pablo (2011). The implications of inflation in an estimated new Keynesian model. *Journal of Economic Dynamics and Control*, 35(6): 947-962.

Gumbau-Brisa, Fabia and Denny Lie (2015). Comments on trend inflation, indexation, and inflation persistence in the new Keynesian Phillips curve. Working Papers 2015-13, University of Sydney.

Hammond, Gill (2012). State of the art of inflation targeting. Handbook No. 29, Centre for Central Banking Studies, Bank of England.

Hatcher, Michael and Patrick Minford (2016). Stabilisation policy, rational expectations and price-level versus inflation targeting: A survey. *Journal of Economic Surveys*, 30(2): 327-55.

Kim, Jinill and Sunghyun Henry Kim (2003). Spurious welfare reversals in international business cycle models. *Journal of International Economics*, 60(2): 471-500.

Nessén, Marianne and David Vestin (2005). Average inflation targeting. *Journal of Money, Credit, and Banking*, 37(5): 837-63.

Ragan, Christopher (2011). The roads not taken: Why the Bank of Canada stayed with inflation targeting. E-briefs 125, C.D. Howe Institute website.

Raskin, Matthew (2013). The effects of the Federal Reserve’s date-based forward guidance. Finance and Economics Discussion Series, Divisions of Research & Statistics and Monetary Affairs, Federal Reserve Board, Washington D.C.

Roisland, Oistein (2006). Inflation inertia and the optimal hybrid inflation/price-level target. *Journal of Money Credit and Banking*, 38(8): 2247-51.

Schmitt-Grohe, Stephanie and Martín Uribe (2004). Solving dynamic general equilibrium models using a second-order approximation to the policy function. *Journal of Economic Dynamics and Control*, 28(4): 755-775.

Smets, Frank and Rafael Wouters (2007). Shocks and frictions in US business cycles: A Bayesian DSGE approach. *American Economic Review*, 97(3): 586-606.

Steinsson, Jón (2003). Optimal monetary policy in an economy with inflation persistence. *Journal of Monetary Economics*, 50(7): 1425-1456.

Vestin, David (2000). Price-level versus inflation targeting in a forward-looking model. Working Paper 106, Sveriges Riksbank.

Vestin, David (2006). Price-level versus inflation targeting. *Journal of Monetary Economics*, 53(7): 1361-1376.

Walsh, Carl (2003). Speed limit policies: The output gap and optimal monetary policy. *American Economic Review*, 93 (1): 265-278.

Walsh, Carl (2011). The future of inflation targeting. *Economic Record*, 87: 23-36.

Woodford, Michael (2003). Interest and prices: Foundations of a theory of monetary policy. Princeton University Press.