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Price-level targeting when there is price-level drift

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Abstract:

Recent research has shown that optimal monetary policy may display considerable price-level drift. Proponents of price-level targeting have argued that the costs of eliminating the price-level drift may be reduced if the central bank responds flexibly by returning the price level only gradually to the target path (Gaspar et al., 2010). We revisit this argument in two variants of the New Keynesian model. We show that in a two-sector version of the model which allows for changes in relative prices across sectors, the costs of stabilisation under price-level targeting remain much higher than under inflation targeting for all policy-relevant horizons. Our conclusion is that extending the policy horizon is not a panacea to reduce the costs of eliminating price-level drift.

Keywords: price-level targeting, optimal monetary policy, commitment

JEL-Classification: E58, E42, E31

Non technical summary

In the canonical New Keynesian model, the optimal monetary policy response to shocks implies a stationary price level. This remarkable result has been put forward as an argument in favour of price-level targeting. However, the optimality of a stationary price level is a very special result, and recent research has shown that optimal monetary policy may display price-level drift if the canonical model is only slightly modified.

If optimal monetary policy involves a non-stationary price level, reverting the price level to the target path will inevitably stabilise prices too much and, consequently, lead to higher volatility of other variables. Yet, to our knowledge, the potential costs of eliminating price-level drift have not been analysed systematically so far. Instead, proponents of price-level targeting have argued that the costs of eliminating the price-level drift may decline if the central bank responds flexibly by returning the price level only gradually to its steady state. In this paper we show one example in which the argument is correct and one example in which it is not.

In our first example, a New Keynesian model with price-level drift, we find that (i) bringing back the price level to its target at a very short policy horizon leads to high volatility and welfare costs, (ii) inflation targeting is better than price-level targeting for policy horizons longer than two quarters, but (iii) for a policy horizon of two years or longer the costs of stabilisation under price-level targeting are not notably higher than those under inflation targeting.

In our second example, a two-sector extension of the New Keynesian model, we illustrate that the costs of stabilisation under price-level targeting remain high over a policy-relevant horizon. Specifically, we find that (i) targeting the price level or the inflation rate at short policy horizons leads to high volatility in other welfare-relevant variables and thus to high welfare losses, (ii) inflation targeting is better than price-level targeting for policy horizons longer than two quarters, and (iii) in contrast to inflation targeting the costs of stabilisation under price-level targeting remain high even if the horizon is extended. We conclude that extending the policy horizon is not a panacea to reduce the costs of eliminating price-level drift.

Nicht technische Zusammenfassung

Im kanonischen neukeynesianischen Modell führt die optimale Reaktion der Geldpolitik auf Schocks zu einem stationären Preisniveau. Dieses bemerkenswerte Ergebnis wird als ein Argument angeführt, auf eine Geldpolitik der Preisniveausteuerung überzugehen. Allerdings handelt es sich bei dem Ergebnis um einen Spezialfall: So zeigen neuere Forschungsarbeiten, dass bereits kleine Änderungen des Grundmodells zu einer Drift im Preisniveau führen können.

Wenn nun optimale Geldpolitik ein nichtstationäres Preisniveau bedingt, dann bedeutet die Rückführung der Preise auf einen Zielpfad, dass sie mehr als optimal stabilisiert werden und es folglich zu stärkeren Schwankungen in anderen makroökonomischen Größen kommt. Diese potenziellen Kosten der Beseitigung einer Preisniveaudrift wurden unseres Wissens bisher noch nicht systematisch analysiert. Befürworter der Preisniveausteuerung haben in diesem Zusammenhang die Vermutung geäußert, dass die Kosten der Rückführung umso geringer ausfallen, je mehr Zeit sich die Zentralbank nimmt, die Preise auf den Zielpfad zurückzuführen. In dieser Arbeit zeigen wir ein Beispiel, in dem die Vermutung zutrifft sowie ein Beispiel, in welchem sie nicht zutrifft.

Im Rahmen unseres ersten Beispiels, einem neukeynesianischen Modell mit Preisniveaudrift, finden wir, dass (i) bei sehr kurzem Politikhorizont die Rückführung des Preisniveaus auf den Zielpfad mit starken Schwankungen und hohen Wohlfahrtskosten verbunden ist, (ii) bei einem Politikhorizont von mehr als zwei Quartalen die Strategie der Inflationsratensteuerung besser abschneidet als Preisniveausteuerung, aber (iii) bei einem Politikhorizont von zwei Jahren oder länger die Stabilisierungskosten bei Preisniveausteuerung nicht nennenswert höher ausfallen als bei Inflationsratensteuerung.

Im Rahmen unseres zweiten Beispiels, einem neukeynesianischen Modell mit zwei Sektoren, illustrieren wir, dass die Stabilisierungskosten bei Preisniveausteuerung auch für einen politikrelevanten Horizont hoch bleiben. Im Einzelnen zeigen wir, dass (i) bei sehr kurzem Politikhorizont sowohl die Preisniveausteuerung als auch die Inflationsratensteuerung mit starken Schwankungen anderer makroökonomischer

Größen und damit mit hohen Wohlfahrtsverlusten verbunden ist, (ii) bei einem Politikhorizont von mehr als zwei Quartalen die Strategie der Inflationsratensteuerung besser abschneidet als Preisniveausteuerung und (iii) dass im Gegensatz zur Inflationsratensteuerung die Stabilisierungskosten bei Preisniveausteuerung hoch bleiben auch wenn der Politikhorizont deutlich verlängert wird. Wir werten unsere Ergebnisse als Indiz dafür, dass die Verlängerung des Politikhorizonts nicht grundsätzlich ermöglicht, die Stabilisierungskosten bei Preisniveausteuerung merklich zu reduzieren.

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1 Introduction

In the canonical New Keynesian model, the optimal monetary policy response to shocks implies a stationary price level (Clarida, Gertler and Galí, 1999, and Woodford, 2003). This remarkable result has been put forward as an argument in favour of price-level targeting. However, as pointed out by Woodford (2003, p 501), the optimality of a stationary price level is a very special result which is not likely to carry over to more general models. Indeed, recent research has shown that optimal monetary policy may display price-level drift if the canonical New Keynesian model is only slightly modified. For instance, Levin et al. (2010) find that, at the zero interest rate bound, optimal monetary policy may involve considerable price-level drift following a contractionary demand shock. Further examples are provided by Eggertson and Woodford (2003), Steinsson (2003), Amano, Ambler and Shukayev (2010) and Giannoni (2010).[2]

If optimal policy involves a non-stationary price level, reverting the price level to the target path will inevitably stabilise prices too much and, consequently, lead to higher volatility of other variables, notably output. Yet, to our knowledge, the potential costs of eliminating price-level drift have not been analysed systematically so far. Instead, proponents of price-level targeting have argued that the costs associated with undoing shock-induced shifts in the price level may be reduced by “a flexible regime that allows for a gradual return of the price level to its target depending on the shocks hitting the economy” (Gaspar, Smets and Vestin, 2010, p 36).

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[1] Christina Gerberding, Rafael Gerke and Felix Hammermann, Deutsche Bundesbank, Wilhelm-Epstein-Strasse 14, 60431 Frankfurt am Main, Germany, email: firstname.lastname@bundesbank.de. The views expressed in this paper are not necessarily those of the Deutsche Bundesbank or the Eurosystem. We appreciate helpful comments by Steve Ambler, Martin Bodenstein, Ali Dib, Dale Henderson, Heinz Herrmann, Thomas Laubach, Harald Uhlig, Jens Ulbrich and Andreas Worms as well as valuable suggestions by Teruyoshi Kobayashi and Alexander Wolman. All remaining errors and shortcomings are, of course, our own.

[2] For seminal contributions on price-level targeting see Svensson (1999) and Vestin (2006). Ambler (2009) and Deutsche Bundesbank (2010) provide a survey.

In the present paper, we revisit the stabilisation costs of price-level targeting in two variants of the New Keynesian model with price-level drift. In order to analyse explicitly the role of the target horizon, we implement the price-level targeting regime as an additional forward-looking constraint that forces the central bank to take the necessary action in order to return the price level to the target path at a given point in time (Smets, 2003). In Section 2, we investigate the effects of extending the target horizon in a version of the New Keynesian model where complete stabilisation of the price level is not optimal on account of non-negligible transactions frictions. In this context, we show the following: (i) Returning the price level to the target path at a very short policy horizon leads to high volatility and welfare costs, (ii) inflation targeting is better than price-level targeting for policy horizons longer than two quarters, but (iii) for a policy horizon of two years or longer the costs of stabilisation under price-level targeting are not notably higher than those under inflation targeting.

However, in Section 3 of the paper, we show that these results are not generally true. To illustrate the point, we present a model variant where the costs of stabilisation under price-level targeting may remain high for all policy-relevant horizons. The model that we consider is a two-sector extension of the New Keynesian model that features nominal rigidities in both an intermediate goods sector and a final goods sector (Huang and Liu, 2005). Such an environment is of particular interest, as it allows us to analyse the implications of changes in relative prices across sectors resulting from sector-specific shocks. Our findings can be summarised as follows: (i) Targeting the price level or the inflation rate at short policy horizons leads to high volatility in other welfare-relevant variables and thus to high welfare losses, (ii) inflation targeting is better than price-level targeting for policy horizons longer than two quarters, and (iii) in contrast to inflation targeting, which converges to the optimal monetary policy (Ramsey policy) rather quickly, the costs of stabilisation under price-level targeting remain high even if the horizon is extended. We conclude that extending the policy horizon is not a panacea to reduce the costs of eliminating price-level drift.

2 Low costs of eliminating a price-level drift

We start by revisiting the emergence of a price-level drift under the optimal commitment policy and show that extending the horizon for returning to a price-level target reduces the welfare costs to only little more than the full commitment solution. The underlying New Keynesian model is summarised by two structural equations. The log-linearised IS curve is given by

$$x_t = E_t x_{t+1} - \frac{1}{\sigma}\left(r_t - E_t \pi_{t+1}\right) + u_t, \tag{1}$$

where x_t is the output gap, π_t is the inflation rate, r_t is the nominal interest rate and u_t is a demand shock. The parameter σ refers to the inverse of the elasticity of intertemporal substitution. The log-linearised Phillips curve is given by

$$\pi_t = \beta E_t \pi_{t+1} + \kappa x_t + e_t, \tag{2}$$

where e_t is a cost-push shock and κ is the slope of the Phillips curve; β symbolises the discount factor of the representative household.

We assume that the central bank seeks to maximise the welfare criterion

$$\mathbb{W} \cong -E_t \sum_{j=0}^{\infty} \beta^j \left\{\pi_{t+j}^2 + \lambda_x x_{t+j}^2 + \lambda_r r_{t+j}^2\right\}, \tag{3}$$

where λ_x and λ_r are weights placed on stabilisation of the output gap and the nominal interest rate. Following Woodford (2003, Chapter 6) the welfare criterion can be viewed as a second-order Taylor approximation to the lifetime utility of the representative household in the underlying model. The structural parameters of the model determine the relative weights λ_x and λ_r. With $\lambda_r > 0$ the criterion takes into account the potential costs of interest rate variability, reflecting both welfare costs of transactions and an approximation to the zero lower bound on nominal interest rates.

The calibration of the model parameters is taken from Galí (2003) and Woodford (2003) and summarised in Table 1. The parameter κ in the Phillips curve implies that firms set their prices on average for one year. The demand and the cost-push shock follow AR(1) processes, where the persistence parameters are set to 0.9, and the white-noise error terms are calibrated to a standard deviation of one.

Table 1: Calibration of parameters

β	σ	κ	λ_x	λ_r
0.99	1	$0.171\overline{6}$	$0.015\overline{60}$	0.077

We begin the analysis of monetary policy with the full commitment solution (denoted Ramsey), where the central bank maximises the welfare criterion (3) subject to the log-linearised IS curve (1) and the log-linearised Phillips curve (2). In Figure 1 we illustrate the impulse responses (dashed lines) to a positive cost-push shock e_t. The lower left panel displays the response of inflation, which returns in the long run to its steady state. Inflation undershoots the steady state for many periods and therefore the price level does not return to its steady state, but drifts significantly (upper left panel). If the central bank cares about volatility of the interest rate it is optimal to stabilise the inflation rate but not the price level. Accordingly, the price level is non-stationary.

Against the outcome of the Ramsey policy, we evaluate the potential costs of eliminating the shock-induced shift in the price level. In particular we assess whether the elimination of the drift becomes less costly if – as proponents of price-level targeting have argued – the central bank extends the policy horizon. Such a policy horizon has already been made explicitly in the case of inflation targeting regimes. We therefore compare pinning down the price level at a given horizon with a corresponding constraint that pins down the inflation rate at that horizon. Smets (2003) explains that this approach captures well the actual behaviour of central banks with an explicit inflation target. In fact, many inflation-targeting central banks have a lexicographic ordering of their objectives in their mandate. As a case in point the Eurosystem – a subset of the European System of Central Banks (ESCB) – has its mandate clearly spelled out in Article 105 of the Treaty establishing the European Community that states: "The primary objective of the ESCB shall be to maintain price stability. Without prejudice to the objective of price stability, the ESCB shall support the general economic policies in the Community with a view to contributing to the achievement of the objectives of the Community as laid down in Article 2." The ECB's Governing Council specified that "price stability is to be maintained over the medium term" (ECB, 1999).

Modelling inflation targeting and the policy horizon as an additional constraint allows us to explicitly take into account two core elements, namely that (i) other target variables of the welfare criterion are subordinated to achieving the inflation target and (ii) the inflation target is not meant to be achieved immediately but over the medium-term horizon. Hence, the central bank not only maximises social welfare but also guarantees that it will return the inflation rate to its target at the pre-specified horizon.

Formally, we impose the condition that under inflation targeting (IT) the expected inflation rate has to return to its target, which is normalised to zero, after H periods:

$$E_t \pi_{t+H} = 0. \tag{4}$$

To evaluate price-level targeting (PLT) we choose the very same approach but alter the constraint so that the expected price level has to return to its initial steady state after H periods:

$$E_t p_{t+H} = 0. \tag{5}$$

The additional constraints amend the optimisation problem as the central bank maximises the welfare criterion (3) not only subject to the model equations (1) and (2) but now takes into account either constraint (4) or (5). Because of the non-recursive nature of the two constraints, the "constrained Ramsey" problems cannot be solved directly using standard methods. We follow Marcet and Marimon (1998) and enlarge the central bank's state space with additional Lagrange multipliers to retrieve the recursive structure (see Smets, 2000, for an illustration).[3]

Figure 1 illustrates the impulse responses after a positive cost-push shock for a price-level target with a horizon H of 4 and 8 periods (left panels). We start with a horizon of $H = 4$ periods, corresponding to one year (solid lines). Accordingly, the price

[3] In Appendix 1 we show that this approach is equivalent in terms of welfare to having an additional term in the loss function that penalises deviations of the price level. The loss of each weight can be matched to a targeting horizon. In contrast to the horizons, the weights lack a meaningful interpretation.

level gets stabilised at the designated horizon of 4 quarters. The respective response of inflation undershoots the steady state by as much as necessary to stabilise the price level. A horizon of $H = 8$ periods (dash-dotted lines) gives the central bank more leeway in achieving the price-level target, and thus the undershooting of the inflation rate lasts longer.

The right panels of Figure 1 display the impulse responses of the price level and inflation rate if the central bank pins down the inflation rate at a given horizon. For a horizon of $H = 4$ periods (solid lines) inflation converges straight to its steady state, whereas for $H = 8$ periods (dash-dotted lines) it initially follows the Ramsey response before returning to its steady state. To stabilise the inflation rate earlier than optimal leads to a positive drift in the price level.

Figure 1: Responses to a positive cost-push shock

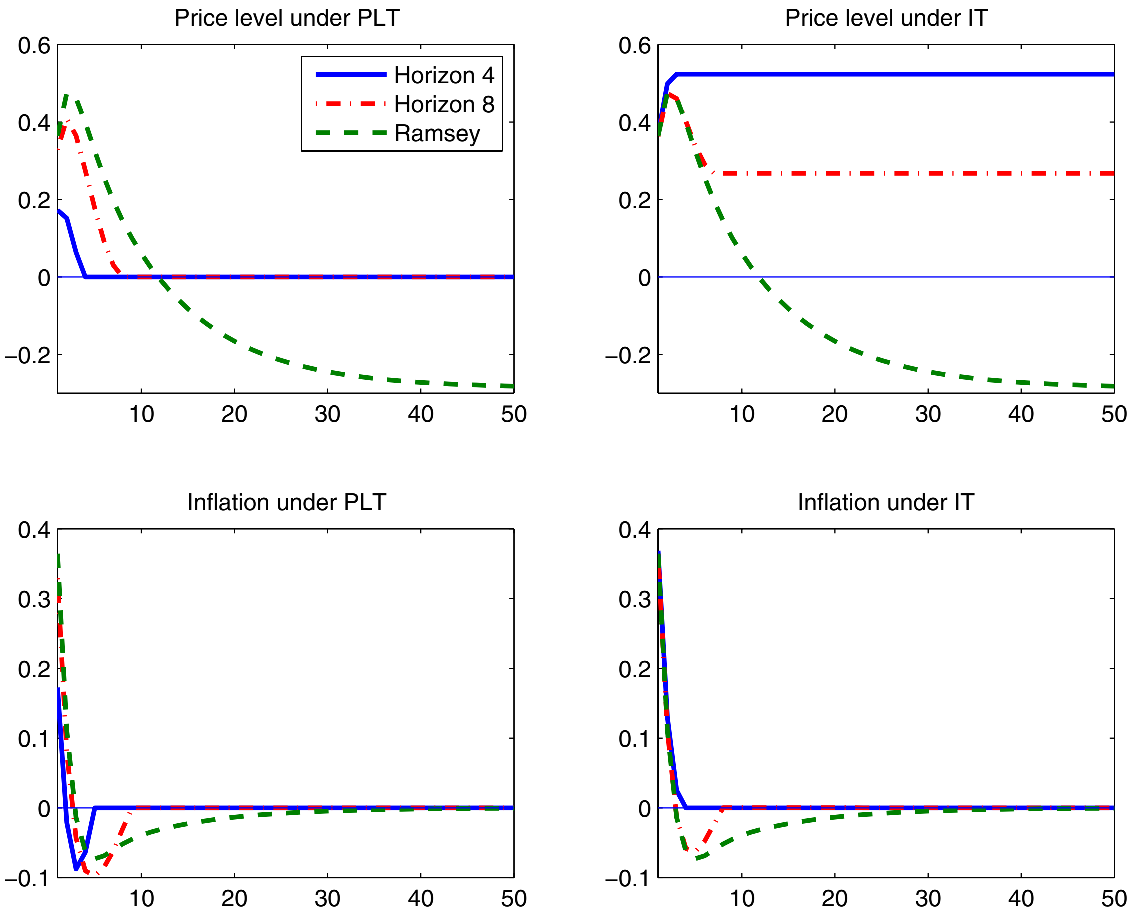


Figure 2 presents the welfare losses (relative to steady state consumption in percent) of the unconstrained (dashed line) and the constrained Ramsey policies as a function of the targeting horizon for $H = 1$ to $H = 16$ quarters. The welfare loss under price-level targeting is indicated by a solid line and under inflation targeting by a dash-dotted line. At $H = 1$, that is, if the central bank pins down the target immediately, there is no difference between targeting the price level and targeting the inflation rate. For both price-level targeting and inflation targeting, the losses decline quickly, but price-level targeting never converges to the unconstrained Ramsey outcome. At a policy-relevant targeting horizon of, say, two years, the welfare losses for price-level targeting as well as inflation targeting fall close to 1 percent relative to the Ramsey policy (Table 2).

Figure 2: Comparison of welfare losses as a function of horizon

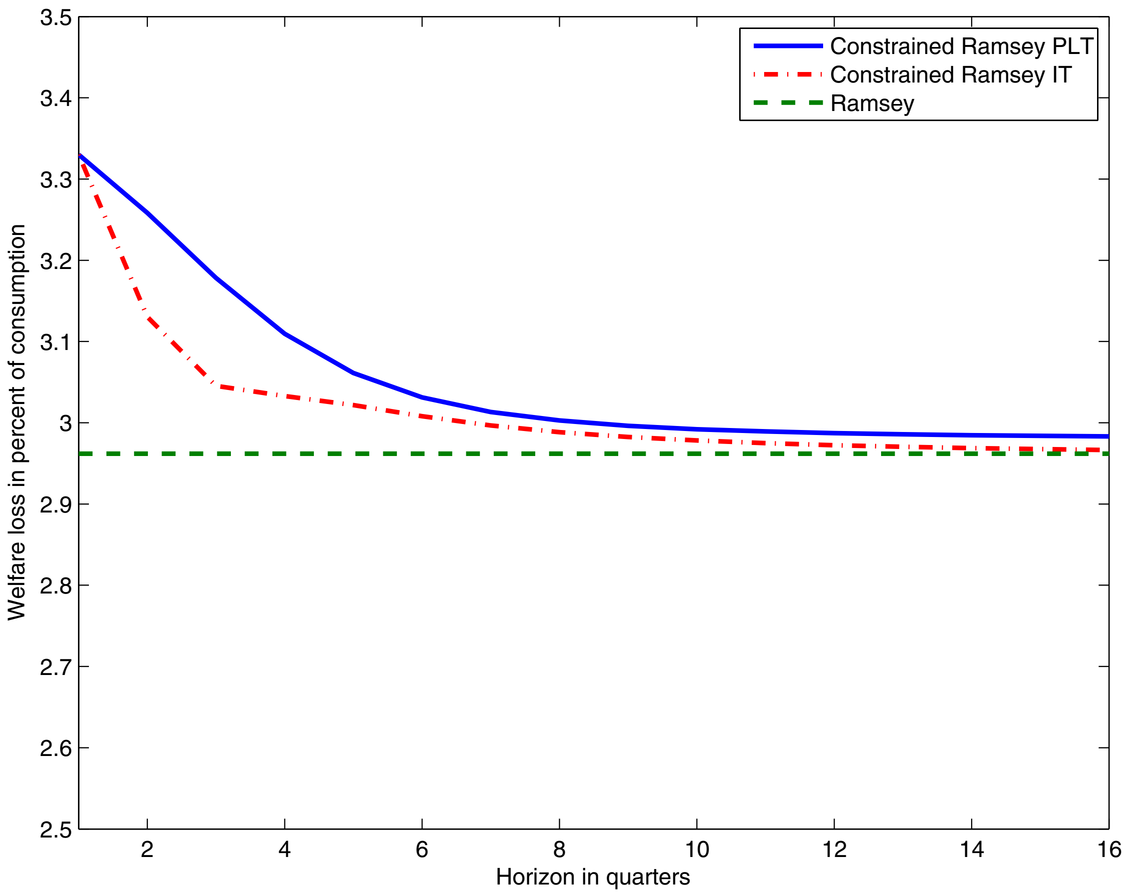


Table 2: Comparison of relative welfare losses

	Loss for Ramsey policy	Relative loss in percent				
		at $H = 1$	at $H = 4$	at $H = 8$	at $H = 12$	at $H = 16$
… for price-level target	2.96	12.43	4.99	1.38	0.85	0.72
… for inflation target	2.96	12.43	2.40	0.89	0.35	0.15

Note: The welfare loss for the unconstrained Ramsey policy is given in percent of steady-state consumption (column 1). The relative loss is measured as the difference between the losses of the constrained and the unconstrained Ramsey policy over the loss of the unconstrained Ramsey in percent (columns 2-6).

We summarise our findings as follows: (i) targeting the price level or the inflation rate at very short policy horizons leads to higher welfare losses than the Ramsey policy, (ii) inflation targeting is only slightly better than price-level targeting for policy horizons $H \geq 2$, (iii) with longer policy horizons the welfare losses of inflation targeting and price-level targeting approach the Ramsey welfare rather quickly and – most importantly – the costs of stabilisation under price-level targeting are not notably higher than those under inflation targeting for a policy-relevant horizon.

3 High costs of eliminating a price-level drift

3.1 A model with two sectors facing nominal rigidities

One of the simplifying assumptions in the canonical New Keynesian model is that the model abstracts from sector-specific changes in technologies and/or demand conditions that may require changes in relative prices across sectors. The price index in the New Keynesian model is the aggregate of prices for many similar goods, which are produced with identical technologies and face identical demand conditions. Due to staggered pricing, there may be heterogeneity in these individual prices, but this heterogeneity implies inefficiencies.[4] It is therefore optimal for the central bank to stabilise the level

[4] In the prototypical New Keynesian model, changes in relative prices between goods within a sector are a fundamental problem as firms cannot re-set their price in each period. Conversely, households wish to consume a wide range of goods in such a way that they demand the same quantity of all goods. It is therefore efficient to offer the same quantities of all types of goods. This requires all goods to always be offered at the same price. Since firms' price-setting behaviour leads to sticky prices, all prices must

of individual prices and thus the aggregate price index. Or, put differently, since all individual prices can be stabilised, monetary policy can undo the distorting effects of staggered price stickiness. As such, it is natural that most of the discussion on price-level targeting has focused on the effects of a shock to the price index of that single final goods sector.

Relaxing the strict assumption of a single sector alters the policy implications considerably. If there is more than one sector, and if these sectors face changing relative technologies (or changing relative demand conditions), stabilisation of all individual prices is no longer optimal. Economic efficiency requires relative prices between sectors to change (the different technologies determine the relative price of one good in terms of the other) and these changes, in turn, require individual prices to change within each sector (for instance, Wolman, 2008 and 2009). Thus, if efficiency *across* sectors requires individual price changes within each sector, complete stabilisation of shock-induced changes in the price index of final goods is no longer the optimal monetary policy prescription, except for special cases. A prominent example of such a special case is Aoki (2001). He shows that if one of two sectors features fully flexible prices, the central bank can still neutralise nominal rigidities. In this case, stabilising only the price index of the sticky-price sector is optimal because prices in the other sector are flexible and may fluctuate with relative productivity. Shock-induced changes in relative prices thus do not interfere with price-level targeting. The necessary adjustment is borne entirely by the prices of those goods with flexible prices without creating any welfare losses.

In the more general case, however, where all sectors feature nominal rigidities, stabilising the prices of one sector at the expense of more volatile prices in another sector is costly. In such an environment, sector-specific productivity shocks will inevitably distort and limit the ability of monetary policy to counteract nominal rigidities.[5] Thus, if sector-specific productivity shocks force relative prices to adjust

be constant over time to ensure the efficient provision of goods. Only then are identical quantities of all goods produced. If, by contrast, the aggregated price level changes over time, price adjustments differ at firm level owing to staggered price stickiness, even at a constant rate of change, and this results in inefficiencies. For a lucid introduction of monetary policy in multi-sector models see Wolman (2008).

5 Shocks that optimally change the relative price across sectors restrict the central bank's ability to achieve an efficient allocation. It is thus not possible to attain the Pareto optimal allocation.

over time, it would generally not be possible for the central bank to completely stabilise all individual prices.

Optimal monetary policy in the presence of multiple sources of nominal rigidities has already been studied by Erceg, Henderson and Levin (2000), who consider price and wage rigidities, as well as by Benigno (2004) and Erceg and Levin (2006), who distinguish between different classes of final goods (tradeable/non-tradeable goods and durable/non-durable goods). Furthermore, Huang and Liu (2005) have studied optimal monetary policy in a two-sector model with a vertical input-output structure and staggered prices at each stage of production. We follow this strand of literature and analyse the welfare implications of price-level targeting in their model. Such an environment is of particular interest, as it allows us to consider the implications of changes in relative prices across sectors resulting from sector-specific demand or productivity shocks.

Overview of the model

The economy includes a representative household, intermediate goods firms, final goods firms, and a central bank. The representative household consumes a bundle of differentiated final goods while supplying labour to the intermediate and final goods sector. Households invest in state-contingent nominal bonds that mature after one period with a payoff of one in the appropriate event. Firms are price-takers in the input markets and monopolistic competitors in the goods markets. Both types of firms set prices in a staggered fashion in the spirit of Calvo (1983). Each intermediate goods firm produces a differentiated intermediate good and sells it to final goods firms. The production of intermediate goods requires only labour as input. Final goods firms produce differentiated final goods by using (homogeneous) labour *and* a composite of intermediate goods. The production of consumption goods therefore goes through two stages, from intermediate goods to final goods. In the end, the household consumes only a composite of differentiated final goods. The price index of the intermediate goods corresponds broadly to the producer price index (PPI), while that of the final goods corresponds to the consumer price index (CPI).

Equilibrium dynamics

A lowercase variable x_t denotes the log-deviation of the corresponding level from its steady-state value $\overline{X}$, whereas x_t^* indicates the log-deviation of X_t from its steady state in the flexible-price equilibrium. Define by q_t^* the (log-linearised) relative price of intermediate goods in units of consumption goods in the flexible-price equilibrium and by c_t^* the natural rate of output (i.e. consumption). Assuming linear preferences in labour hours and log-linearising the optimal pricing decision rule of final goods firms yields

$$\pi_t^f = \beta E_t \pi_{t+1}^f + \kappa^f \tilde{\upsilon}_t^f, \tag{6}$$

where π_t^f is the log-deviation of the CPI inflation from its steady state and $\tilde{\upsilon}_t^f = \phi \tilde{q}_t + (1-\phi)\sigma \tilde{c}_t$ is the real marginal cost of final goods firms, $\tilde{q}_t = \ln\left(Q_t / \overline{Q}\right) - q_t^*$ denotes the relative price gap, $\tilde{c}_t = \ln\left(C_t / \overline{C}\right) - c_t^*$ represents the output gap, ϕ is the share of intermediate goods used in the production of final goods, and σ the inverse of the elasticity of intertemporal substitution.[6] The parameter κ^f is defined as $\kappa^f \equiv \left(1-\beta\alpha^f\right)\left(1-\alpha^f\right)/\alpha^f$ with $\beta \in (0,1)$ symbolising the discount factor of the household and $\left(1-\alpha^f\right)$ denoting the probability that firms in the final goods sector can adjust their prices. Similarly, log-linearising the optimal pricing decision rule of intermediate goods firms yields

$$\pi_t^m = \beta E_t \pi_{t+1}^m + \kappa^m \tilde{\upsilon}_t^m, \tag{7}$$

with $\tilde{\upsilon}_t^m = \sigma \tilde{c}_t - \tilde{q}_t$ referring to real marginal cost in the intermediate goods sector and $\kappa^m \equiv \left(1-\beta\alpha^m\right)\left(1-\alpha^m\right)/\alpha^m$, where α^m is the Calvo parameter of the intermediate goods sector. Log-linearising the consumption Euler equation around its steady state and subtracting its flexible-price counterpart yields an aggregate demand equation in gaps

6 Real marginal cost involves both the real consumption wage and the relative price of the basket of intermediate goods. The real wage is related to the output gap and aggregate employment through the labour supply equation.

$$\tilde{c}_t = E_t\tilde{c}_{t+1} - \frac{1}{\sigma}\left(r_t - E_t\pi^f_{t+1} - rr^*_t\right), \tag{8}$$

where r_t and rr^*_t denote the nominal interest rate and the ex ante real interest rate under flexible prices defined as $rr^*_t = r^*_t - E_t\pi^f_{t+1}$. The latter variable follows

$$rr^*_t = \phi\,\rho^m\Delta a^m_t + (1-\phi)\rho^f\Delta a^f_t \tag{9}$$

with $\Delta a^k_t = a^k_t - a^k_{t-1}$ being the productivity growth in sector $k\in(f,m)$. Both shocks follow a first-order autoregressive process of the form

$$\Delta a^k_t = \rho^k\Delta a^k_{t-1} + \varepsilon^k_t, \tag{10}$$

where ρ^k is the AR coefficient and ε^k_t a white-noise error term. Finally, the law of motion of the relative price gap is given by

$$\tilde{q}_t = \tilde{q}_{t-1} + \pi^m_t - \pi^f_t - (1-\phi)\left(\Delta a^f_t - \Delta a^m_t\right). \tag{11}$$

Note that according to equation (11) the change in the equilibrium level of the relative price is given by $\Delta q^*_t = (1-\phi)\left(\Delta a^f_t - \Delta a^m_t\right)$. Hence, if the two sectors are hit by identical shocks or if intermediate goods are the only input for the final goods sector, that is $\phi = 1$, the equilibrium relative price stays constant (as in the canonical New Keynesian model).

Social welfare

Huang and Liu (2005) derive a welfare criterion based on a second-order approximation of the representative household's utility function. Specifically, social welfare can be expressed as

$$\begin{aligned}\mathcal{W} &= E_t\sum_{j=0}^{\infty}\beta^j U_{t+j}\\ &\cong -E_t\sum_{j=0}^{\infty}\beta^j\left\{\sigma\tilde{c}^2_{t+j} + \phi(1-\phi)\left(\tilde{v}^m_{t+j}\right)^2 + \frac{\theta^f}{\kappa^f}\left(\pi^f_{t+j}\right)^2 + \phi\frac{\theta^m}{\kappa^m}\left(\pi^m_{t+j}\right)^2\right\} + t.i.p.,\end{aligned} \tag{12}$$

where *t.i.p.* represents terms independent of policy. In addition to the usual variables such as the output gap and CPI inflation, the approximated welfare function includes inflation π_t^m based on the producer price index and producers' real marginal cost for intermediate goods $\tilde{\upsilon}_t^m$. In general, the central bank faces trade-offs in stabilising the four components of its objective function.

The calibration of the model parameters is taken from Huang and Liu (2005, pp 1451 and 1452). The calibrated values are summarised in Table 3. As far as possible, each of the two stages of production has the same calibration. The degree of price stickiness (i.e. the fraction of firms that cannot adjust prices) is set at 0.75 for both sectors, and the elasticity of substitution between differentiated goods at the two stages of production is set at 10. The cost share of intermediate input in final goods production is set at 0.5. Finally, following the standard business cycle literature, the AR(1) coefficients of the productivity growth processes are set to 0.95, and both shocks are calibrated to a standard deviation of 0.02.

Table 3: Calibration of parameters

β	α^f	α^m	ϕ	σ	θ^f	θ^m	ρ^f	ρ^m
0.99	0.75	0.75	0.5	1	10	10	0.95	0.95

3.2 Assessing the costs of price-level targeting

Again we start the analysis of monetary policy with the full commitment solution (denoted Ramsey), where the central bank maximises the social welfare function (12) subject to the log-linearised system of equations (6) to (11). Figure 3 depicts the impulse responses (dashed lines) to a negative technology shock in the final goods sector Δa_t^f. The key feature of the Ramsey policy is that the price levels of both sectors do not return to their steady states, but drift substantially. As the representative household cares about other objectives than price level stability and the central bank faces a trade-off in its response to the technology shock, it is optimal to stabilise the inflation rates but not the price levels. Much like the New Keynesian model in Section 2, the levels of the producer price as well as the consumer price are non-stationary.

We explore again to which degree an extension of the policy horizon helps reduce the welfare costs under price-level targeting and compare these costs with those under inflation targeting. We take the ECB as an example for a central bank with an explicit inflation target in terms of the CPI.[7] In the model of Huang and Liu (2005) the CPI corresponds to the prices of final goods. Therefore, a central bank that is constrained to pin down the inflation rate of final goods (representing the CPI) has to return to its target, which is normalised to zero, after H periods:

$$E_t \pi_{t+H}^f = 0. \tag{13}$$

To evaluate price-level targeting we alter the constraint such that the expected price level of final goods has to return to its initial steady state after H periods:

$$E_t p_{t+H}^f = 0. \tag{14}$$

Figure 3 illustrates the impulse responses after a negative technology shock in the final goods sector for a price-level target with a horizon H of 8 and 40 periods.[8] We start with a horizon of $H = 8$ periods, corresponding to two years (solid lines). A first remarkable feature is that the impulse responses of most variables display a much more volatile pattern than in the case of the (unconstrained) Ramsey policy (dashed lines). Notable differences are visible for all variables and not only for the final goods price level that returns to the steady state by construction. As a result, the policy rate becomes quite volatile, too.[9] Specifically, the path of the policy rate exhibits a remarkable volatility towards the end of the horizon, which results from the need to exactly pin

[7] The ECB's Governing Council specified the objective of maintaining price stability by defining price stability as "a year-on-year increase in the Harmonised Index of Consumer Prices (HICP) for the euro area of below 2%" (ECB, 1999). In 2003, the Governing Council clarified that it aims to maintain inflation rates below, but close to, 2% over the medium term (ECB, 2003).

[8] The impulse responses for a negative technology shock in the final goods sector under inflation targeting with $H = 8$ and $H = 40$ are given in Appendix 2.

[9] The fall in the policy rate is not due to the fall in the natural real rate, which drops after the negative technology shock in the final goods sector according to equation (9). Instead, the decrease in the policy rate follows the decline of intermediate goods inflation. Under almost fully flexible final goods prices, the intermediate goods price remains at its steady state level and the policy rate therefore does not move, either. The opposite is true if the intermediate goods prices are almost fully flexible: the final goods prices remain virtually constant whereas intermediate goods prices adjust substantially and the policy rate falls in response to the negative technology shock.

down the price level at the target horizon.[10] This pattern is similar to the dynamics already observed in the hybrid New Keynesian model studied by Smets (2003).

The volatility becomes more pronounced if the horizon is extended to, say, $H = 40$ (dash-dotted lines). Remarkably, for the ten-year horizon the impulse responses do not merely look like a stretched version of the impulse responses under $H = 8$. The reason why the amplitude of the impulse responses increases further is that under full commitment final goods prices still go up even after 40 periods. Price-level targeting eliminates by construction the price-level drift of the final goods sector after 40 periods, whereas the drift in the price level of the intermediate goods sector becomes accordingly *larger*. As a consequence, macroeconomic activity, measured by the output gap $\tilde{c}_t$, contracts with increasing severity if the horizon is extended.

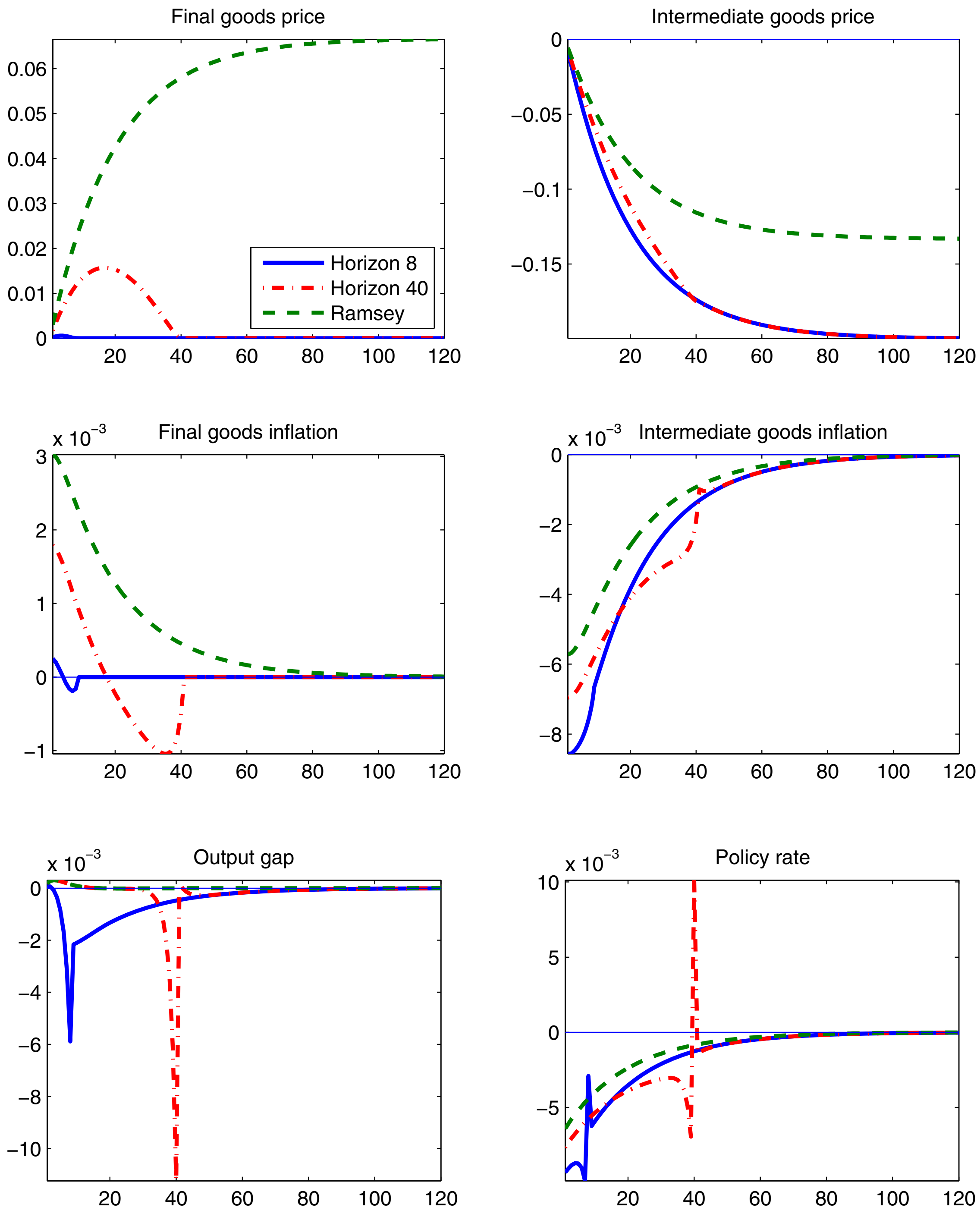
The impulse responses reveal that it is not optimal for the central bank to follow the unconstrained Ramsey path until the pre-specified horizon and then to "adjust". Instead, immediately after the shock is observed the optimal interest rate path under price-level targeting starts to deviate from the unconstrained Ramsey solution such that the build-up of the price drift in the final goods sector is already dampened.[11] In line with that, the optimal response of intermediate goods prices also deviates immediately from the unconstrained Ramsey path. However, the same does not hold for the impulse response of the output gap: here it is optimal to follow the Ramsey path until the end of the horizon and to adjust abruptly such that the price level is exactly pinned down at the desired horizon. Put succinctly, the price-level targeting constraint forces the central bank not only to modify its optimal path quite substantially but to accept strong fluctuations in economic activity and more drift in intermediate goods prices to guarantee that the price level of final goods meets its target.[12]

[10] Note, the welfare function (12) does not imply stabilising the policy rate.

[11] Correspondingly, final goods inflation does not converge to its long-run stead state monotonically but undershoots to render the price level stationary.

[12] The pronounced fluctuations in the output gap reflect the very different weights in the microfounded welfare function (12). Similar to the canonical New Keynesian model the welfare function strongly favours stabilising the two inflation rates over output gap and real marginal cost gap.

Figure 3: Responses to a negative technology shock in the final goods sector



Such volatile impulse responses are obviously unwanted, and correspondingly the welfare of the representative household is always lower when the central bank is constrained. Figure 4 presents the welfare losses (relative to the respective steady state consumption in percent) of the unconstrained (dashed line) and the constrained Ramsey policy (solid line) as a function of the price-level target horizon for $H = 1$ to $H = 120$

quarters, that is up to thirty years. A number of observations can be made. Choosing too small a target horizon comes with a notable loss that is more than 51 percent for a horizon of $H = 1$ and still 19 percent for $H = 120$ relative to the Ramsey policy. Obviously, the difference declines only very gradually. Even for a rather long horizon of more than ten years, the welfare loss has declined only by little (the relative loss is still over 40 percent). Thus, the welfare losses in a two-sector model with nominal rigidities in both sectors are not only rather high, but even choosing a longer horizon fails to reduce the welfare losses to moderate levels.

As the constrained policy problem is by construction worse than the unconstrained policy problem we compare the welfare losses of pinning down the price level at a given horizon with those of pinning down the inflation rate. Figure 4 plots the welfare loss for a Ramsey policy that is constrained to achieve an inflation target at a pre-specified horizon (dash-dotted line).[13] If the central bank meets the target immediately at $H = 1$, there is no difference between targeting the price level and targeting the inflation rate. However, in contrast to price-level targeting, the constrained inflation targeting Ramsey policy converges for longer horizons to the unconstrained Ramsey. More importantly, at a policy-relevant horizon of two years the welfare loss for inflation targeting is considerably lower than the loss for targeting the price level at the same horizon (31 percent versus 51 percent). Thus, and in contrast to the results obtained for the New Keynesian model in Section 2, giving the central bank enough leeway to bring the price level back on target does not solve the “problem” of a drifting price level. Moreover, for price-level targeting the losses decline only gradually if the horizon is extended. Quite the opposite occurs if we extend the horizon for the constrained inflation targeting policy: every additional quarter reduces the welfare loss considerably.

[13] As explained in Section 2, this captures core elements of prevailing inflation targeting regimes.

Figure 4: Comparison of welfare losses as a function of horizon

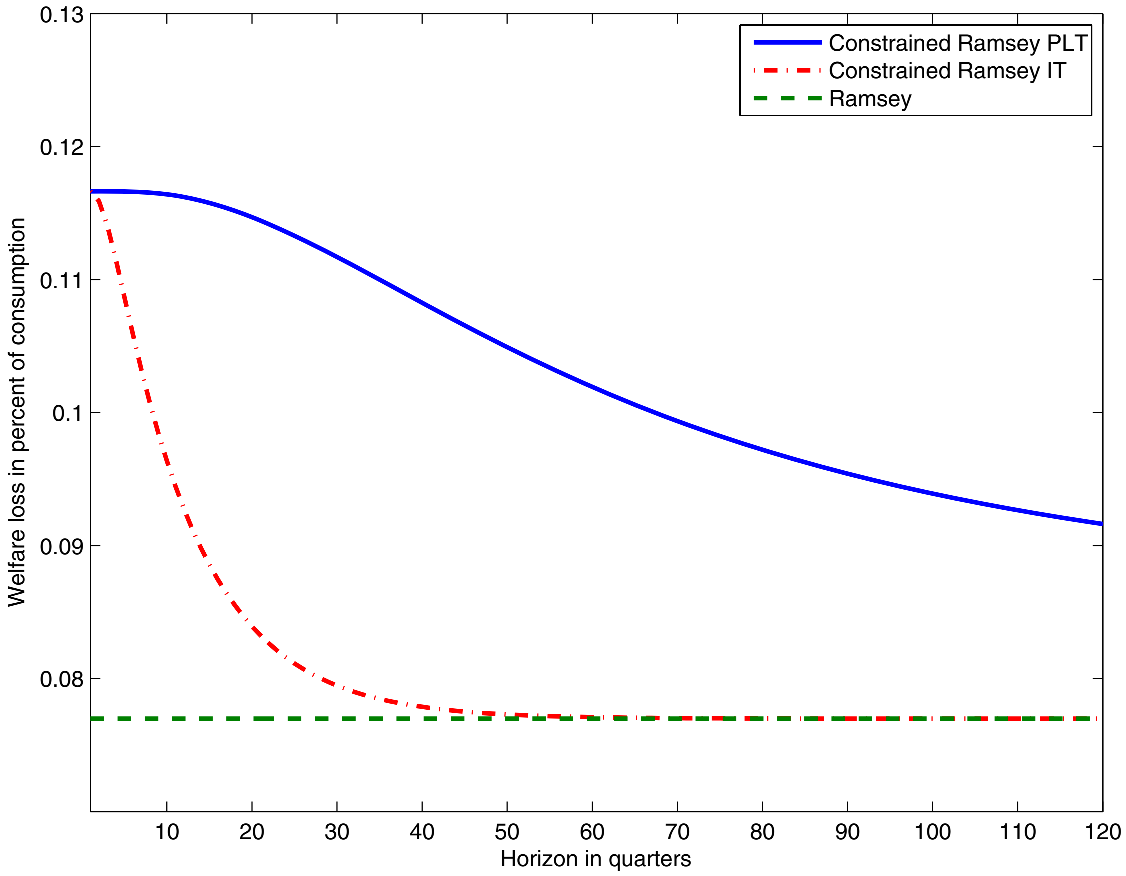
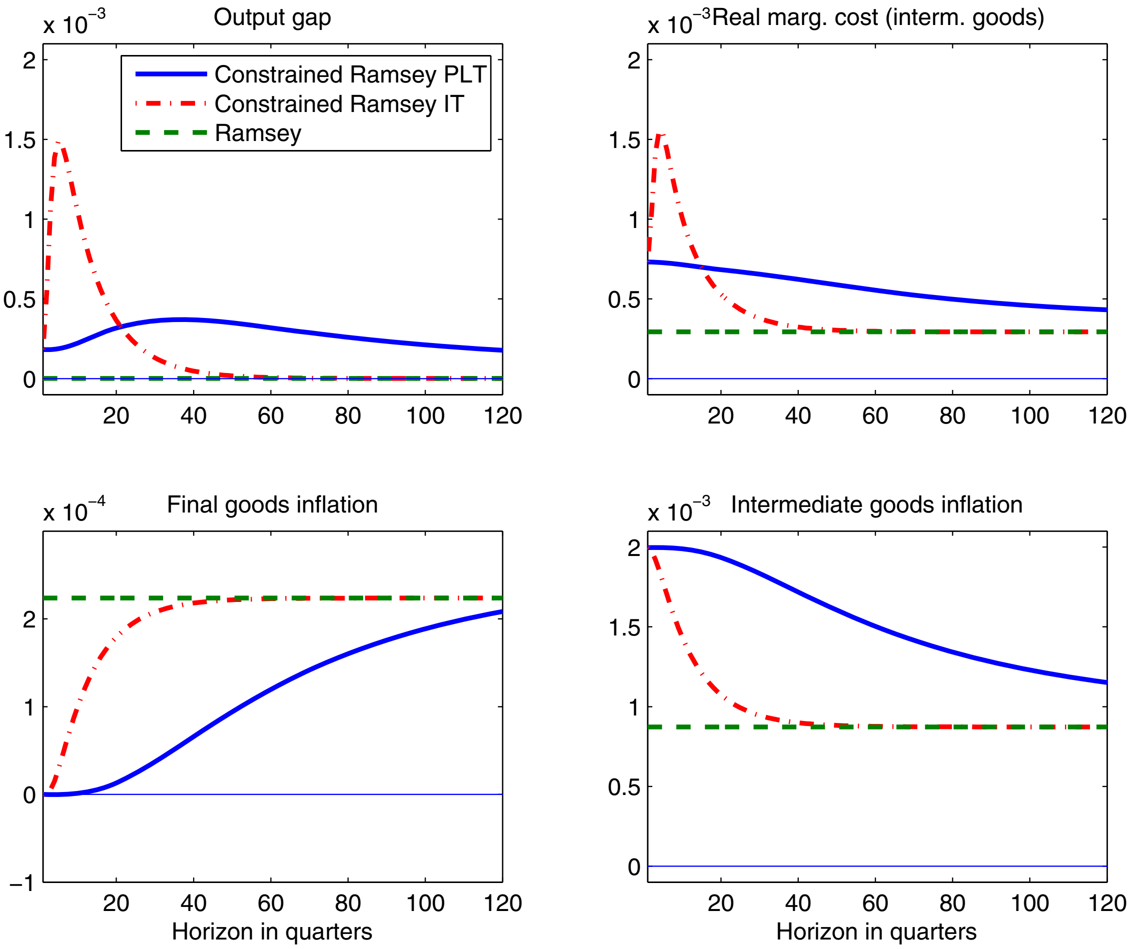


Figure 5 gives additional insights into the welfare costs by portraying the volatility of the variables entering the welfare function (12). As might be expected, the variances of the output gap $\tilde{c}_t$, the real marginal cost in the intermediate goods sector $\tilde{\upsilon}_t^m$ and inflation of the intermediate goods sector π_t^m are larger for a given horizon than their Ramsey counterparts (dashed lines) under both price-level (solid lines) and inflation targeting (dash-dotted lines). In line with the welfare loss as a function of the horizon these variances decrease as the horizon is extended. For price-level targeting the output gap exhibits a hump shape, peaking at $H = 36$, and the variance of inflation in the final goods sector π_t^f is always lower than the Ramsey policy but increases with the horizon. Under constrained inflation targeting the output gap and the real marginal cost show a pronounced hump at $H = 5$ and $H = 4$ respectively. All four variances converge to the Ramsey policy as the horizon is extended. From Figure 5 it is obvious that the gain in stabilising final goods inflation, either by targeting the inflation rate or the price level, is more than offset by the increased volatility of the other target variables. The big difference between the two strategies is that under price-level targeting the variances do not converge to the Ramsey policy. The observation of a less volatile inflation rate for a given horizon is due to the stabilising mechanism of forward-looking agents taking into account that the price level or the inflation rate will eventually return to its target.

Figure 5: Variability of target variables as a function of horizon



We summarise our main findings as follows: (i) targeting the price level or the inflation rate at short targeting horizons leads to a higher welfare loss than the Ramsey policy, (ii) inflation targeting is better than price-level targeting for targeting horizons $H \geq 2$, and (iii) in contrast to inflation targeting, which converges to the Ramsey policy rather quickly, the stabilising costs of price-level targeting remain high even if the horizon is extended.

3.3 Sensitivity analysis

The sensitivity analysis summarised in Table 4 does not alter our main findings. As the welfare losses of both constrained Ramsey policies depend qualitatively in a similar way on key parameters of the model, it shall suffice here to describe the sensitivity of our results with respect to the policy of pinning down the price level on target.

We start by varying the price stickiness in the final goods sector. More rigid prices, $\alpha^f = 0.9$, imply a higher loss for the Ramsey policy, whereas more flexible prices, $\alpha^f = 0.6$, lead to a lower loss than the benchmark. At the same time, under more rigid prices the drift is less pronounced and thus it is less costly to offset the price-level drift and *vice versa*. Under a price-level targeting horizon of $H = 1$ the losses of the three calibrations for α^f coincide (not shown). This notable result is due to the fact that the central bank immediately pins down the price level to target. Prices of final goods remain in their steady state and their price stickiness thus does not matter. This does not hold for longer target horizons. Under more flexible final goods prices the relative loss – the difference between the losses of the constrained and the unconstrained Ramsey policy over the loss of the unconstrained Ramsey – increases massively for short horizons, yet extending the horizon reduces the loss considerably.

Targeting the price level of final goods prices is undesirable as the stabilisation of prices in that sector causes greater price volatility in the intermediate goods sector. The additional volatility comes at cost because prices in the intermediate goods sector are also sticky. To see how these costs depend on price stickiness, we alter the degree of nominal rigidity in the intermediate goods sector. As expected, less flexible prices in the intermediate goods sector, $\alpha^m = 0.9$, increase the Ramsey loss as the economy faces more rigidities. The opposite is true if we decrease price stickiness. More flexible prices in the intermediate goods sector, $\alpha^m = 0.6$, reduce the Ramsey loss as the economy faces fewer rigidities. When price-level targeting pins down prices in the final goods sector, the more flexible prices in the intermediate goods sector facilitate the necessary adjustment. Accordingly, the relative losses are generally lower than in the benchmark.[14] The key role of price stickiness in the intermediate goods sector for the

[14] The lower α^m reduces the weight in the loss function but increases the volatility of intermediate goods inflation.

evaluation of price-level targeting can be illustrated further if intermediate goods prices are almost flexible, $\alpha^m = 0.01$. In this case the loss of the unconstrained economy decreases to a very low level and the additional costs associated with price-level targeting also become almost negligible. Already for a small target horizon of $H = 1$ the increase in loss relative to the unconstrained case amounts to only 0.05 percent. Thus, if prices in the intermediate goods sector are allowed to fluctuate with relative productivity, complete stabilisation of the price index of final goods is close to optimal as in Aoki (2001).

As the share of intermediate goods input in the final goods sector determines how much the welfare function depends on producer price inflation and the marginal cost gap, we also vary the parameter ϕ. A lower share of intermediate goods used in the processing of final goods (implying a higher share of labour), $\phi = 0.10$, decreases the loss of the unconstrained Ramsey policy slightly; the relative losses, however, decrease more sharply. The respective losses are even smaller if almost no intermediate goods are used for the production of final goods, $\phi = 0.01$. This can be understood as ϕ approaching zero simplifies the policy trade-off in equation (12) considerably: in the limit only the output gap and the inflation rate of the final goods sector matter. A higher share of intermediate goods, $\phi = 0.90$, also decreases the loss of the unconstrained Ramsey policy.[15] But if the central bank is constrained by price-level targeting the relative losses are substantially higher than in the benchmark case. For instance, at a horizon of $H = 8$ the relative loss amounts to roughly 95 percent.

Finally, we vary the persistence of the technology processes by reducing the autocorrelation of the processes to $\rho^{f,m} = 0.01$ (we leave the standard deviations unchanged). As before, choosing too small a target horizon for the price level comes with a notable loss. The loss is more than 90 percent for a horizon of $H = 1$, more than 43 percent for $H = 8$ and still almost 8 percent after $H = 40$ quarters. Due to the strongly reduced autocorrelation the loss is only about 3 percent for $H = 120$ relative to the Ramsey policy. The rather low autocorrelation of the technology shocks implies that the welfare loss for targeting the inflation rate drops from over 95 percent for $H = 1$ to less

[15] For ϕ approaching unity the real marginal cost in the intermediate goods sector drops out of the welfare function (12) and thus also simplifies the policy trade-offs.

than ½ percent for $H = 8$. We conclude that the welfare losses of price-level targeting in a two-sector model with nominal rigidities in both sectors remain relatively high even if there is almost no autocorrelation in the technology processes.

Table 4: Sensitivity analysis

	Loss for Ramsey policy	Relative loss in percent for price-level target (*inflation target in italics*)			
		at $H = 1$	at $H = 8$	at $H = 40$	at $H = 120$
Benchmark	0.0770	51.51 *51.51*	51.38 *30.85*	40.62 *1.16*	19.01 *0.00*
$\alpha^f = 0.60$	0.0454	156.91 *156.91*	156.43 *82.31*	123.16 *3.10*	58.32 *0.00*
$\alpha^f = 0.90$	0.1063	9.68 *9.68*	9.63 *6.68*	6.78 *0.16*	2.90 *0.00*
$\alpha^m = 0.01$	0.0001	0.05 *0.05*	0.05 *0.02*	0.03 *0.00*	0.02 *0.00*
$\alpha^m = 0.60$	0.0322	16.70 *16.70*	16.60 *9.37*	12.78 *0.35*	5.93 *0.00*
$\alpha^m = 0.90$	0.1739	332.54 *332.54*	332.31 *178.05*	275.62 *7.10*	134.99 *0.00*
$\phi = 0.01$	0.0089	1.01 *1.01*	1.00 *0.57*	0.80 *0.02*	0.38 *0.00*
$\phi = 0.10$	0.0674	10.10 *10.10*	10.08 *5.74*	8.05 *0.22*	3.80 *0.00*
$\phi = 0.90$	0.0044	95.04 *95.04*	94.75 *67.24*	75.01 *2.50*	34.57 *0.00*
$\rho^{f,m} = 0.01$	0.0014	92.52 *95.52*	43.46 *0.35*	7.58 *0.00*	2.68 *0.00*

Note: The welfare loss for the unconstrained Ramsey policy is given in percent of steady-state consumption (column 1). The relative loss is measured as the difference between the losses of the constrained and the unconstrained Ramsey policy over the loss of the unconstrained Ramsey in percent (columns 2-5).

4 Conclusions

Recent research has shown that optimal monetary policy may display considerable price-level drift. It is not obvious *a priori* whether, under such conditions, a change-over to price-level targeting may still be advantageous. Proponents of price-level targeting have argued that the costs of eliminating the price-level drift may decline if the central bank responds flexibly by returning the price level only gradually to its steady state. In this paper we show one example in which the argument is correct and one example in which it is not.

In our first example, a New Keynesian model with price-level drift, we find that (i) bringing back the price level to its target at a very short policy horizon leads to high volatility and welfare costs, (ii) inflation targeting is better than price-level targeting for policy horizons longer than two quarters, but (iii) for a policy horizon of two years or longer the costs of stabilisation under price-level targeting are not notably higher than those under inflation targeting.

In our second example, a two-sector extension of the New Keynesian model, we illustrate that the costs of stabilisation under price-level targeting remain high over a policy-relevant horizon. Specifically, we find that (i) targeting the price level or the inflation rate at short policy horizons leads to high volatility in other welfare-relevant variables and thus to high welfare losses, (ii) inflation targeting is better than price-level targeting for policy horizons longer than two quarters, and (iii) in contrast to inflation targeting the costs of stabilisation under price-level targeting remain high even if the horizon is extended. We conclude that extending the policy horizon is not a panacea to reduce the costs of eliminating price-level drift.

Appendix 1

As an alternative to giving the central bank an additional price stability mandate in the form of a price-level target and a policy horizon over which the price level must return to target, an additional stabilisation term for the price level can be incorporated in the period loss function

$$\mathcal{L}_t = \pi_t^2 + \lambda_x x_t^2 + \lambda_r r_t^2 + \lambda_p p_t^2 .$$

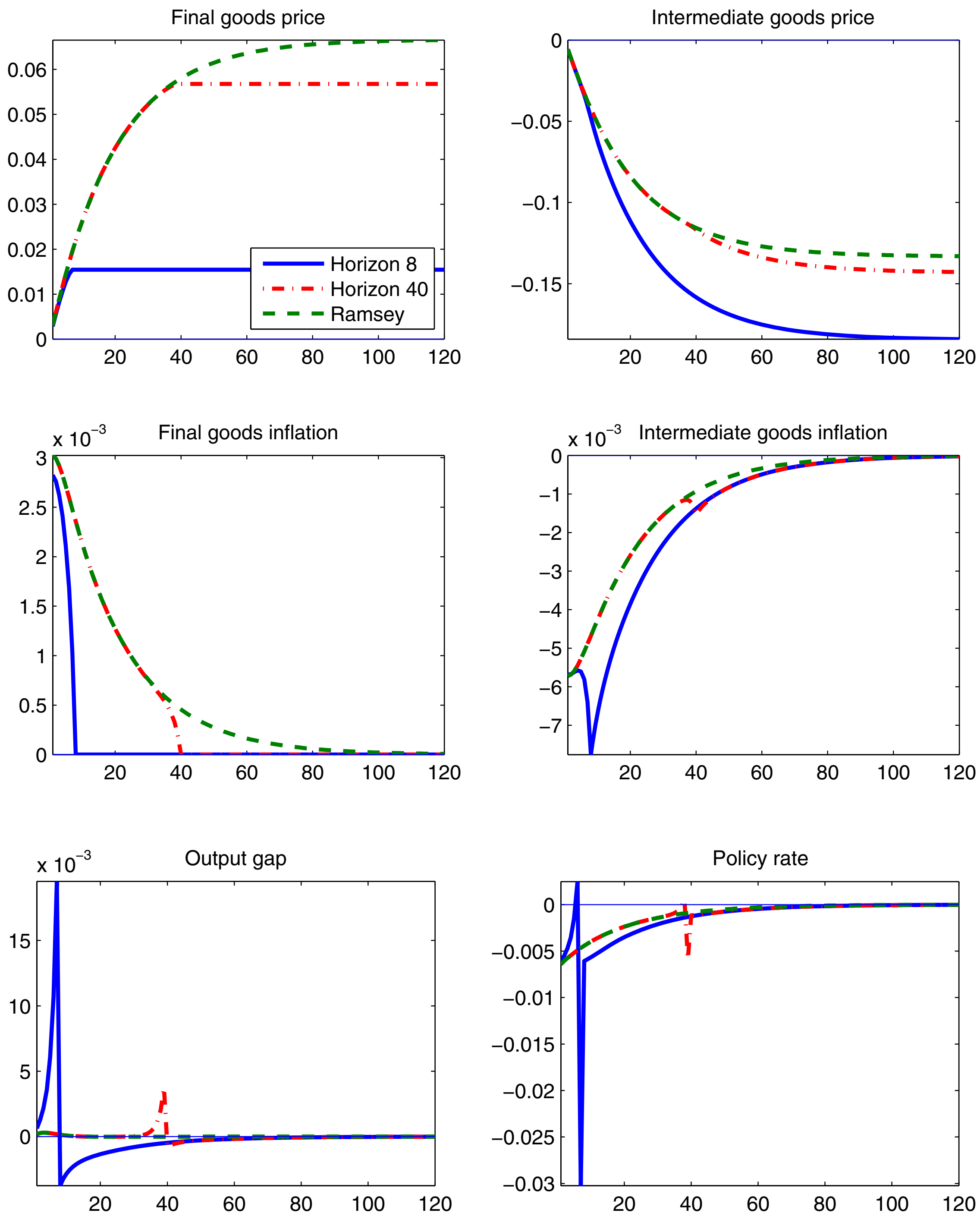
Table A1 shows that the weight λ_p on price-level stabilisation causes a welfare loss that corresponds to the loss for a given targeting horizon.

Table A1: Comparing targeting horizon to weight in loss function

Horizon	Loss	λ_p	Loss
1	3.3300	10000	3.3294
2	3.2582	26	3.2587
3	3.1783	4.3700	3.1783
4	3.1096	1.2500	3.1095
5	3.0612	0.4900	3.0613
6	3.0311	0.2400	3.0315
7	3.0133	0.1400	3.0141
8	3.0027	0.0900	3.0031
9	2.9963	0.0600	2.9953
10	2.9921	0.0490	2.9921
11	2.9893	0.0399	2.9892
12	2.9873	0.0339	2.9873
13	2.9858	0.0297	2.9858
14	2.9847	0.0267	2.9847
15	2.9839	0.0244	2.9839
16	2.9832	0.0226	2.9832

Appendix 2

Figure A1: Responses to a negative technology shock in the final goods sector under inflation targeting



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