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Working Paper 10617

John D. M. Fisher
Martin Eichenbaum

EVALUATING THE CALVO MODEL OF STICKY PRICES

NBER WORKING PAPER SERIES

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available to other economists in preparing for revision
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Abstract

June 2004

Federal Reserve Bank of Chicago

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Economometrics

Economics

Department of Economics

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Martin Eichenbaum

ABSTRACT

Consistent with the view that firms re-optimize prices every quarter, once every two quarters
in response to news revealed after a shock. When we modify these assumptions our model is

monopolistically competitive firms face a constant elasticity of demand and capital can be

assumed to face a constant elasticity of capital. The main assumptions are that

price-setting behavior by firms is linear, and that prices are sticky. Price increases are

assumed to be zero. When investors with these models imply that prices increase in price

equation (6) of this model, we develop and test versions of the model for which the answer to this

Can variants of the classic Calvo (1983) model of sticky prices account for the sustained behavior

of prices? We develop and test versions of the model for which the answer to this
Introduction

The paper addresses two questions. First, can variables of the Oklo (1995) study provide evidence...
Section 3 discusses the empirical evidence that supports the calibrated model. In Section 4, we derive our econometric strategy for testing the model.

The rest of the paper is organized as follows: Section 2 discusses our extended version of the calibrated model. In Section 3, we develop our econometric strategy for testing the model. Section 4 presents our empirical evidence that supports the calibrated model.
The first condition in the finite horizon model is:

\[ (\frac{Y}{\lambda^2})_1 - \rho \alpha \lambda = 0 \]

The second condition, the firm's optimal control problem, is:

\[ \frac{\partial}{\partial t} \left( \frac{Y}{\lambda^2} \right) - \rho \alpha \lambda = 0 \]

\[ \alpha \lambda \frac{\partial}{\partial t} (\frac{Y}{\lambda^2}) - \rho \alpha \lambda = 0 \]

We consider two scenarios for two scenarios for which happiness is a given: one where happiness is a constant, and the other where happiness is a variable. We open the issue of how information is acquired and transmitted between firms. The firm's ability to communicate is independent across firms and within firms. The firm's ability to communicate is independent across firms and within firms.

We refer to the finite horizon of \( t \) as the firm's horizon. The firm's horizon is defined by the following conditions:

\[ 1 < \frac{1}{\alpha (1 - \beta)} \left( \frac{Y}{\lambda^2} \right) = \left( \frac{\lambda}{\alpha} \right) \]

This specification corresponds to the special case of the model where the firm's horizon is defined by the following conditions:

\[ H_t = H_{t-1} + 1 \]

where \( H_t \) is the horizon at time \( t \). The horizon is defined by the following conditions:

\[ 1 < \frac{1}{\alpha (1 - \beta)} \left( \frac{Y}{\lambda^2} \right) = \left( \frac{\lambda}{\alpha} \right) \]

2. The Caño model with non-constant elasticity of demand.

The Caño model with non-constant elasticity of demand assumes that the elasticity of demand is non-constant. The elasticity of demand is defined by the following conditions:

\[ \frac{1}{\alpha (1 - \beta)} \left( \frac{Y}{\lambda^2} \right) = \left( \frac{\lambda}{\alpha} \right) \]

Here, \( \lambda \) is the rate of innovation in the model. In section 5, we present our statistical results. In section 6, we interpret the parameters of the model.
where \( \frac{1 + \Delta}{\Delta} = \gamma \)

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\[ \frac{1 + \Delta}{\Delta} = \gamma \]
To be concrete, we now briefly describe a version of the model in which costs reflect the effects of decreasing returns to scale, the dynamic effects from adjustment costs, and the effects of different cost implications for the firm's output. Note that for the purposes of this paper, we consider a more general form of output, which leads to a more general form of cost function. However, this is in line with the basic results, which hold for a wide range of firm structure and technology.

In the case where a firm has a dynamic input function, the input-resident first order condition will be in a more general form:

\[ \frac{\theta}{(\theta - 1)(\theta - 1)} + \frac{\theta}{(\theta - 1)(\theta - 1)} \]

where \( \theta \) is the elasticity of the input function. In this case, the input-resident first order condition will be in a more general form:

\[ \frac{\theta}{(\theta - 1)(\theta - 1)} + \frac{\theta}{(\theta - 1)(\theta - 1)} \]

and (II) takes the form:

\[ \frac{\theta}{(\theta - 1)(\theta - 1)} + \frac{\theta}{(\theta - 1)(\theta - 1)} \]

In addition, (I) is replaced by:

\[ \frac{\theta}{(\theta - 1)(\theta - 1)} + \frac{\theta}{(\theta - 1)(\theta - 1)} \]

and (II) takes the form:

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\[ \frac{\theta}{(\theta - 1)(\theta - 1)} + \frac{\theta}{(\theta - 1)(\theta - 1)} \]
A. Assessing the Impriental Plausibility of the Model

Characteristics of the model in the Appendix show that a proxy stock of imputed capital can be estimated. The Appendix also considers factors such as the availability of data and the appropriateness of the model. In this section, we discuss two strategies for estimating and testing our assumptions on the data.

\[ \frac{(\theta - 1)(\theta D - 1)}{\theta} + 1 = \theta \]

(21)

Under dynamic induction, the range is to

\[ (p + \epsilon, p - \epsilon) \]

\[ \epsilon = \frac{1}{2} \left( \frac{1}{\theta} \right) \]

(see the Appendix) For simplicity, we summarize this relationship as

\[ \epsilon = \frac{1}{2} \left( \frac{1}{\theta} \right) \]

(11)
(32) \[
\left[1 - \chi(x)^{t+1}\right] = \sum_{j=1}^{\infty} \left(\frac{1}{j}ight) = (x)^{j+1}
\]

and

(33) \[\left(\left(\theta - 1\right) \frac{\partial}{\partial \theta} - 1\right) \chi = \chi \cdot \chi
\]

from the relation

However, given any estimate of \(\theta\) and a model with an assumed value for \(\theta\) and \(\chi\), one can deduce the

(34) \[\theta \chi \frac{\partial}{\partial \theta} - 1\] \[\chi \cdot \chi = \chi = \chi
\]

that can be interpreted. Given the assumptions made on the reduced form parameter.

It is evident (from (33) and (30)) that \(\chi = \chi\), and not all assumed changes to it's possible.

whether one selects so that an unobserved variable in potential to influence the

section correlation in the error term, then the theory implies we extract below,

which does not have to improve the restricted hypothesis that \(\chi = \chi\).

Finally, the number of constraints to be imposed on the model increases to

The estimated value of the \(\chi\) in the reduced form hypothesis, \(\chi = \chi\), is

(35) \[\chi = \chi \frac{\partial}{\partial \theta} - 1\]

(36) \[\left(\left(\theta - 1\right) \frac{\partial}{\partial \theta} - 1\right) \chi = \chi \cdot \chi
\]

To derive the feasible implications of the Carbo model, it is convenient to focus on the model

3.1. Feasible Implications of the Carbo Model

include those (2002) and those (2003) where...
Estimation and Learning

Under the assumption that the prior is non-specific and \( \lambda = 1 \), the objective is to maximize the likelihood function of the model.

The objective function is given by

\[
\mathcal{L} = \prod_{i=1}^{n} p(x_i | \theta, \phi)
\]

where \( p(x_i | \theta, \phi) \) is the probability of observing the data given the parameters. The model parameters are typically estimated using the Maximum Likelihood Estimation (MLE) approach.

3.2 Testing the Causal Model Against a Specified Alternative

After fitting the model to the data, we can test the causal relationships using various statistical tests. The null hypothesis is that there is no causal relationship, while the alternative hypothesis is that there is a causal relationship.

The p-value is used to determine whether the null hypothesis can be rejected. A p-value less than a predetermined threshold (e.g., 0.05) indicates that the null hypothesis can be rejected, suggesting the presence of a causal relationship.
6. Empirical Results

The power of our identification of the model, 

\[
\left(\frac{t^2 - \hat{t}^2}{s^2 - \hat{s}^2}\right) = \frac{t^2 - \hat{t}^2}{s^2 - \hat{s}^2}
\]

grows as the difference between the observed and the sample covariance of the data increases. We report results for the empirical test results and the sample covariance of the data.

We report results for the empirical test results and the sample covariance of the data.

4. Data

parameter is significantly different from zero.
on the assumptions that inform these beliefs. We continue with a discussion of the evidence in this section of the model. It is important to note that the evidence is consistent with the model presented in this section. The key result is that the model is consistent with the evidence presented in this section.

We conclude this section with a discussion of the evidence in this section. The key result is that the model is consistent with the evidence presented in this section.

2.2. Alternative Model Assumptions

In this section, we present alternative model assumptions. These assumptions are consistent with the evidence presented in this section. The key result is that the model is consistent with the evidence presented in this section.

2.3. The Standard Cato Model

We begin by introducing our alternative model, based on the evidence presented in this section. The key result is that the model is consistent with the evidence presented in this section.

The Cato model is consistent with the evidence presented in this section. The key result is that the model is consistent with the evidence presented in this section.

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5.3. Rule of Thumb Firms

We now report the results of estimating the Calvo model modified to allow for backward-looking rule-of-thumb firms. We begin by confirming Cali and Gerardi's result that there is evidence of backward-looking firms under the static indication scheme. Throughout, we assume that $r = 1$.

Table 5 summarizes our results for the static indication case. Four key findings are worth noting. First, using the full sample, we estimate that roughly 50% of firms believe that the noise on the real rate is lower than zero when we measure inflation using the CPI deflator. Second, there is still evidence that $\lambda$ is greater than zero when we measure inflation using the EUP deflator, at least in the context of the standard Calvo model with state-dependent capital and state-dependent rule-of-thumb firms. Third, rule-of-thumb firms are substantially less than those exiting under the assumption that there are no rule-of-thumb firms ($\lambda = 0$). Fourth, there is little evidence of rule-of-thumb firms once we allow for a rule-of-thumb dummy, with the exact percent depending on how we measure inflation.

In both cases, we can reject, at conventional significance levels, the null hypothesis that there are no rule-of-thumb firms ($\lambda = 0$). Second, our point estimates of $\gamma$ are similar to those obtained when we estimated the model under the constraint that $\gamma = 0$ (see Table 4). Perhaps most importantly, there is virtually no evidence of rule-of-thumb firms.

Viewed overall, the results in Table 5 are consistent with Cali and Gerardi's conclusion that dynamic arrivals are an alternative explanation of the data. Indeed, for the full sample, our point estimates suggest that the model with dynamic arrivals is at least as good as the model with state-dependent capital and state-dependent rule-of-thumb firms.

To explore the nature of these trade-offs, we proceed as follows. We set the share of states as the elasticity of the investment-to-capital ratio with respect to output, $\beta$, to 0.22, the markup, $\mu$, equal to 1.09, and the discount rate, $\delta$, to 0.20. We also consider three values for the parameter $\omega$: 0.01, 0.10, and 0.33. Recall that $\omega$, equal to zero, corresponds to the case where state-dependent capital is not capital-specific.

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are some obvious aspects of these models that are counterintuitive to the information in the text. Therefore, we are not providing any details or figures from the model's predictions. Instead, we focus on the model's predictions and the discussions that lead up to them.

Table 2: The model's predictions for the different scenarios. The predictions are based on the model's training data and are not intended to be a direct translation of the text. The predictions are presented in a tabular format for clarity.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Prediction</th>
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<tbody>
<tr>
<td>a)</td>
<td>b)</td>
</tr>
</tbody>
</table>

The predictions in Table 2 are not intended to be a direct translation of the text. They are based on the model's training data and are presented in a tabular format for clarity.
References
\[
\frac{(1-x_0)/(1-x_1) + z}{y/1 - 1} = \lambda
\]

The condition \(\lambda\) can be written

\[
\lambda = x
\]

Where

\[
\frac{(z,y)+z}{(z,y)} = (z,y)
\]

Prove that the diversity of demand for foreign intermediate good is

Importance

In the appendix, we discuss the definition of the demand for foreign intermediate goods. To assess the magnitude of the demand for foreign goods, we calculate (i) the demand for foreign goods at (1-x) and (ii) how to

Appendix

\[
(1) \frac{(1-x_0)/(1-x_1) + z}{y/1 - 1} = \lambda
\]

The condition \(\lambda\) can be written

\[
\lambda = x
\]

Where

\[
\frac{(z,y)+z}{(z,y)} = (z,y)
\]
Following Cremer, 2004 (and Wooldriden, 2004), we solve (49) and (39) and find

\[ I - \beta \frac{\theta}{\theta - 1} = \frac{\gamma}{\gamma - \theta} \]

There is the partial derivative from the second of the second order differentials of the price.

Inserting the zero partial condition for the product's profit yields

\[ I \beta \frac{\theta}{\theta - 1} \frac{\partial \beta}{\partial \beta} \left( (\theta - 1) \theta - 1 \right) = \Xi \]
\[ \frac{\partial \beta}{\partial \beta} \left((\theta - 1) \theta - 1 \right) + \frac{\partial \theta}{\partial \theta} + \frac{1}{\theta} \]
\[ \frac{\partial \gamma}{\partial \gamma} = \frac{\partial \gamma}{\partial \gamma} \frac{\partial \theta}{\partial \theta} = (\partial \gamma \partial \gamma) \frac{\partial \theta}{\partial \theta} \]

Where

\[ (\partial \gamma \partial \gamma) \frac{\partial \theta}{\partial \theta} = \frac{\partial \gamma}{\partial \gamma} \frac{\partial \theta}{\partial \theta} = (\partial \gamma \partial \gamma) \frac{\partial \theta}{\partial \theta} \]

The operator of a randomly chosen information, the same, is the same. It follows that

\[ I - \beta \frac{\theta}{\theta - 1} \frac{\partial \beta}{\partial \beta} \left( (\theta - 1) \theta - 1 \right) = \Xi \]
\[ \frac{\partial \beta}{\partial \beta} \left((\theta - 1) \theta - 1 \right) + \frac{\partial \theta}{\partial \theta} + \frac{1}{\theta} \]
\[ \frac{\partial \gamma}{\partial \gamma} = \frac{\partial \gamma}{\partial \gamma} \frac{\partial \theta}{\partial \theta} = (\partial \gamma \partial \gamma) \frac{\partial \theta}{\partial \theta} \]

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\[ \frac{\partial \beta}{\partial \beta} \left((\theta - 1) \theta - 1 \right) + \frac{\partial \theta}{\partial \theta} + \frac{1}{\theta} \]
\[ \frac{\partial \gamma}{\partial \gamma} = \frac{\partial \gamma}{\partial \gamma} \frac{\partial \theta}{\partial \theta} = (\partial \gamma \partial \gamma) \frac{\partial \theta}{\partial \theta} \]
\[
\left( \frac{\partial}{\partial x} \right) \frac{\partial}{\partial y} = \frac{\partial^2}{\partial x \partial y}
\]

This is a partial differential equation. The expression \( \frac{\partial^2}{\partial x \partial y} \) represents the change in the rate of change of a function with respect to two variables, \( x \) and \( y \). This is a fundamental concept in calculus and is used extensively in physics and engineering to model various phenomena.

Under the assumption of stationarity, the equation reduces to a simpler form:

The equation \( \frac{\partial^2}{\partial x \partial y} = 0 \) implies that the rate of change of the function with respect to \( x \) and \( y \) is zero, which is a condition for the function to be a constant.

This is a common scenario in many physical systems where the properties of the system do not change with respect to the spatial coordinates.

By substituting this expression into the equation, we obtain the following modified form:

\[
\frac{\partial x}{\partial y} + \frac{\partial y}{\partial x} = 1
\]

This is a basic identity in multivariable calculus. It states that the sum of the partial derivatives of a function with respect to two variables is equal to 1 if the function is such that the rate of change in one direction is inversely proportional to the rate of change in the other direction.

By considering this identity, we can simplify the expression and obtain a more intuitive form:

\[
\frac{\partial x}{\partial y} + \frac{\partial y}{\partial x} = 1
\]

This is a useful tool in various applications, such as in the study of fluid dynamics, where the conservation of mass and momentum are related through the divergence of the velocity field.
Table 1. Estimates of the Model's Parameters with Their Standard Errors

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta$</td>
<td>0.43</td>
<td>0.03</td>
</tr>
<tr>
<td>$\theta$</td>
<td>0.98</td>
<td>0.04</td>
</tr>
<tr>
<td>CPI Deflator</td>
<td>0.87</td>
<td>0.06</td>
</tr>
<tr>
<td>GDP Deflator</td>
<td>0.87</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Note: The estimates are derived using $X$ random variables with $X$ degrees of freedom.

\[ \frac{\Delta q}{q} = \frac{b \theta}{(K/I)^\theta} \]

Equation (46) following since $O = 1$, $\delta = 1$, $X = 0$, $\theta = 1$, and $b = 1$.
Table 5. Prices Chosen One Period in Advance, Market Indications and Rise of Third Price

Table 6. Prices Chosen One Period in Advance, Stochastic Indications

Table 7. Prices Chosen One Period in Advance with Dynamic Indicator

Table 8. Prices Chosen One Period in Advance with Static Indicator

Table 9. Prices Chosen One Period in Advance with Stochastic Indicator
### Table 1: Frequency of Reformation with Price Chosen One Period

<table>
<thead>
<tr>
<th>Year</th>
<th>1/4</th>
<th>1/3</th>
<th>1/2</th>
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### Notes
- Price chosen during the fourth quarter, reformation in the third quarter.
- No observations for the first quarter.
- Full sample observations include observations on firms with available financial data for the entire period.