Macroeconomic Effects of Asymmetric Investment Adjustment Costs*

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Abstract

This paper analyses the macroeconomic effects of introducing asymmetric investment adjustment costs in a New Keynesian DSGE model with sticky prices. The motivation lies behind the fact that during contractionary periods investment tends to fall more abruptly than what it increases during economic expansions. The model is able to explain the cyclical behavior of investment, capital, output and real wages with a significant level of accuracy. It is also demonstrated that symmetric models fail to estimate the real pattern of this variables, at least for U.S. data. Despite the good results, it seems that besides the asymmetries on investment adjustments there exist other sources of asymmetries affecting the U.S. economy.

*I am especially grateful to my advisor, Mirko Abbritti, for his invaluable help and guidance. I also want to thank Mikel Casares for many useful comments and suggestions. All remaining errors are mine.
1 INTRODUCTION

By looking at historical data one could learn that investment is prone to fall more abruptly in contractionary periods than it grows in expansionary ones. In this aspect, the current crisis has been no exception. In the majority of industrialized countries the decrease of investment has been substantial and swift. Figure 1 in the appendix displays the evolution of investment as a share of GDP for the U.S. between 1980 and 2014\(^1\). There can be observed precisely this type of behavior. Between 1984 the 1991 the ratio investment to output fall around 23.29%. Then, in a period of nine years it increased around 22.21% to decrease in the following two years about 10.37%. Between 2002 and 2006 it increased 9.83% to dramatically fall an striking 27.85% in the following three years. The IMF predicts that between 2009 and 2014 the share of investment over GDP would have increase around 24.82%. Behind all this numbers lies a common pattern, contractionary periods last on average 4 years and investment falls around 5.12% yearly while expansionary periods last on average 6 years and investment rises around 3.16% per year. This paper is an attempt to study to what extent these asymmetries on investment adjustments affect other macroeconomic variables.

For this purpose, the article introduces a New Keynesian DSGE model with sticky prices à la Rotemberg (1996) and rigidities on investment in an manageable and effective way. This rigidities on investment introduce important asymmetries in the business cycle. While in expansionary periods the increase in investment and capital are rather limited and quite weak for the first quarters, in contractionary periods investment and capital levels fall sharply, specially if the shock is monetary.

It is also demonstrated how models with symmetric investment adjustment costs fail to approximate and explain second and third moments of the real data, actually some estimations even have opposite sign from their real counterparts. On the other hand, the asymmetric specification of the model does a fairly good job explaining the direction of the asymmetries over the business cycle and also provides very accurate results on skewness measures, specially for capital markets.

Eventhough there is a vast literature studying asymmetries in the labor markets such as Pissarides (1985), Shimer (2005), Fahr and Smets (2010) or Abbriti and Fahr (2011), there is still

\(^1\)The data from 2011 to 2014 are predictions estimated by the IMF.
an enormous hole in economic research regarding asymmetries in investment adjustments. To my knowledge, only a few such as Boetel, Hoffmann, and Liu (2007) or den Haan, Ramey, and Watson (2000) have tried to tackle this issue but from very different approaches that the one presented here.

The framework developed below is an attempt to fill that hole and provide an explanation of the effects of different shocks on their transmission to the economy via the asymmetric response of investment adjustments. For doing so the model assumes that firms, specifically wholesale firms, face asymmetric investment adjustment costs. These costs are modelled by a convex function with lower costs for adjusting investment downwards than for increasing it.

The rest of the paper is organized as follows. Section 2 describes the model with sticky prices and asymmetric investment adjustment costs. Section 3 offers the baseline calibration of the model. The main results are reported in Section 4. Finally, Section 5 draws conclusions.

2 THE MODEL

This section presents a simple New Keynesian DSGE model with sticky prices à la Rotemberg (1996) and rigidities on investment. For the latter an asymmetric investment adjustment cost function is introduced in the maximization problem of the wholesale firms which is explained in detail below. Households maximize their lifetime utility over consumption and labor. The economy consists of two sectors of production. The final good sector where firms are monopolistically competitive, and the wholesale sector where firms act in a perfect competition environment. Finally, there is a monetary authority that adopts an augmented Taylor-type rule for setting the nominal interest rate.

2.1 Households

Following Galí (2002), the representative infinitely-lived household values consumption of a CES basket of brands and dislikes effort

$$U = E_0 \sum_{t=0}^{\infty} \beta^t \left( \frac{C_t^{1-\sigma}}{1-\sigma} - \chi \frac{N_t^{1+\phi}}{1+\phi} \right)$$ (1)
where $C_t$ is a consumption index given by

$$C_t = \left[ \int_0^1 (C_t(i))^{\frac{\epsilon}{1-\epsilon}} \, di \right]^{\frac{1}{\epsilon - 1}}$$

with $C_t(i)$ representing the quantity of good $i$ consumed by the household in period $t$. $N_t$ denotes labor, $\beta^t$ is the intertemporal discount factor, and $\epsilon$ is the elasticity of substitution across brands.

Households finance their consumption through wage income and profits (regarded as given). The budget constraint for the periods $t = 0, 1, 2, \ldots$ can be written as

$$\int_0^1 P_t(i)C_t(i) di + Q_t B_t = B_{t-1} + W_t N_t + \pi_t$$

where $P_t(i)$ is the price of good $i$, $W_t$ is the nominal wage and $\pi_t$ are the profits each household gets from the ownership of firms. Notice also that households can save by purchasing one-period bonds, $B_t$, at price $Q_t$.

Given that there are different types of goods, each household must choose the optimal allocation of expenditure across varieties, which yields the demand functions for the individual consumption good

$$C_t(i) = \left( \frac{P_t(i)}{P_t} \right)^{-\epsilon} C_t$$

where $P_t = \left[ \int_0^1 P_t(i)^{1-\epsilon} \, di \right]^{\frac{1}{1-\epsilon}}$ is the aggregate price index. Moreover, conditional on that optimal allocation, total expenditure on consumption can be written as the product of the price index times the quantity index

$$\int_0^1 P_t(i)C_t(i) di = P_tC_t$$

Hence, the final constraint the representative household faces takes the form

$$P_tC_t + Q_t B_t = B_{t-1} + W_t N_t + \pi_t$$

(2)

Now that we have all the equations needed, maximizing (1) subject to (2) and setting the lagrangian function we get the corresponding first order conditions
\[ C_t : \beta^t \frac{1}{C_t^\sigma} - \beta^t \lambda_t P_t = 0 \]  
(3)

\[ N_t : -\beta^t \chi N_t^\phi + \beta^t \lambda_t W_t = 0 \]  
(4)

\[ B_t : \beta^{t+1} E_t \lambda_{t+1} - \beta^t \lambda_t Q_t = 0 \]  
(5)

Combining equations (3) and (4) we get the labour supply curve

\[ \frac{W_t}{P_t} = \chi N_t^\phi C_t^\sigma, \]

and combining equations (3) and (5) we get the Euler equation which determines the intertemporal allocation of consumption

\[ \frac{C_t^{-\sigma}}{P_t} = \beta \frac{1}{Q_t} E_t \left\{ \frac{C_{t+1}^{-\sigma}}{P_{t+1}} \right\} \]

where \( \frac{1}{Q_t} = R_t \) (i.e., the gross nominal interest rate).\(^2\)

### 2.2 Firms

As in Abbriti and Fahr (2011), two sectors of production compose the economy. Firms in the wholesale sector are perfectly competitive and use capital and labor to produce intermediate homogeneous goods. Their output is bought by firms in the final good sector (retailers) who use it as inputs of a technology that transforms them into differentiated goods at no extra cost. Retailers face convex adjustment costs for prices and since they are monopolistically competitive they apply a mark-up over the price of final goods.

#### 2.2.1 Retail Firms

All retailers have one identical technology that produces final goods by transforming one unit of intermediate goods into one unit of differentiated final goods. Final goods are aggregated in a Dixit-Stiglitz fashion with elasticity \( \epsilon \) to the final composite good \( Y_t = \left[ \int_0^1 Y_t(z)\frac{1}{z} dz \right]^{\frac{1}{1-\epsilon}} \). The demand function for the final goods is

\[ Y_t(z) = (p_t(z)/P_t)^{-\epsilon} Y_t \]

\(^2\)In steady state, this equation becomes \( \beta = 1/R \). Notice that present-oriented households have a lower discount factor since they discount the future heavily.
where \( P_t = \left[ \int_0^1 P_t(z)^{1-\epsilon} \, dz \right]^{1/\epsilon} \). Final-good firms buy intermediate goods at price \( P_t \varphi_t \) from wholesale firms and sell their differentiated final good at price \( p_t(z) \). Notice that \( \varphi_t \) is the relative cost of intermediate goods. Hence, the maximization problem for retailers takes the form

\[
\max_{p_t(z), Y_t(z)} E_0 \sum_{t=0}^{\infty} \beta_t \left[ \frac{p_t(z) - P_t \varphi_t}{P_t} - \Gamma_t \left( \frac{p_t(z)}{p_{t-1}(z)} \right) \right] Y_t(z)
\]

subject to

\[
Y_t(z) = \left( \frac{p_t(z)}{p_t} \right)^{-\epsilon} Y_t
\]

where \( \Gamma_t \left( \frac{p_t(z)}{p_{t-1}(z)} \right) \) is the price adjustment cost function.

Maximizing (6) subject to (7) we get the following first order conditions

\[
p_t(z) : \beta_t \left( \frac{1}{P_t} - \frac{\partial \Gamma_t}{\partial p_t(z)} \right) Y_t(z) + \lambda_t \beta_t \epsilon \left( \frac{p_t(z)}{P_t} \right)^{-\epsilon-1} \frac{1}{P_t} Y_t - \beta_{t+1} \frac{\partial \Gamma_{t+1}}{\partial p_t(z)} Y_{t+1}(z) = 0
\]

\[
Y_t(z) : - \frac{p_t(z)}{P_t} + \varphi_t + \Gamma_t - \lambda_t = 0
\]

Now we take (9), dividing it by \( Y_t(z) \) and multiplying it by \( p_t(z) \) to obtain

\[
\frac{p_t(z)}{P_t} - \frac{\partial \Gamma_t}{\partial p_t(z)} p_t(z) + \epsilon \lambda_t - \beta_{t+1} \frac{\partial \Gamma_{t+1}}{\partial p_t(z)} \frac{Y_{t+1}(z)}{Y_t(z)} p_t(z) = 0
\]

where \( \beta_{t+i} = \beta^i \left( \frac{\lambda_{t+i}}{\lambda_t} \right) \).

Combining (9) and (10) we get

\[
\frac{p_t(z)}{P_t} - \frac{\partial \Gamma_t}{\partial p_t(z)} p_t(z) - \epsilon \frac{p_t(z)}{P_t} + \epsilon \varphi_t + \epsilon \Gamma_t - \beta_{t+1} \frac{\partial \Gamma_{t+1}}{\partial p_t(z)} \frac{Y_{t+1}(z)}{Y_t(z)} p_t(z) = 0
\]

The price adjustment cost function takes the form

\[
\Gamma_t \left( \frac{p_t(z)}{p_{t-1}(z)} \right) = \frac{\phi_p}{2} \left( \frac{p_t(z)}{p_{t-1}(z)} - \Pi^* \right)^2
\]

where \( \Pi^* \) is trend inflation.

The first-order conditions with respect to \( p_t(z) \) are

\[
\frac{\partial \Gamma_t}{\partial p_t(z)} = \phi_p \left[ \frac{p_t(z)}{p_{t-1}(z)} - \Pi^* \right] \frac{1}{p_{t-1}(z)}
\]
\[
\frac{\partial \Gamma_{t+1}}{\partial p_t(z)} = \phi_p \left[ \frac{p_{t+1}(z)}{p_t(z)} - \Pi^* \right] \left[ - \frac{p_{t+1}(z)}{p_t(z)} \right] \tag{13}
\]

Introducing (12) and (13) into (11) we get

\[
\frac{p_t(z)}{P_t} - \phi_p \left[ \frac{p_t(z)}{p_{t-1}(z)} - \Pi^* \right] \frac{p_t(z)}{p_{t-1}(z)} - \frac{p_t(z)}{P_t} + \epsilon \varphi_t + \epsilon \Gamma_t + \beta_{t+1} \phi_p \left[ \frac{p_{t+1}(z)}{p_t(z)} - \Pi^* \right] \left[ \frac{p_{t+1}(z)}{p_t(z)} \right] Y_{t+1}(z) = 0
\]

By setting \( \Pi^* = 1 \) and using symmetry, i.e., \( Y_t(z) = Y_t \) and \( p_t(z) = P_t \ \forall \ z \), we get

\[
1 - \phi_p [\Pi_t - 1] \Pi_t - \epsilon + \epsilon \varphi_t + \epsilon \Gamma_t + \beta_{t+1} \phi_p [\Pi_t - 1] \Pi_{t+1} \frac{Y_{t+1}}{Y_t} = 0
\]

that after some rearrangement yields the Phillips curve

\[
\Gamma_t \Pi_t = \epsilon (\varphi_t + \Gamma_t) - (\epsilon - 1) + E_t \left[ \beta_{t+1} \frac{Y_{t+1}}{Y_t} \Gamma'_{t+1} \Pi_{t+1} \right]
\]

where

\[
\Gamma'_t = \frac{\partial \Gamma_t}{\partial \left( \frac{p_t(z)}{p_{t-1}(z)} \right)} = \phi_p [\Pi_t - 1]
\]

\[
\Gamma'_{t+1} = \frac{\partial \Gamma_{t+1}}{\partial \left( \frac{p_{t+1}(z)}{p_t(z)} \right)} = \phi_p [\Pi_{t+1} - 1]
\]

and \( \Pi_t = p_t(z)/p_{t-1}(z) = P_t/P_{t-1} \) since all the final good firms have the same technology and set the same price in equilibrium\(^3\). The setting of this price only depends on the relative cost of the inputs (intermediate goods) and on the price adjustment cost \( \Gamma_t \).

2.2.2 Wholesale Firms

Firms in the intermediate goods sector use capital and labor as inputs and have a production function with constant returns to scale

\[
Y_t = A_t N_t^\alpha K_t^{1-\alpha}
\]

where \( K_t \) is the aggregate capital stock and \( A_t \) is an \( AR(1) \) total factor productivity process.

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\(^3\)Under flexible prices \( \Gamma_t = \Gamma_t' = 0 \), hence \( \varphi_t = \epsilon/(\epsilon - 1) \). That is, under flexible prices, optimal price setting makes all the firms to choose the same price which maintains a constant mark-up over the marginal cost.
The representative firm chooses labor, investment and capital to maximize the expected sum of discounted profits

$$\max_{N_t, I_t, K_t} E_t \left\{ \sum_{t=0}^{\infty} \beta^t \left[ \varphi_t A_t N_t^\alpha K_t^{1-\alpha} - w_t N_t - I_t - T \left( \frac{I_t}{I_{t-1}} \right) \right] \right\}$$

subject to

$$K_t = (1 - \delta)K_{t-1} + I_t$$

$$T \left( \frac{I_t}{I_{t-1}} \right) = \phi_T \left[ \frac{\exp \left( -\psi_T \left( \frac{I_t}{I_{t-1}} - 1 \right) \right) + \psi_T \left( \frac{I_t}{I_{t-1}} - 1 \right) - 1}{\psi_T^2} \right]$$

where $w_t$ is the real wage, i.e., $w_t = \frac{W_t}{P_t}$. $T \left( \frac{I_t}{I_{t-1}} \right)$ is the investment adjustment cost function\(^4\) and $\phi_T$ and $\psi_T$ are the convexity and asymmetry parameters, respectively.

The first order conditions for the wholesale firms are

$$N_t : \alpha \frac{\varphi_t Y_t}{N_t} = w_t$$

$$I_t : \mu_t = 1 + \phi_T \left[ \frac{1 - \exp \left( -\psi_T \left( \frac{I_t}{I_{t-1}} - 1 \right) \right)}{\psi_T I_{t-1}} \right] + E_t \beta_{t+1} \phi_T \left[ \frac{\exp \left( -\psi_T \left( \frac{I_{t+1}}{I_t} - 1 \right) \right) \left( \frac{I_{t+1}}{I_t} \right) - \left( \frac{I_{t+1}}{I_t} \right)}{\psi_T I_t} \right]$$

$$K_t : \mu_t = (1 - \alpha) \frac{\varphi_t Y_t}{K_t} + E_t \beta_{t+1} (1 - \delta) \mu_{t+1}$$

Equation (16) describes the investment decision over time, from which we can interpret that the cost of investment at period $t$ is increasing on investment on the same period but decreasing on future investment. Actually, the lagrange multiplier $\mu_t$ is the Tobin’s Q and in equilibrium its value is equal to 1. Equation (17) states the fact that the expected cost of an investment is equal to the expected value of that investment (given by the marginal productivity of capital) and the expected continuation value.

Since the aim of this paper is to study the macroeconomic effects of introducing an asymmetric investment adjustment cost function the choice of the function itself is not trivial at all. Specifically, we are interested in capturing an upward rigidity behavior, that is, to make it more expensive to invest than disinvest.

\(^4\)This linear function is an adaptation of the one employed by Kim and Ruge-Murcia (2007).
The following properties of (14) are the ones that have motivated its selection. To begin with, notice that the cost not only depends on the magnitude but also on the sign of the investment adjustment. If we consider the case where $\psi_T < 0$ (which is the assumption taken for the purpose of this paper), as the investment at time $t$ increases, the exponential term of the function dominates the linear one and the cost of investment increases exponentially. On the other hand, if the growth rate of investment is smaller than one, that is, if $I_t$ is smaller than $I_{t-1}$, it is the linear term that dominates and the cost associated with the disinvestment increases linearly.

Another property of this function is that as $\psi_T$ tends to zero, it fits the quadratic form which makes a straightforward comparison between the symmetric and asymmetric cases.

Finally, the investment adjustment cost function is differentiable and strictly convex for any $\phi_T > 0$.

Figure 2. Different specifications of adjustment cost curves.

Figure 2 offers a visual impression and a comparison between different specifications of the function. The blue line represents the asymmetric adjustment costs with a $\psi_T = -280$, which is the value we have used in the model. And the dashed red line represents the symmetric adjustment.
costs, that is, when the asymmetry parameter, $\psi_T$, tends to zero.

### 2.3 Monetary Policy

The monetary authority, by adopting an augmented Taylor type rule, sets the short term nominal interest rate by reacting to inflation and output growth. This rule takes the following form

$$\frac{R_t}{R} = \left( \frac{R_{t-1}}{R} \right)^{\omega_r} \left[ \left( \frac{\Pi_t}{\Pi} \right)^{\omega_\Pi} \left( \frac{Y_t}{Y_{t-1}} \right)^{\omega_y} \right]^{1-\omega_r} \varepsilon_t^m$$

where $\omega_r$ is the degree of interest rate smoothing, $\omega_\Pi$ is the response coefficient from steady state inflation and $\omega_y$ is the response coefficient to output growth. The term $\varepsilon_t^m$ captures an i.i.d. monetary policy shock.

### 2.4 Resource Constraint

In order to close the model we need a resource constraint or market clearing condition. In ours, final output may be devoted to either consumption, investment or to cover the investment adjustment costs.

$$Y_t = C_t + I_t + T_t = W_t N_t + \pi_t$$

### 3 CALIBRATION

The calibration of the parameters of this model attempts to capture the most significant structural features of the U.S. economy. Time is measured in quarters.

#### 3.1 Preferences

In order to get a real interest rate of about 3% per year we have set the quarterly discount factor $\beta$ equal to 0.9925. As in Blanchard and Galí (2010), the value of the disutility of labor $\phi$ is set equal to 1, as well as the value of the utility of consumption $\sigma$. Following the range of estimates of Christopoulou and Vermeulen (2008) we have set an elasticity of product sustitution $\epsilon$ equal to 6, implying a gross steady state markup of 1.2.
3.2 Production

The elasticity of output with respect to labor is set to reflect a capital share of 33.33%. For getting an annual depreciation rate of 10% we have set the quarterly depreciation rate of capital \( \delta \) equal to 0.025.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Real Business Cycle</strong></td>
<td></td>
</tr>
<tr>
<td>Discount Factor ( \beta )</td>
<td>0.9925</td>
</tr>
<tr>
<td>Elasticity of Consumption Utility ( \sigma )</td>
<td>1</td>
</tr>
<tr>
<td>Elasticity of Labor Disutility ( \phi )</td>
<td>1</td>
</tr>
<tr>
<td>Elasticity of Product Subs. ( \epsilon )</td>
<td>6</td>
</tr>
<tr>
<td>Production Function ( \alpha )</td>
<td>( 2/3 )</td>
</tr>
<tr>
<td>Capital Depreciation Rate ( \delta )</td>
<td>0.025</td>
</tr>
<tr>
<td><strong>Price and Investment</strong></td>
<td></td>
</tr>
<tr>
<td>Price Rigidity ( \phi_p )</td>
<td>22.7</td>
</tr>
<tr>
<td>Investment Rigidity ( \phi_T )</td>
<td>1</td>
</tr>
<tr>
<td>Investment Asymmetry ( \psi_T )</td>
<td>-280</td>
</tr>
<tr>
<td><strong>Monetary Policy</strong></td>
<td></td>
</tr>
<tr>
<td>Int. Rate Smoothing Coeff. ( \omega_r )</td>
<td>0.85</td>
</tr>
<tr>
<td>Response to Inflation ( \omega_I )</td>
<td>1.5</td>
</tr>
<tr>
<td>Response to Output Growth ( \omega_Y )</td>
<td>0.125</td>
</tr>
<tr>
<td><strong>Shocks</strong></td>
<td></td>
</tr>
<tr>
<td>Std. Dev. Productivity Shock ( \sigma_A )</td>
<td>0.8%</td>
</tr>
<tr>
<td>Autocorr. Productivity Shock ( \rho_A )</td>
<td>0.95</td>
</tr>
<tr>
<td>Std. Dev. Monetary Shock ( \sigma_m )</td>
<td>0.15%</td>
</tr>
</tbody>
</table>

3.3 Price and Investment Rigidities

We have set the value of the convexity parameter of price adjustments \( \phi_p \) equal to 22.7, which is line with a Calvo parameter of \( \zeta = 0.63 \) and a mean duration of three quarters founded by Smets and Wouters (2007) in their estimated Phillips curve relationships.
3.4 Monetary Policy and Shocks

The persistency of the transitory productivity shock is $\rho_A = 0.95$, as in Casares (2009), and its corresponding standard deviation $\sigma_A$ is set equal to 0.8%. The standard deviation of the monetary shock is $\sigma_m = 0.15$. The values chosen for these standard deviations fall within the range of values estimated by Smets and Wouters (2003). For the monetary policy we set the values for the interest rate smoothing coefficient and the response to inflation equal to $\omega_r = 0.85$ and $\omega_\Pi = 1.5$, respectively, as in Abbriti and Fahr (2011), and $\omega_Y = 0.125$.

4 THE EFFECTS AND TRANSMISSION OF SHOCKS

This section provides an analysis of how the introduction of asymmetries on adjustments to investment affect other variables. This transmission can be either directly, through production costs or through intertemporal considerations in adjusting investment levels, or indirectly, through the general equilibrium responses of other variables.

4.1 Impulse Response Functions

Let’s start considering a technology shock. Figure 3 displays a positive technology shock that leads to an increase in productivity and a decrease on the employment level during the first quarter. This finding is in line with previous research such as Galí (1999). But from the first period onwards the employment level increases meaning that this variable is procyclical.

This shock also leads to an increase in the productivity of workers that causes an increase in real wages, supported by a decrease in prices coming from a fall in in the marginal costs for firms.

The reduction in the relative cost of intermediate goods is transmitted to the final goods firms as a reduction of their production costs since this is the only cost they pay during their whole production process. On the other hand, wholesale firms may not gain as much because some of their costs, such as real wages, have increased. Notice that real wages are much more persistent because the productivity shock is persistent. Marginal costs fade away because the monetary authority maintains inflation at a low level. This is the reason why the change in real wages lasts longer than the change in the relative cost of intermediate goods which, after one year, comes
back to its steady state level.

The largest increase due to the positive shock is given in investment followed by output, consumption, and capital respectively. The persistency of this four variables, together with real wages, is very different from others such as inflation because they deviate for a prolonged period of time.

If we analyze now the responses to a negative shock, we can observe the importance of the asymmetries in the investment adjustment costs. The fall in investment is much faster than the increase caused by the positive shock. This asymmetry is strongly transmitted to the nominal interest rate, to labor and inflation during their first quarters and, in a lower degree to capital, consumption and production.

*Figure 3.* Impulse responses following positive and negative technology shocks of 2 standard deviations.

For this shock it seems that capital is the variable that is going take longer to return to its steady state level. This makes perfect sense because investing in capital, and hence increasing its level, is more costly than reducing investment or not investing at all. In a sense, this is what happened at the beginning of the current economic crisis. The U.S. investment level fall over a 24% between 2007 and 2009, while after the same period of time, 2 years, the level is around 88%
of that of 2007\(^5\). This effect will become more notorious when analyzing a monetary shock, which comes next.

Figure 4 illustrates a monetary policy shock, with a positive shock defined as being looser than the Taylor rule would imply and therefore expansionary. By looking at this figure we can observe that after a positive monetary shock the nominal interest rate decreases stimulating the economy and increasing the levels of consumption and investment. This provokes a rise in the aggregate demand that is followed by an increase in the labor demand. Such increase in the employment level makes real marginal costs rise. Prices go up and inflation ends up offsetting the decrease of the nominal interest rate, and hence the expansionary monetary policy.

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\(^{\text{5}}\)This data is taken from Reuters EcoWin (2011).
different. While the latter come back to their stationary levels in one year or less, the first two deviate for a longer period of time, specially capital which does not reach its initial level even after twenty quarters.

On the other hand, when the monetary shock is contractionary, the effect on all of the variables is basically the same as before but with the opposite sign, except for investment and capital. Here is where the asymmetries generated by the model can be really appreciated. The fall in the investment level is particularly strong as it doubles the increase it had for the positive shock capturing the essence of this paper, that is, it is more expensive to invest than disinvest. And this effect is much higher than the one previously displayed for the technology shock. Of course this investment effect is transmitted to the level of capital that cannot recover its steady state level for a long period of time.

4.2 Comparison Between the Moments of the Data and the Moments of the Model

4.2.1 Second Moments

Table 2 offers a comparison between second moments of the real data\textsuperscript{6} and those obtained from the model under the assumption of symmetric and asymmetric investment adjustment costs, denoted by "Sym" and "Model" respectively. The motivation behind this comparison is to find out whether we can obtain better estimates than those provided by standard models with symmetric investment adjustment costs.

For the standard deviations of the selected variables, the asymmetric model estimations are in general closer to the real data than the ones obtained from the symmetric model. Actually, the symmetric model overestimates the values of all the standard deviations, except for the estimation of the real wage which is actually better than the one from the asymmetric model. Output and inflation give the most accurate results.

For the case of the coefficients between the standard deviations of the different variables with respect to the standard deviation of the output the asymmetric model does better for all the variables observed. Notice that the accuracy of the coefficient for investment is almost perfect.

\textsuperscript{6}This values are taken from Abbriti and Fahr (2011).
And regarding the correlation coefficients both model predict the same sign as in the data and there are no big differences in terms of accuracy. But it is worth mentioning that the asymmetric model is more precise when it comes to estimate the correlation between investment and output. Since the aim of this research is to study and explain the behavior of investment (and how this affects other macroeconomic variables) it can be reasonably argued that the model fulfills fairly well its purpose.

Table 2. Second moments of HP-detrended series in the data and the model. The data goes from 1970:Q1 to 2010:Q1.

<table>
<thead>
<tr>
<th>U.S.</th>
<th>$\sigma(x)$</th>
<th>$\sigma(x)/\sigma(y)$</th>
<th>$\rho(x,y)$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Data</td>
<td>Sym</td>
<td>Model</td>
</tr>
<tr>
<td>Output $Y_t$</td>
<td>1.55</td>
<td>0.98</td>
<td>1.27</td>
</tr>
<tr>
<td>Inflation $\Pi_t$</td>
<td>0.31</td>
<td>0.45</td>
<td>0.44</td>
</tr>
<tr>
<td>Real Wage $w_t$</td>
<td>0.80</td>
<td>1.13</td>
<td>1.21</td>
</tr>
<tr>
<td>Investment $I_t$</td>
<td>5.43</td>
<td>2.14</td>
<td>4.55</td>
</tr>
</tbody>
</table>

4.2.2 Third Moments

Table 3 displays the skewness of annual log changes from the data and the two specifications of the model, symmetric and asymmetric. By doing this the paper is trying to tackle two main issues. Firstly, it is looking for an explanation of the asymmetries observed in the data and, secondly, it is attempting to determine if the introduction of asymmetric investment adjustment costs improves the match between the moments of the data and those of the model.

The best estimations are those for output, real wages and investment which all decrease at a higher speed than they increase, meaning that they are negatively skewed. The estimation for labor also implies negative skewness but its value is pretty far from the one of the real data. Not only the signs obtained from the asymmetric model go in the same direction as the data does but also its values are more accurate than the ones provided by the symmetric model. With the only exception of the inflation estimation, the asymmetric model clearly overcomes the symmetric one.

By looking at the second column of Table 3 it can be observed that the model specification of symmetric investment adjustment costs cannot capture the basic features of the real data.
Actually, most of the skewness of the variables generated by this model are close to zero and, for the case of the output, the sign of the skewness is pointing in the opposite direction of its empirical counterpart. Others, such as Abbriti and Fahr (2011), have pointed out that the little skewness provided by symmetric models stems from non-linearities in the utility and production functions.

Due to the introduction of asymmetries in the investment adjustment costs the model not only amends the wrong direction of skewness of the symmetric specification, but it also allows us to capture the degree of skewness of capital markets fairly well. Since what is being studied is the investment on capital equipment, and not on financial assets, one possible source of such asymmetries can be the existence of important fixed costs. Another possible explanation can be provided with the following example. Let’s imagine a firm that when set up required an important initial investment. Once the economy reached its steady state level the firm invested just enough to replace the depreciated capital. Then, suddenly a negative shock, either technological or monetary, hits the economy and the firm finds it more profitable (less costly) to declare itself bankrupt in lieu of making new investments.

Overall, the model with asymmetries on investment point in the right direction for explaining the skewness of many macroeconomic variables. However, the model fails to explain the behaviour of other variables, namely inflation and employment. This clearly indicates that other institutions, such as labor markets, suffer from asymmetries. Actually, there is a an extensively research done in the field of labor market rigidities, Christoßel et al. (2009), Faccini and Ortigueira (2010), Fahr and Smets (2010), Abbriti and Fahr (2011) and many others. A model merging asymmetries in both markets, labor and capital, may be a good idea for future research.

<table>
<thead>
<tr>
<th>U.S.</th>
<th>Skewness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Data</td>
</tr>
<tr>
<td>Output $Y_t$</td>
<td>-0.69</td>
</tr>
<tr>
<td>Labor $N_t$</td>
<td>-0.86</td>
</tr>
<tr>
<td>Inflation $\Pi_t$</td>
<td>1.09</td>
</tr>
<tr>
<td>Real wage $w_t$</td>
<td>-0.67</td>
</tr>
<tr>
<td>Investment $I_t$</td>
<td>-0.86</td>
</tr>
</tbody>
</table>
5 CONCLUSIONS

This paper has characterized the dynamics of the business cycles by introducing asymmetries in the adjustment of investment. This asymmetry in the model is what allows to capture several facts of the third moments of the data, that is what this research is aimed to do.

The framework developed in this paper introduces investment rigidities into a New Keynesian framework with sticky prices à la Rotemberg (1996). The asymmetric investment adjustment costs makes investment increases more costly and thereby slower than disinvestments.

A monetary shock and a technological shock are introduced to test the effectiveness of the model. The economy seems to be more sensitive for the latter and its effects last longer (mainly because of its persistency) than the ones generated by a monetary shock. After a positive technology shock firms become more productive and this is exploited by increasing employment and real wages. Output increases as well as consumption and investment. After a year the economy is better than what it was before the shock with higher levels of the variables just mentioned and without suffering from inflation. On the other hand, following a monetary policy, all the variables except investment and capital come back to their steady state levels after the first period. This means that the effects of such policy are rapidly offset.

It looks like asymmetric investment adjustment costs are only one source of asymmetries affecting the U.S. economy since this model fails to explain the behavior of some variables such as inflation and employment. It seems that there are other parts of the economy where asymmetries exist as well. Hence, extensions building upon complementarities between capital markets and, for example, labor markets may further improve the fit of the model with the data on the issue of asymmetries.
REFERENCES


APPENDIX

Figure 1. U.S. investment, % of GDP (1980-2014).

Source: IMF, World Economic Outlook.