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EPEE

CENTRE D'ETUDE DES POLITIQUES ECONOMIQUES DE L'UNIVERSITE D'EVRY

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04 – 05

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Abstract

This note proposes a full description of the Calvo price-setting model based on partial prices indexation and studies the interaction between partial indexation and trend inflation. We show that to use a hybrid version of the Phillips curve partly decreases the risks of overestimate due to the omission of trend inflation.

Keywords: Phillips curve ; inflation inertia; trend inflation; degree of indexation

JEL classification: E31

1 Introduction

The specification of the New Keynesian Phillips curve based on staggered prices has been intensively used in many recent discussions of monetary policy. Specifically, a host of dynamic stochastic general equilibrium models use Calvo's (1983) formulation: when firms have the opportunity to change their price they set this price equal to the average desired price until the next opportunity arises. However, two main issues are still problematic. First, most of the papers in the sticky-price literature are based on a log-linearization around the zero inflation steady state but unfortunately this assumption is counterfactual. Ascari (2003) has clearly shown that disregarding *trend inflation* is quite far from being an innocuous assumption and that results obtained by models log-linearized around a zero inflation steady state are misleading.[1] Second, at the aggregate level, current inflation will depend on future expected inflation but not on *lagged inflation*. However, this specification has been criticized on the ground that it does not fit very well the econometric evidence about co-movements of real and nominal variables: according to the New Keynesian Phillips curve, inflation should be a more forward-looking than seems to be.

In this paper, we argue that these two problems can be partly mutually solved at once by resorting to a model where indexation on past inflation is allowed. This framework, advocated by Christiano *et al.* (2003), Sbordone (2003), Smets and Wouters (2003), and Woodford (2003), assumes that prices are automatically raised in accordance with some mechanical rule between the occasions on which they are reconsidered. We extend Woodford's (2003) exposition of *partial backward indexation* to an economy with positive trend inflation and study the interaction between trend inflation, degree of indexation and Calvo price-setting.

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[1] In the same spirit, Bakhshi *et al.* (2003) build on the pure forward-looking work by Ascari (2003) in examining the interaction between strategic complementarity and trend inflation.

2 The Calvo model of sticky prices under partial price indexation

2.1 Optimal pricing decision

The forward-looking model of price setting due to Calvo (1983) is modified to allow for the possibility that firms that do not optimally set their prices may nonetheless adjust it to keep up with the previous period increase in the general price level.

In each period, a firm faces a constant probability, $1 - \phi$, of being able to reoptimize its nominal price and chooses a price $P_t^*(z)$ that maximizes the expected discounted sum of profits

$$\mathbb{E}_t \sum_{j=0}^{\infty} \phi^j \Lambda_{t,t+j} \left[P_t^*(z) X_{t,t+j} - MC_{t+j} \right] \frac{Y_{t+j}(z)}{P_{t+j}}, \tag{1}$$

subject to the sequence of demand constraints:

$$Y_{t+j}(z) = \left(\frac{P_t^*(z) X_{t,t+j}}{P_{t+j}} \right)^{-\varepsilon} Y_{t+j}, \tag{2}$$

where $\Lambda_{t,t+j} = \beta^j \left(U'(C_t) / U'(C_{t+j}) \right)$ is the discount factor between time t and $t + j$, $U'(C_{t+j})$ is the marginal utility of consumption in $t + j$, $Y_t(z)$ is the level of output of firm z, MC_t is the nominal marginal cost, $\varepsilon > 1$ is the elasticity of substitution across goods, and [2]

$$X_{t,t+j} = \begin{cases} \prod_{k=0}^{j-1} \pi_{t+k}^{\xi} & j > 0 \\ 1 & j = 0 \end{cases} \tag{3}$$

$X_{t,t+j}$ describes the fact that if the firm z does not reoptimize its price, it updates it prices according to the rule:

$$P_t(z) = \pi_{t-1}^{\xi} P_{t-1}(z) \tag{4}$$

where $\pi_t = P_t/P_{t-1}$ is the gross inflation rate. As in Christiano *et al.* (2003), we interpret the Calvo price-setting mechanism as capturing firm's response to various costs of changing prices. The basic idea is that in the presence of these costs, firms fully optimize prices only periodically, and follow simple rules for

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[2] We do not index MC_t by z because we assume that all firms have identical marginal costs.

changing their prices at other times. The coefficient $\xi \in [0, 1]$ indicates the degree of indexation to past prices, during the periods in which firm is not allowed to reoptimize.

It follows that the aggregate price level can be expressed as:

$$P_t = \left[\phi \left(\pi_{t-1}^{\xi} P_{t-1} \right)^{1-\varepsilon} + (1 - \phi) (P_t^*)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}. \tag{5}$$

Let us define the relative price by $p_t^* (z) = P_t^* (z) / P_t$ and using the fact that $X_{t,t+j} = (P_{t+j-1}/P_{t-1})^{\xi}$, the first-order condition of this problem can be expressed as

$$p_t^* (z) = \left[\frac{\varepsilon}{\varepsilon - 1} \frac{\mathbb{E}_t \sum_{j=0}^{\infty} \phi^j \Lambda_{t,t+j} MC_{t+j} \left(\left(\frac{P_{t+j-1}}{P_{t-1}} \right)^{\xi} \frac{P_t}{P_{t+j}} \right)^{-\varepsilon} Y_{t+j}}{\mathbb{E}_t \sum_{j=0}^{\infty} \phi^j \Lambda_{t,t+j} \left(\left(\frac{P_{t+j-1}}{P_{t-1}} \right)^{\xi} \frac{P_t}{P_{t+j}} \right)^{1-\varepsilon} Y_{t+j}} \right] \tag{6}$$

We show that the optimal relative price depends on current and future demand, aggregate inflation rates, and discount factors.

2.2 The hybrid Phillips curve under trend inflation

We log-linearize (6) around a steady state with generic trend inflation ($\bar{\pi}$) to get [3]

$$\hat{p}_t^* = \left(1 - \phi \beta \bar{\pi}^{\varepsilon(1-\xi)} \right) \mathbb{E}_t \sum_{j=0}^{\infty} \left(\phi \beta \bar{\pi}^{-\varepsilon(\xi-1)} \right)^j$$

$$\times \left[\hat{\Lambda}_{t,t+j} + \hat{y}_{t+j} + \widehat{mc}_{t+j} + \varepsilon \left(\sum_{k=1}^{j} \widehat{\pi}_{t+k} \right) - \varepsilon\xi \left(\sum_{k=0}^{j-1} \widehat{\pi}_{t+k} \right) \right]$$

$$- \left(1 - \phi \beta \bar{\pi}^{(1-\varepsilon)(\xi-1)} \right) \mathbb{E}_t \sum_{j=0}^{\infty} \left(\phi \beta \bar{\pi}^{(1-\varepsilon)(\xi-1)} \right)^j$$

$$\times \left[\hat{\Lambda}_{t,t+j} + \hat{y}_{t+j} + (1-\varepsilon)\xi \left(\sum_{k=0}^{j-1} \widehat{\pi}_{t+k} \right) - (1-\varepsilon) \left(\sum_{k=1}^{j} \widehat{\pi}_{t+k} \right) \right] \tag{7}$$

In making use of mathematical properties concerning the double sum, we obtain equivalently,

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[3] Hat variables indicate log-deviations from steady-state levels.

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$$\hat{p}_t^* = - \left(\phi\beta\bar{\pi}^{\varepsilon(1-\xi)}\right)\left(\bar{\pi}^{(\xi-1)}-1\right)\left(1-\phi\beta\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\mathbb{E}_t\sum_{j=0}^{\infty}\left(\phi\beta\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)^j$$

$$\times\left[\hat{y}_{t+j+1}+\frac{\left(\phi\beta\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)}{1-\left(\phi\beta\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)}\left((1-\varepsilon)\xi\widehat{\pi}_{t+j+1}+(\varepsilon-1)\widehat{\pi}_{t+j+2}\right)\right]$$

$$+\left(\bar{\pi}^{(\xi-1)}-1\right)\left(\phi\beta\bar{\pi}^{\varepsilon(1-\xi)}\right)\left(\hat{y}_t-(1-\varepsilon)\xi\widehat{\pi}_t-(\varepsilon-1)\mathbb{E}_t\widehat{\pi}_{t+1}\right)$$

$$+\left(\phi\beta\bar{\pi}^{\varepsilon(1-\xi)}\right)\left(\mathbb{E}_t\widehat{\pi}_{t+1}-\xi\widehat{\pi}_t\right)+\left(1-\left(\phi\beta\bar{\pi}^{\varepsilon(1-\xi)}\right)\right)\widehat{mc}_t$$

$$+\left(\phi\beta\bar{\pi}^{\varepsilon(1-\xi)}\right)\mathbb{E}_t\hat{p}_{t+1}^* \tag{8}$$

Log-linearizing the aggregate price level (5) in the model gives

$$\hat{p}_t^* = \frac{\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}}{1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}}\left[\widehat{\pi}_t-\xi\widehat{\pi}_{t-1}\right] \tag{9}$$

Finally, using (8) and (5), we obtain the hybrid Phillips curve under trend inflation

$$\widehat{\pi}_t = \frac{\xi}{\left[\left(1+\xi\beta\bar{\pi}^{(1-\xi)}\right)+\left(1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1-\bar{\pi}^{(1-\xi)}\right)\beta\left(1-\varepsilon\right)\xi\right]}\widehat{\pi}_{t-1}$$

$$+\frac{\beta\left(1-\left(1-\bar{\pi}^{(1-\xi)}\right)\left(\varepsilon+(1-\varepsilon)\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\right)}{\left(1+\xi\beta\bar{\pi}^{(1-\xi)}\right)+\left(1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1-\bar{\pi}^{(1-\xi)}\right)\beta\left(1-\varepsilon\right)\xi}\mathbb{E}_t\widehat{\pi}_{t+1}$$

$$+\frac{\left(1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1-\left(\phi\beta\bar{\pi}^{\varepsilon(1-\xi)}\right)\right)}{\left[\left(1+\xi\beta\bar{\pi}^{(1-\xi)}\right)+\left(1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1-\bar{\pi}^{(1-\xi)}\right)\beta\left(1-\varepsilon\right)\xi\right]\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}}\widehat{mc}_t$$

$$+\frac{\left(1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1-\bar{\pi}^{(1-\xi)}\right)\beta}{\left[\left(1+\xi\beta\bar{\pi}^{(1-\xi)}\right)+\left(1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1-\bar{\pi}^{(1-\xi)}\right)\beta\left(1-\varepsilon\right)\xi\right]}$$

$$\times\left\{\hat{y}_t-\left(1-\phi\beta\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\mathbb{E}_t\sum_{j=0}^{\infty}\left(\phi\beta\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)^j\right.$$

$$\left.\times\left[\hat{y}_{t+j+1}+\frac{\left(\phi\beta\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)}{1-\left(\phi\beta\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)}\left((1-\varepsilon)\xi\widehat{\pi}_{t+j+1}+(\varepsilon-1)\widehat{\pi}_{t+j+2}\right)\right]\right\} \tag{10}$$

The presence of trend inflation alters the structure of the hybrid Phillips curve in two ways. First, the coefficients on past and future inflation are functions of the degree of indexation and trend inflation. Second, there is a complex additional forward-looking structure.

3 Quantitative investigations

We now seek to understand the respective effects of the degree of indexation and trend inflation on the dynamics of the hybrid Phillips curve. For that, one remarks that (10) can be written in a compact way:

$$
\begin{aligned}
\widehat{\pi}_t = {} & \alpha_b\left(\bar{\pi}, \xi\right) \widehat{\pi}_{t-1} + \alpha_f\left(\bar{\pi}, \xi\right) \mathbb{E}_t \widehat{\pi}_{t+1} + \lambda\left(\bar{\pi}, \xi\right) \widehat{mc}_t \\
& + \Omega\left(\bar{\pi}, \xi\right) f\left(\mathbb{E}_t \widehat{\pi}_{t+i}, \mathbb{E}_t \widehat{y}_{t+i}\right)
\end{aligned} \tag{11}
$$

where

$$
\alpha_b\left(\bar{\pi}, \xi\right) = \frac{\xi}{\left[\left(1 + \xi\beta\bar{\pi}^{(1-\xi)}\right) + \left(1 - \phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1 - \bar{\pi}^{(1-\xi)}\right)\beta\left(1-\varepsilon\right)\xi\right]}
$$

$$
\alpha_f\left(\bar{\pi}, \xi\right) = \frac{\beta\left(1 - \left(1 - \bar{\pi}^{(1-\xi)}\right)\left(\varepsilon + \left(1 - \varepsilon\right)\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\right)}{\left(1 + \xi\beta\bar{\pi}^{(1-\xi)}\right) + \left(1 - \phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1 - \bar{\pi}^{(1-\xi)}\right)\beta\left(1-\varepsilon\right)\xi},
$$

$$
\lambda\left(\bar{\pi}, \xi\right) = \frac{\left(1 - \phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1 - \left(\phi\beta\bar{\pi}^{\varepsilon(1-\xi)}\right)\right)}{\left[\left(1 + \xi\beta\bar{\pi}^{(1-\xi)}\right) + \left(1 - \phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1 - \bar{\pi}^{(1-\xi)}\right)\beta\left(1-\varepsilon\right)\xi\right]\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}},
$$

$$
\Omega\left(\bar{\pi}, \xi\right) = \frac{\left(1 - \phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1 - \bar{\pi}^{(1-\xi)}\right)\beta}{\left[\left(1 + \xi\beta\bar{\pi}^{(1-\xi)}\right) + \left(1 - \phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1 - \bar{\pi}^{(1-\xi)}\right)\beta\left(1-\varepsilon\right)\xi\right]}.
$$

Figure 1 shows the sensitivity of the values of coefficients on past (α_b) and future (α_f) inflation, the elasticity of inflation with respect to changes in the marginal cost (λ), and the coefficient before the additional forward-looking structure (Ω) to trend inflation $(1 \leq \bar{\pi} \leq 1.1)$ and the degree of indexation $(0 \leq \xi \leq 1)$. First, we observe that trend inflation has few impact on α_b and α_f and that it is naturally the degree of indexation that governs their respective values. Second, Ω is negative, convex in $\bar{\pi}$ and very small (of order 10^{-3}). Ω tends naturally toward zero when ξ raises, so the additional forward-looking structure tends to disappear. Third, when $\xi = 0$, Ascari's result is found: the higher the level of trend inflation, the smaller the values of λ. It appears then that the dynamic response of inflation to marginal costs is then overestimated if trend inflation is not taken into account.

However, this last result is attenuated as the degree of indexation increases. Introducing an additional backward structure into the Phillips curve makes it automatically less dependent on trend inflation.[4] As shown in Table 1, whereas the model predicts that the dynamic response of inflation to marginal

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[4] This result is robust to different values for ε and ϕ.

cost should be reduced by 15% if annualized trend inflation is 1% when $\xi = 0$, it would be reduced by only 4% when $\xi = 0.75$.

The preceding conclusions are reflected on the value of the crucial structural parameter ϕ. By disregarding additional term $f\left(\mathbb{E}_t \widehat{\pi}_{t+i}, \mathbb{E}_t \hat{y}_{t+i}\right)$ at first approximation and for a given λ, we obtain

$$
\begin{aligned}
\phi = & -\left\{2\left[\left(\lambda\beta\xi\left(1-\varepsilon\right)-1\right)\bar{\pi}^{(1-2\varepsilon)(\xi-1)} + \left(\varepsilon-1\right)\lambda\beta\xi\bar{\pi}^{2(1-\varepsilon)(\xi-1)}\right]\right\}^{-1} \\
& \times \left\{\left(1+\lambda\xi\varepsilon\right)\beta\bar{\pi}^{\varepsilon(1-\xi)} + \left(1+\lambda\left(1+\beta\xi-\beta\xi\varepsilon\right)\right)\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right. \\
& -\left[\left(\left(\lambda+1\right)^2 + \lambda\beta\xi\left(\lambda\beta\xi+\lambda\beta\xi\varepsilon^2 - 2\left(\lambda\varepsilon+\lambda\beta\xi\varepsilon-\lambda-\varepsilon+1\right)\right)\right)\bar{\pi}^{2(1-\varepsilon)(\xi-1)}\right. \\
& +2\left(\beta\xi-1+\lambda\left(-\lambda\beta\xi^2\varepsilon^2 + \lambda\xi\varepsilon + \lambda\beta\xi^2\varepsilon - \beta\xi\varepsilon + 1 + 2\xi - \xi\varepsilon\right)\right)\beta\bar{\pi}^{(1-2\varepsilon)(\xi-1)} \\
& \left.\left. +\left(\lambda^2\xi^2\varepsilon^2 + 2\xi\varepsilon + 1\right)\beta^2\bar{\pi}^{2\varepsilon(1-\xi)}\right]^{1/2}\right\}
\end{aligned}
\tag{12}
$$

Figure 2 visualizes the sensitivity of this parameter to ξ and $\bar{\pi}$. We immediately notice that taking into account of trend inflation as well as increasing the degree of indexation reduce ϕ. However, just like for λ, this reduction attenuates with the increase in the degree of indexation. As summarized in Table 1, whereas the model predicts that the probability to not change the price should be reduced by 2% if annualized trend inflation is 1% when $\xi = 0$, it would be reduced by 0.6% when $\xi = 0.75$. We can see behind this phenomenon an explanation to the excessively high values of this parameter often obtained in the literature. Indeed, to forget trend inflation in a purely forward-looking Phillips curve would tend to bias upward the estimates whereas to specify a hybrid version of the Phillips curve prevents a too large error during estimation. Consequently, if we think that the inflation is very inertial (with a rather high degree of indexation), the estimation bias due to trend inflation will be weak even while using the following hybrid Phillips curve

$$
\widehat{\pi}_t = \frac{\xi}{1+\xi\beta}\widehat{\pi}_{t-1} + \frac{\beta}{1+\xi\beta}\mathbb{E}_t\widehat{\pi}_{t+1} + \frac{\left(1-\phi\right)\left(1-\phi\beta\right)}{\left(1+\xi\beta\right)\phi}\widehat{mc}_t
\tag{13}
$$

For that, one must make the assumption that the prices that cannot be reset are indexed not only to a part of the past inflation rate but also to a part of trend inflation.[5] But, if the empirical results conclude to a low value for ξ, it

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[5] Note that in this case the aggregate price level is given by $P_t = \left[\phi\left(\bar{\pi}^{1-\xi}\pi_{t-1}^{\xi}P_{t-1}\right)^{1-\varepsilon} + \left(1-\phi\right)\left(P_t^*\right)^{1-\varepsilon}\right]^{1/(1-\varepsilon)}$

is then necessary to be careful on the validity of the estimates of ϕ.

Finally, in the extreme case of a full indexation scheme ($\xi = 1$), the model predicts that the growth rate of inflation depends upon real marginal costs and the expected future growth rate of inflation. The force of this theoretical assumption is that the derivation of the hybrid Phillips curve is possible whatever the level of trend inflation. But a serious weakness is that coefficients on past and future inflation sum to 1, and, for β close to 1, they are approximately the same. Unfortunately, this last point is rarely empirically verified.

4 Conclusion

This note proposes a full explanation of the Calvo price-setting model based on partial prices indexation to derive a Hybrid Phillips curve. Since it can hardly be justified to assume zero trend inflation to describe and model the data of post-war inflation, we take into account trend inflation and study the interaction between partial indexation and trend inflation. In particular, we find that the higher the degree of indexation and the less trend inflation has an influence on the value of the parameters of the hybrid Phillips curve. Consequently, overestimate due to the omission of trend inflation disappears with the increase of the degree of indexation. In the case of economies with low inflation and with a quite large degree of indexation, one can then make the assumption, without too many fears, that the prices that cannot be reset are indexed not only to a part of the past inflation rate but also to a part of trend inflation.

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Table 1. Values of $\left[\lambda\left(1,\xi\right)-\lambda\left(\bar{\pi},\xi\right)\right]/\lambda\left(1,\xi\right)$ **as a function of** $\bar{\pi}$ **and** ξ

	$\bar{\pi}=(1.01)^{\frac{1}{4}}$	$\bar{\pi}=(1.02)^{\frac{1}{4}}$	$\bar{\pi}=(1.05)^{\frac{1}{4}}$	$\bar{\pi}=(1.08)^{\frac{1}{4}}$	$\bar{\pi}=(1.1)^{\frac{1}{4}}$
$\xi=0$	15%	30%	63%	86%	95%
$\xi=0.25$	12%	23%	51%	72%	83%
$\xi=0.5$	8%	16%	36%	53%	63%
$\xi=0.75$	4%	8%	19%	29%	35%

Parameter configuration: $\beta=0.99, \phi=0.75, \varepsilon=10.$

Table 2. Values of $\left[\phi\left(1,\xi\right)-\phi\left(\bar{\pi},\xi\right)\right]/\phi\left(1,\xi\right)$ **as a function of** $\bar{\pi}$ **and** ξ

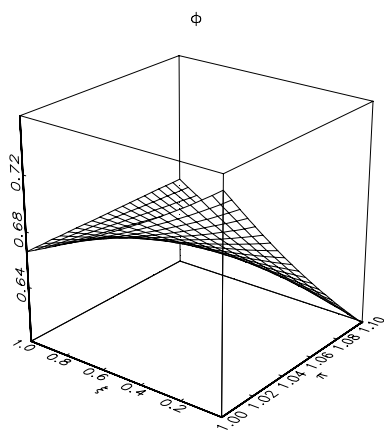|	$\bar{\pi}=(1.01)^{\frac{1}{4}}$	$\bar{\pi}=(1.02)^{\frac{1}{4}}$	$\bar{\pi}=(1.05)^{\frac{1}{4}}$	$\bar{\pi}=(1.08)^{\frac{1}{4}}$	$\bar{\pi}=(1.1)^{\frac{1}{4}}$
$\xi=0$	2%	5%	11%	17%	20%
$\xi=0.25$	2%	4%	8%	13%	16%
$\xi=0.5$	1%	2%	6%	9%	11%
$\xi=0.75$	0.6%	1%	3%	5%	6%

Parameter configuration: $\beta=0.99, \varepsilon=10, \lambda=0.086.$

Figure 1. Values of $\alpha_b, \alpha_f, \lambda, \Omega$ as a function of $\bar\pi$ and ξ
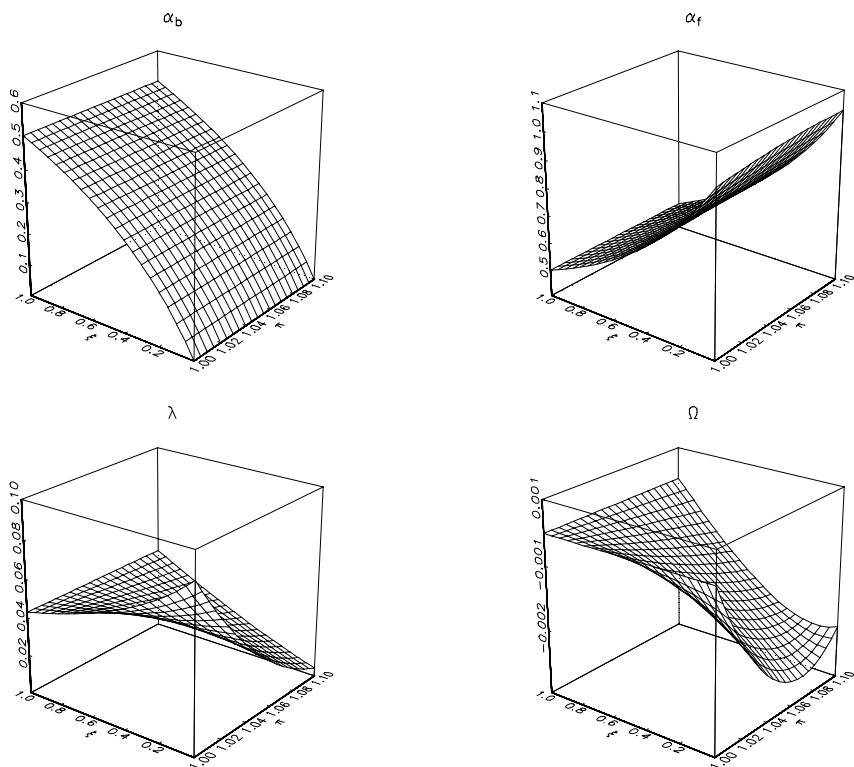
Parameter configuration: $\beta = 0.99, \phi = 0.75, \varepsilon = 10$.

Figure 2. Values of ϕ as a function of $\bar\pi$ and ξ

Parameter configuration: $\beta = 0.99, \varepsilon = 10, \lambda = 0.086$.

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