ABSTRACT

Title of dissertation: ESSAYS ON FACTOR ADJUSTMENT DYNAMICS

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This study analyzes dynamic production input factor decisions using the annual Census of Manufacturing firms from Colombia and monthly production data from a glass mould firm. It proposes a model that is able to explain the empirical evidence about capital and employment adjustment observed in these data-sets, namely the mix of smooth and lumpy adjustment, and both the static and dynamic interrelation in capital and employment adjustment. The key points of the explanation are the joint analysis of capital and employment adjustment and the existence of adjustment costs for capital and labor. These adjustment costs take the form of disruption in the production process and reallocation of internal resources to adjust the input factors, fixed costs of adjusting factors and congestion effects in the adjustment costs, meaning that it is more costly for firms to adjust capital and employment at the same time. The study uses a structural approach and a simulated minimum distance algorithm to estimate the adjustment cost parameters in the case of the Census of Manufacturing Firms and a calibration procedure to explore the fit of the model in the specific case of the glass mould firm

ESSAYS ON FACTOR ADJUSTMENT DYNAMICS

by

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DEDICATION

To my father, mother, brother and wife

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INTRODUCTION

Along the years, managers, economists and engineers have shared a common question: how to maximize the gains from an industry operation. This simple question has stimulated a broad range of research, ranging from the development of mathematical tools and computer algorithms for the solutions of the problem, to applications in specific industries and the analysis of the aggregate implications for the overall economy.

Maximizing the profits is equivalent to choosing optimally production input factors, a problem that has received a lot of attention in the economic literature. This research has lead to remarkable developments in production theory, in industrial organization and in business cycles analysis. At the firm level, starting with the work of Holt et al. (1960), the standard approach has been to fit quadratic cost functions to the production problem in order to obtain linear decision rules for the amount of inputs to use. More recently, in order to get closer to the discrete decisions observed at the micro level, other line of research has considered different types of non quadratic adjustment costs functions and different types of non-linear (i.e. discrete) decision rules as the key to determine optimal operation decisions, as in Rust (1987) and Hall (2000).

At the aggregate level, the neoclassical model of investment and labor demand had also used quadratic adjustment costs functions in order to match the smooth adjustment observed at the aggregate level. Hall and Jorgenson (1967), Abel (1979) and Hamermesh and Pfann (1996) are examples of this approach. Nadiri and Rosen (1969) also uses convex adjustment costs to explain the aggregate interrelation between capital and labor adjustment. These explanations for the investment and labor demand rely on the representative agent paradigm according to which the aggregate economy can be described by a single representative agent and the heterogeneity across agents comes from pure luck, because they receive different shocks in productivity and demand.

The problem with this approach is that recent studies using firm level data such as Caballero et al. (1995), Caballero et al. (1997),Narazani (2004) and Sakellaris (2004) have shown that the representative agent does not act according to the convex cost model. In particular, three key facts about investment and dynamic employment demand emerge from this evidence: first, there are a lot of inaction periods when firms do nothing and some periods when the firms adjust continuously; second, when firms adjust there is a mix of very large and small adjustments; and third, there is an interrelation between capital and labor adjustment, which means significant dynamic correlations and a higher probability of investing when the firm is hiring more workers and viceversa.

Building in part over this empirical evidence and over single-agent decision studies[1], Caballero and Engel (1999), Cooper et al. (1999), Cooper and Haltiwanger (2005) and Cooper et al. (2004), to mention a few, have proposed models which do not rely only on quadratic adjustment costs and are able to generate discrete

[1]Like the Bus replacement problem in Rust (1987)

and non smooth adjustment. They are dynamic in nature and match both the micro evidence and the macro facts. However, these models do not explain the interrelation between employment and capital adjustment since they analyze each factor by separate. Also, they have been subject to criticism because of the lack of direct empirical support for the existence of adjustment costs.

This dissertation addresses directly those two criticisms and continues this line of research exploring firm's behavior with a focus on the real rigidities that firms face when they desire to optimally adjust the combination of production input factors. Specifically, it analyzes from an empirical and theoretical point of view the costs that firms have to pay when adjusting capital and the number or workers, together with the patterns of energy and materials adjustment. The first chapter uses an annual census of manufacturing firms while the second one focuses in a single firm with monthly data on production. The implications of a model that explain their behavior are compared when applied to both cases.

In the first chapter, I analyze the empirical evidence about factor adjustment dynamics using the Colombian Annual Manufacturing Census from 1982 to 1998, and propose a model able to account for the three facts mentioned above and observed in this data set (i.e. mix of smooth and lumpy adjustments, mix of small and large adjustments and interrelation in capital and employment adjustment).

The main feature of this chapter's dynamic model of firms' factor demand decisions is the existence of adjustment costs for capital and employment. The adjustment cost structure captures key features of the data such as reductions in output during adjustment (disruption cost), the costs of installing capital and creating or destroying a job vacancy (fixed costs), a convex cost component introduced to capture the observed mix of smooth and lumpy adjustment, and an extra cost of adjusting capital and labor simultaneously (congestion effects).

The adjustment cost structural parameters of the model are estimated by applying a minimum distance algorithm. The structural methodology allows me to reject statistically the existence of fixed costs and to accept the existence of disruption costs for capital and labor, the convex costs for capital and the existence of congestion effects. The conclusions of the analysis are that (i) there exist significant dynamic interrelations between factor adjustments; (ii) both interaction effects in the adjustment cost parameters and the convex and non convex nature of the adjustment costs appear to be important in explaining firms' mix of smooth and lumpy adjustments on the one hand and small and large adjustments on the other hand, in capital and employment; and (iii)depending on their capital to labor ratio, firms either do not adjust or adjust only capital, only labor or both capital and labor simultaneously.

The second chapter presents direct evidence of the adjustment costs that a glass mould firm has to pay when adjusting capital and employment in response to the arrival of new orders using detailed monthly data on production. At this frequency, it is observed a disruption in the production process due to the installation of small units of capital represented by specific tools with limited life (usually less than one year). This cost is measured in man hours and quantified as an average of 1.6% of the total sales. Hiring a worker also increases the average production time (decreases productivity) by 1.02%

The existence of a powerful union also creates a high cost of adjusting the number of workers through established fees for firing and hiring in addition to the high legal firing costs. These costs are asymmetric and quantified in US$53,000 and US$1,320 dollars respectively. Given the high technology involved in the process, hiring a new worker implies an extra cost of training for the specific process and a cost in the lower productivity this new worker has while learning quantified in US$1,534 dollars. Moreover, the adjustment of one worker increases the disruption cost in the adjustment of capital by 1.17%, the same congestion effect observed in the case of the colombian data.

I describe these adjustment costs and the production process using the model from the previous chapter to understand the effect on the factor adjustment dynamics, comparing the results with the ones in the previous chapter. Overall, the higher frequency of the data and the particularities of the firm help to understand the nature of the adjustment costs observed at the firm level.

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Chapter 1

An Empirical Model of Factor Adjustment Dynamics

1.1 Introduction

It was not until a decade ago, with the availability of new firm-level datasets, that lumpiness and infrequent adjustment in capital and labor[1] could be observed in firms' behavior; this was in stark contrast to the smooth adjustment shown in aggregate data for those factors[2]. At the same time, models attempting to explain the aggregate behavior of these variables had to be revised to account for the microeconomic facts if models with micro foundations were to be useful in terms of policy and predictions at the firm and aggregate levels. However, previous studies of adjustment have tended to analyze one factor at a time, which has made it difficult to understand the joint adjustment of capital and labor at the micro level and its macroeconomic implications.

Looking for a better understanding of firms' factor adjustment behavior, this paper analyzes to what extent it is important to consider joint capital and labor decisions at the firm level from an empirical and theoretical point of view. Specifically,

[1]The term labor is used in this paper to indicate the number of workers which can also be referred to as employment.

[2]In order to clarify terms, lumpiness refers to coexistence of inaction and large adjustments with little in between; this is the opposite of a smooth adjustment that occurs when the adjustment is done in a continuous way. The main distinctive feature between them is the existence of long inaction periods and large adjustments in the case of lumpy adjustments and the non existence of inaction periods in the case of smooth adjustments; note, however, that one could observe large and smooth adjustments at the same time.

it asks whether firms adjust labor independently of capital, if there exist interaction in this adjustment and what the nature of this interrelation is. Although capital and labor movements are the main focus, I also incorporate materials and energy adjustments into the analysis.

The implicit view in the early investment[3] and labor demand literature was that profit-maximizing firms would adjust factor demand constantly in response to shocks in demand and productivity. It was natural to think that way since the aggregate series were smooth, and the literature instead focused on issues such as the role of the cost of capital, the serial correlation in investment and the aggregate dynamics of labor demand. Recent firm-level empirical studies have shown, however, that firms do not adjust as often as they should under convex costs, and when they do adjust, this response comes often simultaneously from adjustment in several margins. Moreover, new emerging evidence, such as that presented in this paper, shows that capital and labor adjustment distributions have fat tails, a mix of small and large adjustments and a mass point around the inaction region, which has been taken as evidence of lumpy adjustment[4]; the recent evidence also shows that their adjustments are interrelated[5].

Subsequent models of investment and labor demand made efforts to incorporate this emerging empirical evidence and specially the lumpy and infrequent

[3]See Hall and Jorgenson (1967), Tobin (1969), Abel (1979) and Hayashi (1982) among others.

[4]Davis and Haltiwanger (1992), Davis et al. (1996), Caballero et al. (1995, 1997) and Cooper and Haltiwanger (2005), have shown the mentioned patterns in the separate analysis of labor and capital adjustment distributions using micro-level data. Rust (1987) shows the lumpy nature of the adjustment for a single agent in the case of machine replacement.

[5]Nadiri and Rosen (1969) using aggregate data and Sakellaris (2004), Eslava et al. (2004) and Narazani (2004), using micro data, find that the adjustment processes for capital and labor are interrelated.

adjustment[6]. An important point they neglect, however, is that firms adjust not just along one but along several margins, particulary for capital and labor. The few studies that consider capital and labor together do so at a very aggregate level, which does not exploit the rich and heterogeneous adjustment observed at the micro level and does not account for the correlation among adjustments[7]. As a consequence, estimated parameters governing the adjustment of capital and labor in response to shocks may be biased[8].

The lack of understanding of factor adjustment at the firm level has important implications. For example, increasing firing costs may affect capital formation. Or a policy aiming to increase investment may not be as effective as expected if labor hiring/firing costs are unaffected or if the elasticity of factor use with respect to its relative price is not properly estimated. Non-convexities arising from adjustment costs, understood as infrequent and lumpy movements, may lead to very different industry responses to public policies aimed at job creation, destruction or investment. There is a need to estimate those responses in a consistent and realistic way, not

[6]These facts were incorporated in the early theoretical literature as models of infrequent adjustment, while later models also attempted to reproduce the lumpiness in such adjustments. See for example Dixit and Pindyck (1994), Abel and Eberly (1994, 1998) in the case of investment and Hamermesh (1989), Hamermesh and Pfann (1996) in the case of labor. More recent work includes Cooper and Haltiwanger (2005) and Cooper et al. (2004), who consider also the small and smooth adjustments present in such distributions in conjunction with episodes of large and infrequent adjustments.

[7]At the macro level, see Shapiro (1986), Hall (2004) for analysis of capital and labor adjustment assuming convex costs . Caballero et al. (1995, 1997), Cooper and Haltiwanger (2005), Cooper et al. (2004) analyze capital and labor adjustment in a separate way. Rust (1987) analyzes investment for a single firm. Abel and Eberly (1998) model capital and labor adjustment but do not take into account the interactions between them. Rendon (2005) features a model with a simpler adjustment cost structure, to answer if liquidity constraints restrict job creation.

[8]The biases arise because the models analyze the response of either capital or labor to shocks, incorporating all the other factor decisions into the shocks. For example, movements in one factor, such as, capital would affect the shock in a labor adjustment model, and the real response of labor to shocks would be overstated.

only for the sake of predicting the effects of public policies, but also because the behavior of aggregate investment and job creation and destruction is directly affected by the microeconomic response of firms to shocks in demand and technology.

In exploring these issues, this paper uses firm level data from the Colombian Annual Manufacturing Census, covering the period 1982 to 1998. This is a unique data set because it contains firm level data on the value of production, energy and materials, prices for each product and each material used, the number of workers and payroll and book values of equipment and structures. The existence of firm level prices opens a wide range of empirical possibilities[9]; in this paper they are useful because they allow the precise identification of technology and demand shocks and of input factor elasticities and considerably reduce the measurement error in factor demand due to confusion between prices and quantities[10].

In line with recent studies, the empirical analysis reveals the mix of small and large adjustments in the capital and labor adjustment distributions, which also present fat tails and large inaction periods; the analysis also uncovers their interrelated nature. In addition to these studies, the analysis reveals the adjustment patterns in energy and materials and their relation to capital and labor adjustment. The picture that emerges is that in response to shocks, firms adjust capital and labor in a non-trivial, interrelated way. Firms also adjust energy and materials when they

[9] With the existence of firm level prices for the whole Census of manufacturing firms, issues that before could not be clearly analyzed because of identification problems or simply because of lack of data, can be analyzed better. Among them we could mention the comprehensive analysis of price stickiness or the effects of technology shocks in the business cycle.

[10] Note that while other studies, dealing with different issues, have used a similar Colombian dataset, all but Eslava et al. (2004) and Eslava et al. (2005) use a shorter period (up to 1991) and they do not have price information. I follow Eslava et al. (2004) in the Total Factor Productivity (TFP) and demand shocks estimation.

are hit by demand and technology shocks. This is not surprising if we think that firms face a profit maximization problem over all inputs. What is interesting is the observed dynamics of the adjustment.

The data analysis motivates the main contribution of this paper, which is to propose, analyze and estimate a theoretical model of firm behavior that combines a labor decision problem with a machine replacement problem along with a rich specification of adjustment costs. None of the previous models in the literature have been able to explain the interrelation between capital and labor adjustment, in part because the existence of this type of empirical evidence is very recent and not complete for all the production factors, and in part because of the difficulty in the analysis and estimation of such a model (analytically or numerically).

The proposed adjustment cost structure captures key features of the data such as reductions in output during adjustment (disruption costs), the cost of installing capital and creating or destroying a job vacancy (fixed costs) and a convex cost component introduced to capture the observed mix of smooth and lumpy adjustment[11].

One of the key features in the model is the presence of interaction effects in the adjustment of capital and labor. Interaction effects are precisely defined as the

[11] An important point not addressed here relates to the current debate about the production factors' response to technology shocks. Besides the serious identification issues faced in the literature trying to estimate technology shocks (where IV methods or other identifying assumptions attempt to differentiate technology shocks from other shocks given the lack of rich enough firm level data and especially of firm level prices), previous work has not considered the possibility that, while adjusting, firms decrease production (as it is shown later in this paper), suggesting the presence of an adjustment cost in productivity shock estimates that may lead to misleading conclusions about the effects of pure technology shocks on factor adjustment. This is an important insight that may be worth exploring in future work. See for example Shea (1998), Gali (1999), Basu et al. (2004), Christiano et al. (2003), and Alexopoulus (2004). I thank Martin Eichenbaum for highlighting this point.

extra cost or benefit[12] of jointly adjusting capital and labor. If the interaction effect is a cost I call it congestion effect, and if it is a benefit I call it complementarity effect. For example, the interaction effect may be present as congestion if firms have to train new workers to operate new machines, incurring in this way in an extra cost; or in the opposite way, the interaction may be present in the form of a complementarity effect, for example, if the incorporation of a new process in a production plant requires a new physical space for the machines or the workers, and this space can be shared by them; another example of the congestion effect would be if disruption in the production process occurs while incorporating new workers and machines simultaneously, incurring production losses that may be greater or less than if hiring new workers or making new investments independently.

Once the key parameters such as factor elasticities, productivity shocks and demand shocks are estimated, the theoretical model is compared with the data in two ways. First, the adjustment cost parameters from the model are arbitrarily chosen in order to give an example of the implications for firm behavior. In a second stage, these adjustment cost parameters are estimated with a minimum distance algorithm in order to match key moments that comprehensively describe firms' adjustment patterns in capital and employment. The decision rules and the time series implications that emerge from the model are also analyzed. This part of the paper is the core analytical contribution because it gives an idea of how labor and capital adjustments are potentially interrelated and how they interact (or not) at the firm

[12] It is important to note that the model does not restrict this effect to be a cost but it also can be a benefit. It is the empirical analysis which determines it as a cost.

level, depending on the capital to labor ratio a particular firm has.

The model is indeed a good representation of firm behavior: it is able to reproduce the mix of smooth and lumpy adjustments in the one hand, and the mix of large and small adjustments in the other hand observed empirically for capital and labor. Moreover, the dynamic relationships observed in the data are also reproduced. The model that best fits the data includes the interaction term in the adjustment costs for capital and labor and it is present as a congestion effect, which suggests that investment influences hiring decisions in an important way (and viceversa) because the extra cost that this joint decision implies. The congestion effects are key, especially to match the contemporaneous correlation between capital and labor adjustment. It turns out that, according to the model, the type of real rigidity (represented by the type of adjustment cost the firms face) is as important as the interaction between capital and labor adjustment, which appears as an extra cost (congestion effect). The structural methodology allows me to reject statistically the existence of fixed costs and to accept the existence of disruption costs for capital and labor, the existence of convex costs for capital but not for labor and the existence of congestion effects. Finally, the benchmark model of convex costs, widely used in the macroeconomic literature, is not able to explain by itself the type of behavior observed in firm investment and dynamic employment demand decisions.

The paper proceeds as follows. Section 2 presents the empirical evidence, which is descriptive and with minimal structure imposed on the data. Section 3 presents the model used to explain the empirical patterns and discusses the adjustment cost assumptions. Section 4 discusses some important numerical issues dealing with the model and analyzes the decision rules that emerge from an illustrative parameterization of the model. Section 5 recovers the parameters governing the joint adjustment of capital and labor from the model and carries on some experiments in order to give an idea of the goodness of fit in the estimated parameters. Section 6 concludes and gives directions for further research.

1.2 Factor Adjustment: An Exploration of the Facts from the Microdata

The first task is to analyze empirically whether capital and labor adjustments are interrelated. Because the variables of interest are adjustments, I look at the gross investment rate and at the growth in demand for labor, energy and materials. I start by showing the distribution of factor adjustments, then presenting basic correlations among them. Given the low (but statistically different from zero) correlation among factor adjustments, I analyze the behavior of the variables during large adjustment and inaction episodes.[13] I use again basic correlations of the incidence of adjustment, also analyzing the conditional probability of inaction or adjustment.[14] I also run a VAR(1) for factor adjustments to get a sense of the magnitude of the dynamic interactions between factor adjustments at the firm level for the whole range inputs. Finally, I explore if different types of firms exhibit different patterns in the capital and labor adjustments. Specifically, I divide Census of Manufacturing firms in high and low capital intensive firms. The analysis reveals that the adjustment

[13]The criteria used to define inaction and large episodes is discussed later in the paper.

[14]To give continuity to the argument in the main text, I present in the appendix an additional analysis of the interrelations between labor and capital during periods of large adjustments. In particular, I use a variation of the methodology of Sakellaris (2004) and Letterie et al. (2004) to analyze the interrelated adjustment between capital, labor, energy and materials.

distributions present very similar patterns across firms and the contemporaneous correlations keep the significance and low variation in all types of firms; the dynamics of adjustments, however, is heterogenous depending on the firms characteristics, at least in the dimension considered here. Even if this analysis is beyond the scope of the present paper, it suggests that it is worth to explore more the differences by sector in capital and employment adjustments.

These empirical exercises are built around the issue of interest, which is the interrelation in capital and employment adjustment. The distributions show a mix of small and large adjustments of capital and labor with large inaction periods at the firm level; this has been interpreted in the literature as lumpy adjustment, but it misses the point that infrequent adjustment periods can be followed by smooth and small adjustment periods. In the case of materials and energy, the adjustment is more continuous, but they show also a mix of small and large adjustments; in this sense, their adjustment can not be called lumpy as the capital and labor adjustment; these distributions also show differences in the frequency of adjustment across factors. This micro evidence is in contrast to the smooth aggregate series that have been extensively analyzed in the literature. The contemporaneous correlations, and the analysis of the episodes of large adjustments and inaction, show that these adjustments indeed have a statistically significant degree of interrelation.[15] The VAR(1) aims to show that the dynamic interrelation between factor adjustment holds during all episodes of adjustment, not just spikes, which are important and

[15] The analysis of these episodes, found in the appendix, reinforces the view that adjustments are interrelated, that there is a mix of small and large adjustments and a mix of smooth and lumpy factor adjustments, and that there exists evidence of adjustment costs based on the observation of the decrease in productivity and output after the adjustment, especially in the case of capital.

also statistically significant.

While the main focus of this paper is the adjustment of capital and labor, I also consider energy and materials adjustment in order to motivate the assumption below that these factors are adjusted at no cost. The distributions of adjustment presented later on justify this claim, as will become clear.

This section is in the same spirit as other recent work showing evidence on the interrelation between capital and labor adjustment using micro data. Narazani (2004) focuses on a small subset of large Italian firms to study capital and labor adjustment. Sakellaris (2004) shows evidence on the interrelation in factor adjustment in episodes of considerable adjustment in capital and labor. Letterie et al. (2004) analyze this adjustment for Denmark firms and Polder and Verick (2004) compare the adjustment dynamics in Denmark and Germany. Eslava et al. (2004) use the same dataset used in this paper and employ Caballero, Engel and Haltiwanger's (1995, 1997) methodology to analyze the nonlinear interrelation between capital and labor adjustment. None of these studies, however, contain the structural approach and comprehensive analysis that this paper presents.

One of the most important points to note is that the analysis is carried over the whole Census of manufacturing firms, and not just for a subset as most previous studies have done. It is also important to note the high quality of the capital measure, something not common in this type of panel, and the fact that the existence of prices at the firm level reduces measurement error in factor adjustment, a unique characteristic of this dataset. This initial exploration of the facts is the basis for the factor adjustment model presented later.

1.2.1 Data

The data come from the Colombian Annual Manufacturing Census (AMS) during the period 1982 -1998. The AMS is an annual unbalanced panel of around 13,000 firms per year containing firms with more than 10 employees or sales above a certain limit. It contains the values of production, materials and energy consumption; physical quantities of energy; prices for each product and material used; production and non-production workers and payroll; and book values of equipment and structures. I use the panel of pairwise continuing firms constructed by Eslava et al. (2004), which accounts for a total of 2,167 firms in the period 1982-1998. I choose to work with a balanced panel because I do not analyze the effects of firm entry or exit. In this section I describe how the variables were constructed. For more information about the construction of the variables, see Eslava et al. (2004).

Price level indices are constructed for output and materials using Tornqvist indices. Tornqvist indices are the weighted average of the growth in prices for all individual products (or materials) generated (used) by the plant. The weights are the average of the shares in the total value of production (or materials used). More formally, the index for each plant j producing outputs (or using materials) h in year t is:

$$\ln P_{jt} = \ln P_{jt-1} + \Delta P_{jt}$$

with $P_{j1982} = 100$ as the base year, $\Delta P_{jt} = \sum_{h=1}^{H} \bar{s}_{hjt} \Delta ln(P_{hjt})$ representing the weighted average of growth in prices for all products h, and $\bar{s}_{hjt} = \frac{s_{hjt}+s_{hjt-1}}{2}$ as the simple average of the share of product (material) h in plant j's total value of production (materials usage).

Quantities of materials and output are constructed by dividing the reported value by the prices. Energy quantities and number of workers are reported by the plants. Investment represents gross investment and is generated from the information on fixed assets reported by the plants. More specifically, gross investment is calculated recursively with the formula

$$I_{jt} = K_{jt}^{NF} - K_{jt}^{NI} + d_{jt} - \pi_{jt}^{A}$$

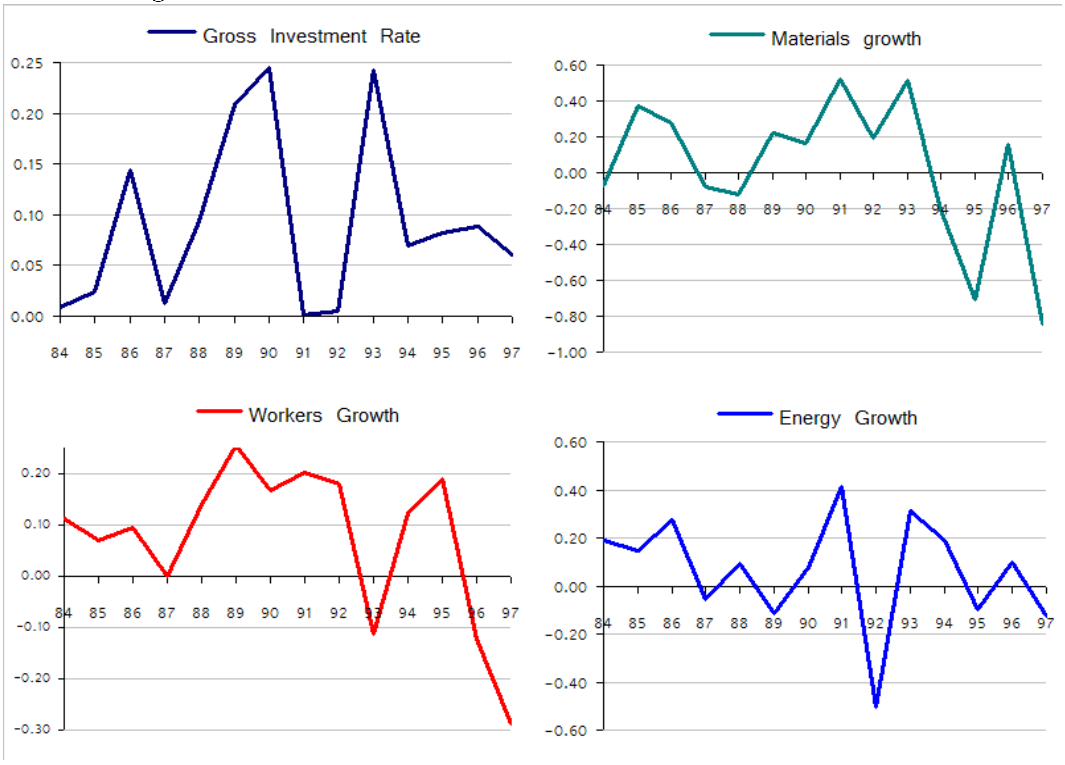
where $K_{jt}^{NF} - K_{jt}^{NI}$ is the difference in the value of the fixed assets reported by plant j at the end and beginning of year t and $d_{jt} - \pi_{jt}^{A}$ is the depreciation minus the inflation adjustment reported by plant j at the end of year t. In the rest of the paper, all the variables are in logs unless indicated. The reported growth is the log difference, and the observations are considered outliers if they are greater than 10 (adjustment of 1000%) or lower than -1 (adjustment of -100%).

1.2.2 Basics About Factor Adjustment: Distributions and Correlations

Distributions of Factor Adjustments

Before showing the complete distributions of factor adjustment for the whole Census of Colombian Firms during the period from 1982 to 1998, it is useful to introduce the behavior of one particular firm during this period. The selected firm is from the food sector and satisfies no particular criteria other than illustrating of how

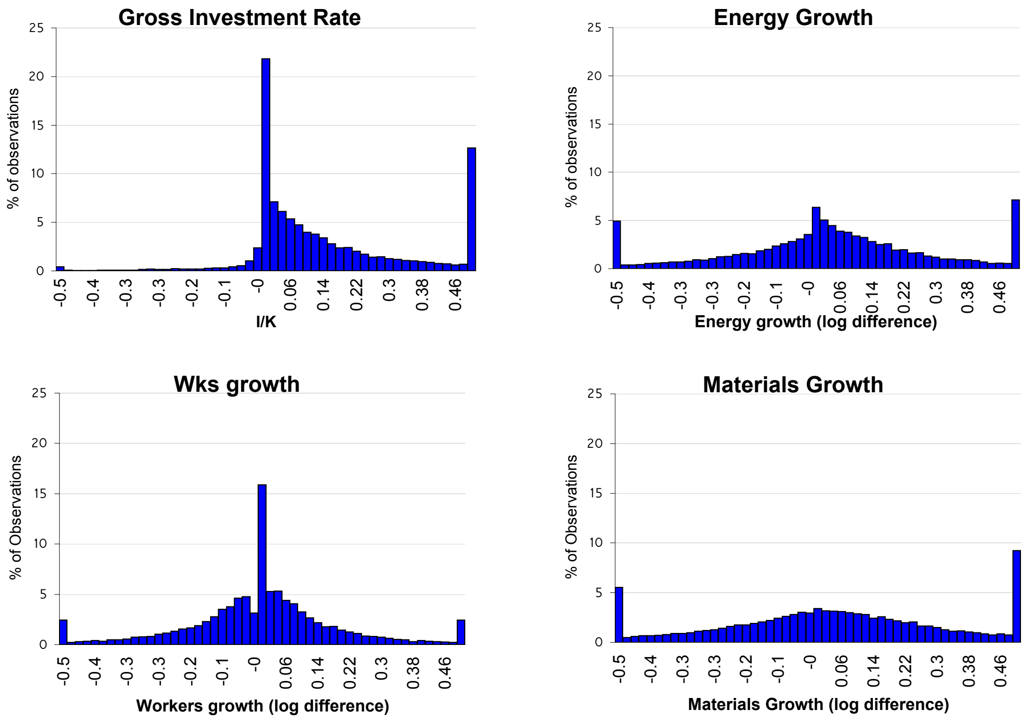
Figure 1.1: Factor Adjustment for a Particular Firm from the Colombian Census of Manufacturing Firms.



individual firms adjust input factors . Figure 1.1 shows the time series behavior for this firm in the case of capital, employment, energy and materials adjustments. This figure illustrate the basic patterns observed in the panel. In particular, for this firm there is no negative investment; there exist some periods of inaction in capital and labor; the firm continuously adjusts energy and materials; and there are periods of large adjustment in all the factors mixed with periods of small adjustment.

Figure 1.2 shows the distribution of factor adjustments for all plants in my sample. The factors are capital, employment (number of workers), energy and materials. Table 1.1 summarizes figure 1.2. In Table 1.1, the inaction zone is defined as an adjustment lower than 1% in absolute value, while the spikes are defined as

Figure 1.2: Distributions of Factor Adjustment. Percentage of observations (y-axis) in a range of adjustment (x-axis)



adjustments above 20% in either direction.[16] An observation is defined as the adjustment of firm j in year t. I will analyze these distributions in terms of the frequency, symmetry and size of the adjustments.

With respect to the size of adjustments, there is no standard definition for large or small adjustments, but a visual inspection of the capital and labor adjustment distributions shows a combination of small and large values with a mass point

[16]The inaction and spike zones are defined with this arbitrary criteria to give a sense of "small" and "large" adjustment and to be consistent with previous literature on factor adjustment.

around the inaction region(i.e. zero adjustment). The existence of these mass points around zero adjustment and the fat tails of the distributions can be interpreted as lumpy adjustment; for example, in table 1.1, the lumpy pattern can be observed in the proportion of the adjustments above 20%, considering this number as a large adjustment indicator, compared to the proportion of the adjustments lower than 1% in absolute value, considering this as the inaction region; in the other hand, the smooth adjustment can be observed in the proportion of adjustments below 20% and above the inaction region. The materials and energy adjustment distributions fail to be considered lumpy under this criteria since the percentage of observations in the inaction region is not very high; what these distributions show is more a continuous adjustment with jumps in the size of the adjustments.

Perhaps a more standard measure of how many extreme observations are observed in a distribution is the excess kurtosis. In the case of input factor adjustments, all distributions have large excess kurtosis, indicating that many observations are far away from the mean.[17] Specifically, excluding outliers greater than 10 in each distribution (which is an adjustment of 1000%) the excess kurtosis measures are 59, 35, 11 and 92 for capital, employment, materials and energy adjustment respectively. Excluding the outliers greater than 2 (adjustment of 200%) the excess kurtosis measures remain large and equal to 7.65, 7.96, 2.2 and 3.85, respectively. These numbers indicate fat tails in the distributions of adjustment and a clear lumpy adjustment pattern for capital and labor because of the existence of a mass point around the

[17]The normal distribution has an excess kurtosis of zero. The fatter the tails of a distribution, the bigger the excess kurtosis.

Table 1.1: Distribution of factor adjustment(%)

	$\frac{I}{K}$	$\frac{\Delta L}{L}$	$\frac{\Delta m}{m}$	$\frac{\Delta e}{e}$
Inaction ($abs(y) < 1\%$)	18.9	13.4	3.2	5.6
Positive Spike ($y > 20\%$)	29.8	11.6	28.4	23.7
Negative Spike ($y < 20\%$)	1.8	11.1	18.8	15.8
$\rho(y, y_{-1})$	0.025	-0.057	0.0	-0.298
Number of Obs	24467	34243	31977	34597

inaction region; in the case of materials and energy, as it was said before, it indicates the existence of large adjustments but not of a lumpy pattern since there is no mass point around the inaction region.

With respect to the symmetry of the adjustments, figure 1.1 suggests that the investment distribution is very asymmetric: there is very little negative investment. This suggests irreversibility of capital in Colombia. The labor adjustment distribution is much more symmetric. Putting together those two distributions, we can conclude that it is easy for firms to adjust employment negatively but not capital, perhaps because of differences in the adjustment costs involved for each input factor (the selling price of capital is lower than the buying price) due in turn to the physical nature of the factors reflecting the irreversibility of capital. Materials and energy distributions are also symmetric, though not as much so as the employment adjustment distribution.

With respect to the frequency of adjustments, we observe that firms often leave capital and employment essentially fixed, but adjust materials and energy more frequently. This is the justification for the assumption later in the model that materials and energy are not subject to adjustment costs. Firms adjust them in an almost continuous fashion. The evidence for Colombia is in line with the evidence for the U.S. using the LRD (Longitudinal Research Database), where lumpiness in capital and employment is also present together with significant periods of smooth adjustment. This evidence alone suggests the presence of adjustment costs and, as many others have pointed out, may indicate (S,s) behavior in capital and employment adjustment.

Summarizing the information observed in the distributions, we can conclude that: (i) the distributions of input factor adjustment have fat tails; (ii) the investment distribution is asymmetric, showing a large degree of irreversibility, while the labor adjustment distribution is highly symmetric; (iii) Capital and employment adjustments are infrequent (large mass point around zero adjustment) but materials and labor adjustment are much more frequent (no mass points around zero). Points (i) and (iii) signal the existence of lumpiness in the adjustment of capital and labor due to non-convex costs in capital and labor adjustment; and (iv) small and large values coexist in the distributions of adjustment for all the factors.

Correlations of Factor Adjustments

Table 1.2 shows the contemporaneous correlations among factor adjustments[18]The highest correlation coefficients are for employment and materials growth, followed by the correlations between materials and energy growth and employment and energy growth. The correlation between the investment rate and employment growth

[18]The correlations are calculated regressing adjustment on time dummies to take out business cycle effects, and I consider only the residuals which reflect firm-level shocks. Another interesting possibility would be to consider the business cycle effects as well, but this is left for future work.

Table 1.2: Factor adjustment contemporaneous correlation

	$\frac{I}{K}$	$\frac{\Delta L}{L}$	$\frac{\Delta m}{m}$	$\frac{\Delta e}{e}$
$\frac{I}{K}$	1			
$\frac{\Delta L}{L}$	0.057	1		
$\frac{\Delta m}{m}$	0.026	0.175	1	
$\frac{\Delta e}{e}$	0.041	0.107	0.147	1

All correlations are statistically different from zero at 1% significance

is small but nonzero. All the correlations are statistically different from zero. Moreover, even if the correlation coefficient for capital and employment growth hides a considerable amount of sectoral heterogeneity, many sectors[19] share a similar coefficient, which is near the one reported in Table 1.2.

The contemporaneous correlations give a sense that capital and employment adjustment periods are interrelated. However, given the low correlation between capital and employment, it is worth analyzing the correlation of adjustment during inaction periods, during spike episodes and during a combination of both.[20] The questions here are whether inaction or spikes in employment are correlated with inaction or spikes in capital, and whether inaction or spikes in one factor increase the probability that firms adjust the other factor. Equivalently, we could ask if firms stagger capital and labor adjustments. If firms stagger, we would observe a negative correlation between the incidence of adjustments in investment and employment and an increase in the probability of adjustment conditional on inaction in the

[19]The sectors present in the data are Food, Drinks and Beverages, Tobacco, Textiles, Wood, Paper, Chemicals and Rubber, Oil, Glass and Non-metallic, Metals and Metal products, Machinery and others. Of these, just the Oil sector, the Drinks and Beverages sector and the Tobacco sector have a negative correlation coefficient.

[20]The inaction and spike episodes are defined as above: less than 1% in absolute value for inaction and more than 20% in absolute value for the spikes.

Table 1.3: Correlations among incidence of episodes (dummies for inaction/spikes)

	Dummies for:	Investment Rate: $\frac{I}{K}$ Inaction	Spike	Pos Spike	Employment Growth: $\frac{\Delta e}{e}$ Inaction	Spike	Pos spike
$\frac{I}{K}$	Inaction	1					
	Spikes	-0.335*	1				
	Pos. Spike	-0.241*	0.719*	1			
$\frac{\Delta e}{e}$	Inaction	0.081*	-0.035*	-0.030*	1		
	Spike	0.006	0.030*	0.006	-0.229*	1	
	Pos spike	-0.041*	0.055*	0.024*	-0.231*	0.361*	1
	Neg spike	0.040*	0.01	0.026*	-0.216*	0.364*	-0.325*

The correlations are among 0/1 dummies during large adjustment episodes
*: statistically different form zero at 1% of significance. Dummies for inaction are defined as 1 if $abs(x) < 0.01$ and dummies for spikes are defined as 1 if $x > 0.2$

other factor.

To further explore these issues, and to characterize firms' adjustments during inaction and spike episodes, the rest of the subsection explores the correlation between the incidence of zeros and spikes in capital and employment and the probabilities of inaction/spike in one factor conditional on inaction/spike in the other factor.[21]

Even though the definition of inaction and spikes given above may be somewhat arbitrary and may be capturing adjustments that are not small or large for certain types of capital,[22] it is useful to characterize the behavior of capital and employment around "small" and "large" episodes of adjustment. Table 1.3 shows the correlation of the incidence of inaction and spikes in investment and employment adjustment.

[21]The appendix has a more extensive analysis of the behavior of several variables around inactions and spikes in capital and employment adjustment.

[22]For example, many firms need small tools important for production which signal a positive investment but lower than 1% of their capital stock.

After a closer look at table 1.3, several facts emerge[23].First, the correlation between investment and employment adjustment is positive and higher during inaction times than during spike times for both factors. Moreover, the only statistically significant correlation during spikes in employment is with spikes in investment, due to positive employment spikes and not negative ones. Also, the negative correlation between the incidence of positive spikes in employment and inaction in capital suggests that after a positive spike in employment, there is inaction in capital. All this would suggest that during some periods, firms increase capital and employment in large amounts at the same time, and have inaction periods for the two factors after the adjustment.

There is also a positive correlation between negative spikes in employment and both inaction and positive spikes in investment. This suggests that sometimes firms substitute one factor for another (increasing capital and decreasing employment) and at other times firms choose to adjust only employment down given the high irreversibility of capital. Table 1.3 suggests that capital and labor tend to move together during inaction and spike episodes.

Table 1.4 shows the results of estimating four different logit models, each one for investment and employment and inaction and spikes respectively, where the dependent variable is the probability of adjustment or inaction in one factor and the independent variables include the adjustment and inaction[24]status in the other

[23]Two clarifying points: first, observe that the correlation between Inaction and spikes episodes is not -1 because these episodes are not consecutive and instead there exist adjustments larger than 1% and smaller than 20% in between; second, the "spikes" are different from "positive spikes" in the sense that they include negative spikes.

[24]both dummies are included at the same time

factor. The logit estimation includes controls for firm-specific variables such as Total Factor Productivity (TFP) and demand shocks[25] and the adjustment of energy and materials. It is important to control for the shocks in this context since they lessen the chances that the comovement between employment and investment is merely due to an omitted third factor. Moreover, controlling for the TFP and demand shocks identify the movements in employment and capital as dependent not only from shocks but from other sources, in this case interpreted later as adjustment costs.

From table 1.4, it can be observed that the probability of inaction in investment increases if there is inaction in employment. The same is true in the case of employment, but the effect is not statistically significant. At the same time, the probability of an investment spike increases if there is an employment spike, and the probability of an employment spike increases when there is an investment spike. These numbers confirm the conclusions drawn from table 1.3: capital and labor tend to move together. The probability of inaction in employment decreases when there is an investment spike. The other effects are not statistically significant. All these numbers suggest that, on the one hand, when there is a large adjustment in either capital or employment, it is more likely that firms are having large adjustments in both factors; on the other hand, when firms do not adjust employment, it is more likely that they do not adjust capital, but when firms do not adjust capital, it does not mean necessarily that they do not adjust labor.

As further evidence of the interrelation of capital and labor adjustment, other

[25]The estimation of these shocks is explained later in the paper in the calibration section.

Table 1.4: Probability of inaction/adjustment conditional on Inaction/adjustment of the other factor

Variable x		Investment P(inaction/x)	Investment P(Spike/x)	Employment growth P(inaction/x)	Employment growth P(Spike/x)
Investment	Inaction			0.057 (0.071)	0.012 (0.061)
	Spike			-0.11† (-0.06)	0.205** (0.048)
Employment Growth	Inaction	0.143* (0.067)	-0.033 (-0.058)		
	Spike	-0.033 (-0.059)	0.208** (0.046)		
Observations		12864	17055	12410	14459

†/*/** significant at 10%, 5% and 1%. TFP, demand shocks and year effects in regression Dummies for inaction are defined as 1 if $abs(x) < 0.01$ and dummies for spikes are defined as 1 if $x > 0.2$

interesting results on the dynamic behavior of the input factors around episodes of spikes and inaction in capital and labor are reported in the appendix. In particular, there is evidence that TFP and output fall after periods of adjustment, especially in the case of capital, suggesting a cost in terms of foregone profits.

The analysis in tables 1.3 and 1.4 examines the case of large changes in capital and labor. A natural question that follows is whether this analysis extends to all adjustments in a dynamic context. I discuss the basic empirical approach for this problem next.

1.2.3 Factor Adjustment Interrelation: Dynamic Dependence

In this subsection, I present the coefficients of a simple VAR with one lag, intended to describe how firms' factor adjustments are dynamically interrelated.

The VAR variables of interest are gross investment and growth in employment, energy and materials. The coefficients and their statistical significance are quite robust to several controls. The reported VAR is estimated controlling for shocks in demand and productivity[26] and for year effects. Table 1.5 shows the results for this estimation procedure.

Table 1.5: Dynamic relations in factor adjustment

	$\frac{I}{K}$	$\Delta L/L$	$\Delta m/m$	$\Delta e/e$
$(\frac{I}{K})_{-1}$	-0.008 0.006	-0.008 (0.003)**	0.023 (0.004)**	-0.038 (0.006)**
$(\frac{\Delta L}{L})_{-1}$	0.037 (0.017)*	-0.147 (0.007)**	0.049 (0.012)**	0.091 (0.017)**
$(\frac{\Delta m}{m})_{-1}$	-0.007 0.01	0.024 (0.004)**	-0.247 (0.007)**	0.036 (0.010)**
$(\frac{\Delta e}{e})_{-1}$	0.013 -0.007	0.009 (0.003)**	0.006 (0.005)*	-0.345 (0.007)**
Observations	17653	17653	17653	17653
R-squared	0.03	0.07	0.26	0.23

Standard errors in parentheses; **/* significant at 1% and 5%;
year effects and shocks in regression

Table 1.5 shows that an increase in labor demand signals a posterior investment episode (the coefficient of the effect of lagged labor growth on investment is positive and statistically significant). Moreover, the coefficient of lagged investment in the labor equation is negative and significant. F-tests for the cross coefficients of labor and capital in this VAR with 4 variables and in a simpler version with just capital and employment were run to verify Granger causality. Both coefficients are different from zero, which does not give much more information since it is not conclusive about which one causes the other.

[26] Later in the paper I explain how these shocks are estimated using the price information

It is important to note that the other factors exhibit large coefficients and small standard errors, indicating that the firms use several margins of adjustment in capital, labor, materials and energy. Moreover, the diagonal elements (the autocorrelation) for all factors are negative, suggesting that if firms adjust in one period it is very likely that either they will not do so the next period or that they will adjust in the opposite direction. The negative autocorrelation in the VAR is a reflection of the patterns from the distribution of adjustments. Capital is the factor with smaller negative autocorrelation in adjustment, which may signal inaction in the following periods since the distributions show a mass around zero and the negative coefficient signals inaction or adjustment in the opposite direction, as mentioned above. Materials and energy are the factors with higher negative autocorrelation in adjustment, which may signal instead free adjustment in the opposite direction the following period.

An interesting point with respect to the autocorrelation coefficient in the investment rate is that it changes sign when controlling for individual firm characteristics through fixed effects (being positive when fixed effects are not present, showing a similar coefficient to that of the simple contemporaneous correlations). This suggests that unobservable characteristics are important and that the simple autocorrelation observed before in table 1.2 may be a result of aggregation effects more than firm-level effects[27].

[27] Exploring this issue even further, this autocorrelation coefficient for the investment rate maintains a consistently positive sign in 2 sectors (Wood and Paper), and maintains the negative sign in the Chemicals sector for both cases. Moreover, the size of the coefficient and the statistical significance is important in 8 out of 12 sectors when controlling for fixed effects, and it is statistically significant in just 2 sectors when fixed effects are not present, the two with a consistently positive sign.

1.2.4 The Role of Heterogeneity

One question that emerges after the empirical exercises above is if the same adjustment patterns repeat for all types of firms. In particular, this subsection asks if the interrelation between capital and labor adjustment, if the fat tails and the mix of small and large adjustments present in the distributions of adjustments, and if the dynamic correlations among adjustments, are present for all types firms. The characteristic chosen to answer this question is the capital intensity a firm has, dividing the data in high and low capital intensive firms. The following empirical exercises take the high capital intensive firms as the ones in the upper quartile of the capital to labor ratio; the low capital intensive firms are in the lower quartile in that ratio.

Figure 1.3 shows the distributions of adjustments for capital, labor, energy and materials in the case of low and high intensive capital firms. Even if the patterns are the same in both groups, the main difference is present in the investment rate distributions, since low capital intensive firms adjust in a more lumpy way: the percentage of observations with zero adjustment in capital is more than 30%, while in the case of the high capital intensive firms is 15%; in the other hand, the percentage of observations with an investment rate of 50% or more is 15% for the low capital intensive firms, while it is less than 10% in the case of high capital intensive firms. In the case of labor, materials and energy adjustment, they are very similar. Based on these distributions of adjustments, we can conclude that there is not much heterogeneity and that the patterns of interest observed in the previous sections are

Table 1.6: Factor adjustment contemporaneous correlation: Low Capital Intensive Firms (Lower quartile in $\frac{K}{L}$ ratio)

	$\frac{I}{K}$	$\frac{\Delta L}{L}$	$\frac{\Delta m}{m}$	$\frac{\Delta e}{e}$
$\frac{I}{K}$	1			
$\frac{\Delta L}{L}$	0.063*	1		
$\frac{\Delta m}{m}$	0.031	0.170*	1	
$\frac{\Delta e}{e}$	0.019	0.078*	0.093*	1

*significant at 1%

Table 1.7: Factor adjustment contemporaneous correlation: High Capital Intensive Firms (Upper quartile in $\frac{K}{L}$ ratio)

	$\frac{I}{K}$	$\frac{\Delta L}{L}$	$\frac{\Delta m}{m}$	$\frac{\Delta e}{e}$
$\frac{I}{K}$	1			
$\frac{\Delta L}{L}$	0.039	1		
$\frac{\Delta m}{m}$	0.032	0.143	1	
$\frac{\Delta e}{e}$	0.079	0.103	0.139	1

All correlations are statistically different from zero at 1% significance

very similar across firms, suggesting adjustment costs in capital and labor adjustment for all types of firms, perhaps with a higher influence of non-convexities(i.e. disruption and fixed costs in the sense explained later as opposite to convex costs) in the case of firms with a low capital to labor ratio.

Tables 1.6 and 1.7 show the contemporaneous correlations among factors for low and high capital intensive firms respectively. The most important point these tables show is that the correlation in capital and labor adjustment is statistically significant for both groups and not very different; in this case, we also observe that both groups are not very different and that heterogeneity is not very important.

This heterogeneity in the contemporaneous correlations is more important

Figure 1.3: Distribution of Factor Adjustment in High and Low Capital Intensive Firms. % of observations (y-axis) in a range of adjustment (x-axis) .

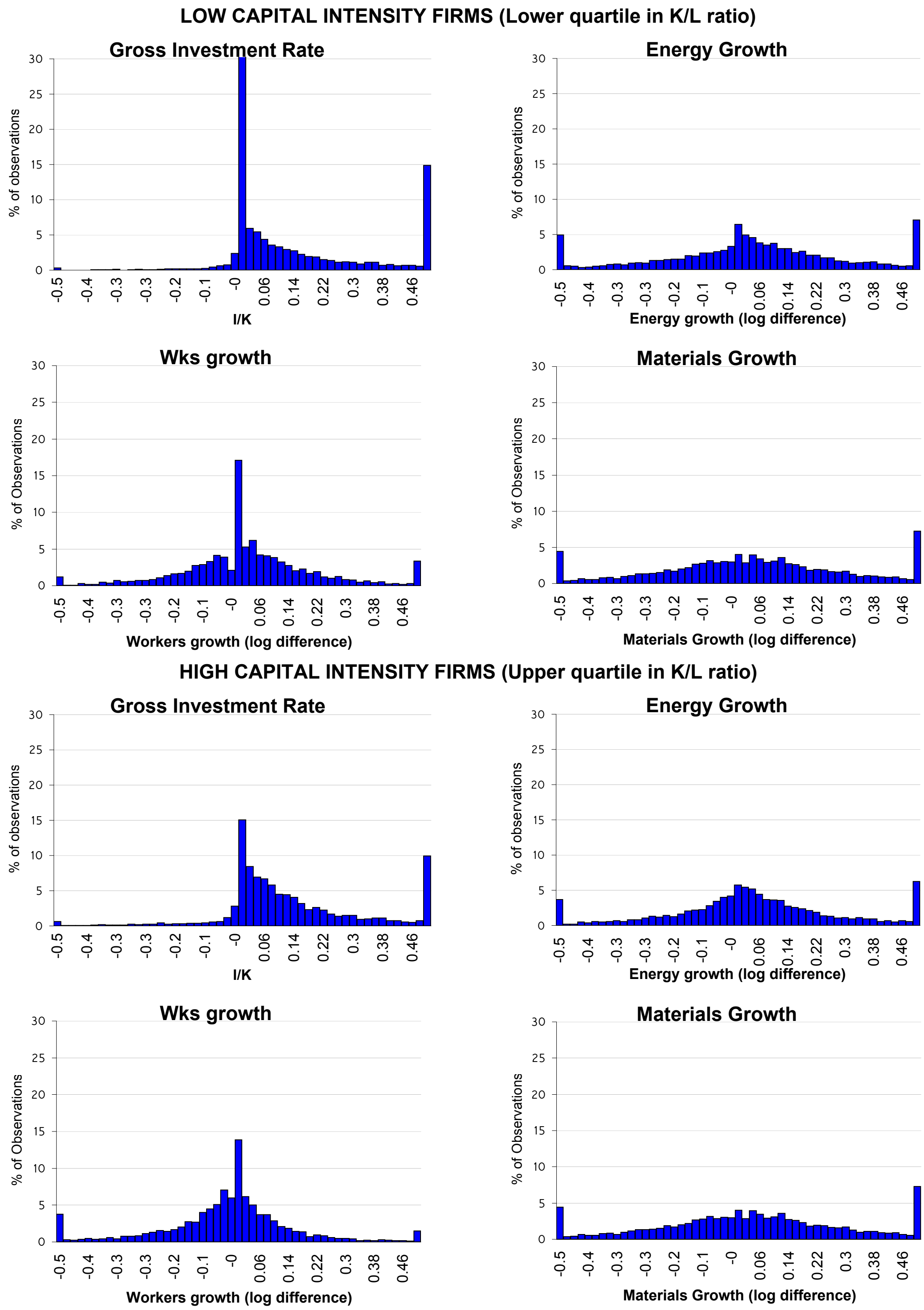


Table 1.8: Probability of inaction/adjustment conditional on Inaction/adjustment of the other factor: Low Capital Intensive Firms

Variable x		Investment		Employment growth	
		P(inaction/x)	P(Spike/x)	P(inaction/x)	P(Spike/x)
Investment	Inaction			0.35	-0.08
				(0.13)**	(0.11)
	Spike			0.17	0.06
				(0.13)	(0.10)
Employment Growth	Inaction	0.41	-0.06		
		(0.13)**	(0.13)		
	Spike	-0.06	0.16		
		(0.11)	(0.10)		
Observations		3269	3839	2800	3372

†/*/** significant at 10%, 5% and 1%. TFP, demand shocks and year effects in regression
Dummies for inaction are defined as 1 if $abs(x) < 0.01$ and dummies for spikes are defined as 1 if $x > 0.2$

when considering the probability of adjustment given inaction/adjustment in the other factor. Table 1.8 and 1.9 illustrate this point. None of the coefficients estimated for the high capital intensive firms is statistically significant and many signs are different to the estimated considering all types of firms; for example, for the high capital intensive firms, the probability of inaction in investment decreases with inaction in employment growth, while it increases in the estimation with all the firms; in the same way, the probability of a spike in employment growth increases with inaction in investment, which is the opposite when. considering all types firms in the estimation. The coefficients are closer to the obtained for all types of firms in the case of the low capital intensive firms and some are statistically significant as well. We can say from these tables that the low capital intensive firms tend to move more together than in the case of the high capital intensive firms.

Table 1.9: Probability of inaction/adjustment conditional on Inaction/adjustment of the other factor: High Capital Intensive Firms

Variable x		Investment		Employment growth	
		P(inaction/x)	P(Spike/x)	P(inaction/x)	P(Spike/x)
Investment	Inaction			0.02	-0.20
				(0.18)	(0.15)
	Spike			-0.13	0.08
				(0.12)	(0.10)
Employment Growth	Inaction	-0.1	-0.12		
		(0.19)	(0.12)		
	Spike	-0.24	0.04		
		(0.17)	(0.11)		
Observations		1898	3520	2612	3034

†/*/** significant at 10%, 5% and 1%. TFP, demand shocks and year effects in regression
Dummies for inaction are defined as 1 if $abs(x) < 0.01$ and dummies for spikes are defined as 1 if $x > 0.2$

In the case of the dynamic correlations, heterogeneity seems to play a more important role and firms seem to show a different behavior. Tables 1.10 and 1.11 show a VAR(1) estimated for low and high capital intensive firms respectively. With respect to the dynamic interrelation between capital and labor adjustment, the only sign consistent in all the estimations is the effect of the lagged investment rate in the labor adjustment, even if not significant for each subgroup but significant for all the Census of Manufacturing firms. In the case of the effect of lagged labor growth in the investment rate, the high capital intensive firms have a slightly higher coefficient than that estimated for all the firms and it has the same sign, which does not happen in the case of the low capital intensive firms The low capital intensive firms present. The other coefficient look similar in general, but the autocorrelation of investment rates is positive in contrast to the coefficient obtained when all the firms

Table 1.10: Dynamic relations in factor adjustment: Low Capital Intensive Firms

	$\frac{I}{K}$	$\Delta L/L$	$\Delta m/m$	$\Delta e/e$
$(\frac{I}{K})_{-1}$	0.023	-0.002	0.038	-0.135
	0.037	0.011	0.021	(0.030)**
$(\frac{\Delta L}{L})_{-1}$	-0.055	-0.167	0.071	0.083
	0.044	(0.013)**	(0.025)**	(0.035)*
$(\frac{\Delta m}{m})_{-1}$	0.002	0.019	-0.281	0.055
	0.025	(0.008)*	(0.014)**	(0.020)**
$(\frac{\Delta e}{e})_{-1}$	0.009	0.006	-0.013	-0.412
	0.016	0.005	0.009	(0.013)**
Observations	4540	4540	4540	4540
R-squared	0.04	0.1	0.29	0.31

Standard errors in parentheses; **/* significant at 1% and 5%;
year effects and shocks in regression

are considered. In general, we can say that the dynamic correlation coefficients estimated for the high capital intensive firms look more similar to the estimates considering all the firms; this suggests some room to explore with respect to the dynamic behavior across heterogeneous firms.

The empirical evidence presented above indicating the infrequent nature and the mix of smooth and lumpy adjustment in capital and labor, indicates a dynamic dependence in these adjustments. There is some heterogeneity in the dynamic relations and in the case of inaction and large adjustment episodes, but the interrelation pattern is present across all types of firms. In the following section, I set up a model that aims to explain the patterns observed in the data, in particular, the infrequent and lumpy adjustments, and the interrelation among factor adjustment. The main features of the model are the presence of convex and non-convex adjustment costs in capital and labor (but not in the other factors) and the possibility of mutual interaction effects in the form of congestion (if more costly) or complementarities (if

Table 1.11: Dynamic relations in factor adjustment:High Capital Intensive Firms

	$\frac{I}{K}$	$\Delta L/L$	$\Delta m/m$	$\Delta e/e$
$(\frac{I}{K})_{-1}$	0.023	-0.002	0.006	-0.026
	(0.007)**	0.004	0.007	(0.009)**
$(\frac{\Delta L}{L})_{-1}$	0.042	-0.182	0.011	0.044
	0.029	(0.015)**	0.028	0.038
$(\frac{\Delta e}{e})_{-1}$	0.019	0.032	-0.249	0.06
	0.016	(0.008)**	(0.015)**	(0.021)**
$(\frac{\Delta m}{m})_{-1}$	0.01	0.007	0.034	-0.357
	0.011	0.006	(0.011)**	(0.015)**
Observations	4231	4231	4231	4231
R-squared	0.06	0.08	0.25	0.22

Standard errors in parentheses; **/* significant at 1% and 5%;
year effects and shocks in regression

cheaper) in the adjustment process through different adjustment costs if the firms adjust capital and labor independently or at the same time. As stated previously, non-convexities in the decision problem coming from the adjustment costs cause jumps or infrequent movements in firms' factors and interaction effects are defined as changes in cost due to joint adjustment.

The driving forces of factor adjustment in the model are technology and demand shocks, but not factor price shocks; this is assumed for simplicity. Simplicity also leads me to assume symmetry in the adjustment costs, an assumption that can be tested in the data. This assumption seems very plausible in the case of labor adjustment, as the analysis in the appendix reveals a marked symmetry in the behavior of all variables around bursts of job creation and destruction. Another important assumption is the lack of inventories as an adjustment variable. This could be an argument for using only sectors without significant inventories in the estimation procedure. Factor price effects, inventory adjustments and asymmetry of the adjustment costs are interesting and are left for future work.

1.3 A Dynamic Model of Firms' Factor Adjustment

This model must capture the existence of small and large adjustments and the mix of smooth and lumpy adjustments and allow for several margins of factor adjustment as described in section 2. At the same time, the model must also capture the observed interrelation between capital and labor adjustment. This section describes the model and analyzes its main implications. For notation purposes, the subscript *it* is dropped, but is implicitly applied to all the variables.

1.3.1 Basics

Demand and Production Function

There is imperfect competition and firms face a downward sloping demand curve

$$Q^d = \left(\frac{P}{X}\right)^{-\psi} \tag{1.1}$$

where X is a stochastic shock to demand, ψ is the price elasticity of demand and P is the price level.

The production function incorporates capital, labor, materials and energy. Capital and labor are costly to adjust, while materials, energy and hours[28] per worker can be adjusted at no cost. In this context, hours can be thought of as a

[28] In some range, firms adjust employment instead of hours because they pay wage premia for overtime.

form of labor utilization, and while this is not explored in the model, energy is likely to be correlated with capital utilization. The assumption here is that all firms have the same Cobb-Douglas production function and that elasticities and factor shares vary by sector[29]. This function does not represent an aggregate production function but instead the production function of each firm. If we were to assume heterogeneity in the production function, it would introduce too much complexity in the problem and a separate analysis would have to be done for each firm or industry. Since I am interested here in the average behavior of firms, this functional form seems to be the one that can characterize the greatest number of firms. Formally,

$$Q^s = Bk^{\chi} (lh)^{\alpha} e^{\xi} m^{\nu} = Ak^{\chi} l^{\alpha} \tag{1.2}$$

where χ, α, ξ and ν are the input factor elasticities for capital, labor, energy and materials, $A = Be^{\xi} m^{\nu} h^{\alpha}$, B is a productivity shock, k is the capital level, l is the stock of workers, h represents hours per worker, e is energy consumption and m is the materials level. It is convenient for notation to cluster the terms for hours, energy, materials and productivity in the term A, since they are optimally chosen period by period in a static maximization problem and there are no intertemporal links in their case.

Revenue Function and profit

Putting together (1.1) and (1.2) we get the revenue function:

$$R(\bar{z}, k, l) = \bar{z} k^{\hat{\theta}} l^{\hat{\mu}} \tag{1.3}$$

[29]In future work I plan to explore the role of heterogeneity in the elasticities.

where: $\bar{z} = XA^{\left(1-\frac{1}{\psi}\right)}$, $\hat{\theta} = \chi\left(1-\frac{1}{\psi}\right)$, $\hat{\mu} = \alpha\left(1-\frac{1}{\psi}\right)$. This type of revenue function is used by most of the literature because of the lack of firm-level information on prices. It has a demand component that is hard to identify separate from the technology shock, even if estimated at the firm-level. For the Colombian Census of Manufacturing, however, firm-level prices are observed. In equation(1.3), firms implicitly account for the effects of their input choices on output prices when maximizing profit. The existence of firm-level prices allowed Eslava et al. (2004) to obtain arguably unbiased estimates of the input elasticities and the elasticity of demand, which I utilize in this paper.

Before defining the firm's intertemporal decision problem, it is useful to define the profit level. Profit incorporates the cost of all the inputs, including the adjustment cost which will be defined more formally later in this section. For now, profit is given by $\Pi(z, l_{-1}, l, k, k') = zk^{\theta}l^{\mu} - w(l) - C(z, l_{-1}, l, k, k')$ where $w(l)$ is the payment to employment, $C(\bullet)$ is the adjustment cost, z is a term that incorporates the technology and demand shocks, together with materials and energy price shocks. Note that the input factor elasticities are given by $\theta = \hat{\theta} * M$ and $\mu = \hat{\mu} * N$, where M and N are terms that incorporate the elasticities of materials and energy coming from the static optimal firm choice for hours, materials and energy.[30]

[30] Without this simplifying notation, the complete expression including materials and energy would be $\Pi(\bullet) = \bar{z}k^{\hat{\theta}}l^{\hat{\mu}} - l(w_0 + w_1 h^{\zeta}) - C\left(z, l_{-1}, l, k, k'\right) - p_e e - p_m m$. Note the functional form assumed in the wage equation representing a base payment plus a payment for the hours, where ζ is the hours wage elasticity. The main difference in both equations is the term for the shocks, $\bar{z}$, and the explicitness of the energy and material prices, $p_e e - p_m m$.. In the text, the term z captures all of them since the firm solves a static optimization problem in energy and materials every period that can be characterized in the term z.

Firms' Decision Problem

I start by discussing the timing of the decisions and the outcomes.[31] Firms choose employment taking into account the employment level in the previous period. Newly hired workers become productive in the same period. However, new investment becomes productive only in the next period. In this sense there is a "time to build" for capital but not a "time to hire" for employment. Firms also chose hours, energy and materials and can adjust them at no cost. Formally, the firm's problem is given by:[32]

$$
\begin{aligned}
V(z,k,l_{-1}) &= \max_{k',l}\left\{\Pi(z,l_{-1},l,k,k') + \beta\int V(z',k',l)f(z'/z)dz'\right\} \\
&= \max_{k',l}\{zk^{\theta}l^{\mu} - w(l) - C(z,l_{-1},l,k,k') \\
&\qquad +\beta\int V(z',k',l)f(z'/z)dz'\}
\end{aligned}
\tag{1.4}
$$

where $I = k' - (1-\delta)k$ represents investment and δ represents depreciation. $C(\bullet)$ is the cost of adjustment, which takes different parameter values depending on whether the firm adjusts employment, capital or both. β is the discount factor and the integral term represents the expected value of the firm subject to shocks z. This shock distribution $f(z'/z)$ includes the joint distribution of the demand and productivity shocks $h(x'/x)$ and $g(A'/A)$ respectively. I assume these shocks are independent.[33]

[31] The model proposed is similar in several dimensions to the ones used by Abel and Eberly (1998), Cooper et al. (1999), Cooper and Haltiwanger (2005) and Cooper et al. (2004).

[32] The notation implicitly states that firms optimally choose energy, materials and hours in a static maximization problem. These values are embedded in the term z.

[33] This assumption would not hold if the productivity shocks were not idiosyncratic but instead common, since in this case TFP would be correlated with demand. Since the estimations of the shocks in this paper take out the aggregate effects, this effect is mitigated. This assumption has been used before by Syverson (2005) to estimate production functions using demand shift

The cost of adjustment $C(\bullet)$ potentially includes disruption costs, fixed costs and convex costs. The existence of a disruption cost taking the form of lower productivity in adjustment periods is justified by the findings of Power (1998) and Sakellaris (2004). In the appendix, I show that production and TFP decrease when adjustment takes place, especially after investment spikes. In an additional empirical exercise not shown here, I regressed TFP against a dummy of adjustment (separately for capital and employment), obtaining a negative and significant coefficient for both factors, giving more support for the inclusion of this disruption cost. The disruption cost can also be associated with the stochastic adjustment cost present in Caballero and Engel (1999).

The convex cost term does not have a clear micro-foundation but has been assumed to exist in previous literature because of the smooth adjustment observed at the macro level. The distributions shown in section 2 also present regions of smooth and lumpy adjustments as discussed previously. In the analysis in the appendix, some firm-level adjustments look smooth[34] and the convex cost is incorporated into the model to capture this fact. This mix of smooth and lumpy adjustment is more pronounced in the evidence for the U.S. in Sakellaris (2004) than in the evidence shown in the appendix of this paper. One of the main advantages of the modeling mechanism taken in this paper is the ability to identify the importance of such a cost at the firm level.

The fixed adjustment cost can be seen as representing installation costs (in

instruments to calculate productivity and in the recent discussion about the relevance of VAR to business cycles analysis.

[34]Lumpy adjustment is observed in the peaks for the growth variables and smooth adjustment is observed in the smooth slope of the coefficients for these adjustments.

both time and resources) in the case of capital and firing and hiring costs in the case of labor.[35]

Specifically, the functional form assumed for the adjustment costs when firms adjust l (labor), k (capital) or kl (capital and labor), is the following:

$$C\left(z,k,I,l,l_{-1}\right)=\begin{cases} C^{l} & =\lambda_{l}R(\bullet)+F_{l}l_{-1}+\frac{\gamma_{l}}{2}\left(\frac{\Delta l}{l_{-1}}\right)^{2}l_{-1} \qquad if \quad \Delta l\neq 0 \\ C^{k} & =\lambda_{k}R(\bullet)+F_{k}k+\frac{\gamma_{k}}{2}\left(\frac{I}{k}\right)^{2}k+p_{I}*I \quad if \quad I\neq 0 \\ C^{lk} & =C^{l}+C^{k}+\lambda_{lk}R(\bullet)+F_{lk}\sqrt{l_{-1}k} \\ & +\frac{\gamma_{lk}}{2}\left(\frac{I}{k}\right)\left(\frac{\Delta l}{l_{-1}}\right)\sqrt{l_{-1}k} \qquad if \quad \Delta l*I\neq 0 \end{cases} \tag{1.5}$$

In the case of labor or capital adjustment, (C^l and C^k respectively) the first term $\lambda_j R(\bullet)$ represents the disruption cost, the second term involving F_j represents the fixed cost and the third term involving γ_j represents the convex cost, with j=k(capital) and l(labor). In the case of capital adjustment, there is an extra cost which represents the investment price and it can take values of $p_I = \{p_{buy}, p_{sell}\}$ depending on if the firm buys or sells capital. The asymmetry in the price for buying and selling capital implies that capital is not fully reversible, which is easily observed in the distribution for capital adjustment shown at the beginning of the paper.

If the firm adjusts capital and employment at the same time, the adjustment cost is the sum of the cost of adjusting capital (C^k), plus the cost of adjusting employment independently (C^l), plus a collection of terms that represent the extra cost of the joint adjustment. The parameters are then $\{\lambda_k, \lambda_l, \lambda_{kl}\}$ for the disruption cost, $\{F_k, F_l, F_{kl}\}$ for the fixed cost, $\{\gamma_k, \gamma_l, \gamma_{kl}\}$ for the convex cost and p_I for the

[35] The set up of the model and, specifically, the setup of the adjustment cost model, will allow the estimation procedure below to distinguish which component is more important in the factor adjustment process.

investment price.

To check for the existence of interaction effects in the adjustment of capital and employment, the cost function for joint capital and employment adjustment is assumed to be a linear function of the adjustment cost for employment, the adjustment cost for capital and an interaction term. That is, $C^{kl} = C^{k} + C^{l} + C^{joint\ adjustment}$. To be more precise, if interaction effects exist, the terms reflecting joint adjustment, (λ_{lk},γ_{lk} and F_{lk}), will be different from zero. This interaction will be in the form of a congestion effect if the cost is positive or in the form of a complementarity if the cost is negative (i.e. it is a benefit). Intuitively, interaction effects in the disruption cost mean that forgone profits due to interruption in the production process, or decreases in productivity while adjusting capital and labor, may be higher (congestion) or lower (complementarities) than when adjusting just one factor. For example, the learning process for new workers operating new machines maybe more expensive than the cost of training new workers and of buying new machines separately, inducing a congestion effect. Congestion effects in the fixed cost may be due to higher installation costs for workers specific to certain machines, and congestion effects in the convex costs may be due to a longer adjustment period in the plants.

1.3.2 Analysis of the Model

The approach in this paper differs from previous analysis in the modeling of the adjustment cost for capital and labor together and in the possibility for interaction effects in this adjustment. These features may lead to behavior different from traditional models, where firms have just one factor that is costly to adjust. In particular, even with convex costs, in our model firms may have inaction regions because of corner solutions in the optimization problem. The economics of joint adjustment can be summarized as "adjust if the marginal benefit is bigger than the marginal cost of adjustment." In this sense, the relative values of the adjustment costs play a key role, since they determine which factor to adjust.

The subsections that follow will highlight the main differences between this model and the conventional models, and the new implications of considering joint adjustment of capital and labor when they are costly to adjust. As a final point, the firm's optimization problem assumes that firms have already optimally chosen hours, energy and materials as a function of the state space composed of the shocks in demand and technology, the capital stock and number of workers.

Case 1. No Adjustment Costs

I will start with the case where no adjustment costs are present. In this case, the firm faces a static optimization problem for capital and labor, in addition to the static optimization problem faced for energy and materials and captured in the term z.

The FOCs are:[36]

$$k': \quad \beta \int V_{k'}\left(z', k', l\right) f\left(z'/z\right) dz' \quad = \quad p_I \tag{1.10}$$

$$l: \quad \mu z k^{\theta} l^{\mu-1} \quad = \quad w_l(l) \tag{1.11}$$

It can be seen that labor and capital are very sensitive to shocks. Without adjustment costs, the correlation between investment and demand and technology shocks is very high, and the same is true for employment adjustment. It is clear that in order to reproduce the main features of the data some nominal or real rigidity is needed. The initial candidate in the literature was the convex cost component, later adding non convex costs to account for inaction and lumpiness. This topic is analyzed next.

Case 2. Adjustment Costs for Capital and Employment

If firms face any type of adjustment costs, the analysis changes. The FOCs and envelope conditions of the problem in the general case are:

$$k': \quad C_{k'}(z, l_{-1}, l, k, k') + \beta \int V_{k'}\left(z', k', l\right) f\left(z'/z\right) dz' \leq 0 \tag{1.12}$$

$$l: \mu z k^{\theta} l^{\mu-1} - w_l(l) - C_l(z, l_{-1}, l, k, k') + \beta \int V_l\left(z', k', l\right) f\left(z'/z\right) dz' \leq 0 \tag{1.13}$$

$$C_{l_{-1}}(z, l_{-1}, l, k, k') - V_{l_{-1}}\left(z, k, l_{-1}\right) \leq 0 \tag{1.14}$$

$$\theta z k^{\theta-1} l^{\mu} + (1-\delta) * C_{k'}(z, l_{-1}, l, k, k') - C_k(z, l_{-1}, l, k, k') - V_k\left(z, k, l_{-1}\right) \leq 0 \tag{1.15}$$

[36] The FOCs for labor, energy, materials and hours under the full specification of the model using the profit function in footnote (30) are:

$$l: \quad \mu \bar{z} k^{\hat{\theta}} l^{\hat{\mu}-1} e^{\tau} m^{\varphi} = w_0 + w_1 h^{\zeta} \tag{1.6}$$

$$h: \quad \hat{\mu} \bar{z} k^{\hat{\theta}} (lh)^{\hat{\mu}} h^{-1} e^{\tau} m^{\varphi} = \zeta w_1 l h^{\zeta-1} \tag{1.7}$$

$$e: \quad \tau \bar{z} k^{\hat{\theta}} (lh)^{\hat{\mu}} e^{\tau-1} m^{\varphi} = p_e \tag{1.8}$$

$$m: \quad \phi \bar{z} k^{\hat{\theta}} \theta (lh)^{\hat{\mu}} e^{\tau} m^{\varphi-1} = p_m \tag{1.9}$$

In this case, hours are independent of shocks, as can be seen from (1.7) and (1.6): $h = \left(\frac{w_0}{w_1(\zeta-1)}\right)^{\frac{1}{\zeta}}$.

These FOCs and envelope conditions reveal that the functional form of the adjustment costs is crucial to understanding firm's factor adjustment. These expressions are inequality conditions because of the possibility of corner solutions. Equations (1.12), (1.13), (1.14) and (1.15) will hold with equality only when the adjustment in both factors is nonzero. The firm will adjust one factor if the net gain of adjustment is higher than if the firm adjusts the other factor or both employment and capital together. This opens the possibility of staggered adjustment, even if the adjustment cost is convex, which differs from previous models where convex adjustment costs imply continuous adjustment.

Another point to notice is that the discounted marginal value of labor adjustment depends on investment, and the discounted marginal value of investment depends on labor adjustment, whenever firms decide to adjust both factors or whenever the adjustment cost reflects interaction effects.

Convex Adjustment Costs

With convex costs, hours depend on shocks and are negatively related to employment.[37] As mentioned above, if firms face convex costs in both factors, there is a possibility of inaction if adjusting one factor gives a higher net marginal benefit than adjusting both factors at the same time. It has been thought that convex costs guarantee continuous adjustment, but that is not the case in the setting presented

[37]To show this, take the full specified model and assume a convex cost model where the interaction term in the adjustment cost for capital and labor is not present. In that case, the FOCs for labor and hours imply $h = \left(\frac{\mu z k^{\theta} e^{\tau} m^{\varphi}}{\zeta w_1 l^{1-\mu}}\right)^{\frac{1}{\zeta-\mu}}$. Since $\zeta > 1 > \mu$, hours are negatively related to employment. However, this feature of the convex cost model with the functional forms assumed would not be supported by the data, since the correlation between hours growth and labor growth with firm-level data is positive, in contrast to the U.S.

in this model.

If both equations hold with equality(i.e., when adjustment is nonzero in both factors), an interesting result can be seen, assuming a convex cost only for the interrelation term: $\gamma_{kl}(l - l_{-1})\left(\frac{I}{k}\right)$. Updating (1.14) and plugging the result into (1.13), we find:

$$E\left(\frac{I'}{k'}\right) = \frac{1}{\beta\gamma_{kl}}\left\{w_0 + \gamma_{kl}\left(\frac{I}{k}\right) - \mu z k^{\theta} l^{\mu-1}\right\} \tag{1.16}$$

From (1.16) we can see that investment rates are positively correlated in time, which is a common feature of convex cost models of investment. Moreover, since $\mu < 1$, it can be shown that the investment rate in period $t+1$ is positively correlated with the change in labor in period t. Also, because investment and labor are simultaneously determined, $\frac{d(\frac{I}{k})}{dl}$ does not have a clear meaning unless we can assume some causality. If causality were the case (for example, if firms adjust labor first and then decide investment according to capacity constraints) we would have a negative relationship between the change in labor and the change in the investment rate.[38]

Convex and Non-Convex Adjustment Costs

When hit by a demand or productivity shock, the firm decides whether to adjust capital, labor or both, and at the same time decides the optimal level of materials, energy and hours.[39] The firm's problem is given by (1.4) and the optimality

[38]This comes from applying the implicit function theorem where $\frac{d(\frac{I}{k})}{dl} = -\frac{dE\left(\frac{I'}{k'}\right)/dl}{dE\left(\frac{I'}{k'}\right)/d\left(\frac{I}{k}\right)}$.

[39]The FOCs for the static optimization problem are conditional on λ and, under the full specification of the model, given by:

$$\begin{aligned} h: \quad \hat{\mu}(1-\lambda_j)\bar{z}k^{\hat{\theta}}(lh)^{\hat{\mu}}h^{-1}e^{\tau}m^{\varphi} - \zeta w_1 l h^{\zeta-1} &= 0 && (1.17)\\ e: \quad \tau(1-\lambda_j)\bar{z}k^{\hat{\theta}}(lh)^{\hat{\mu}}e^{\tau-1}m^{\varphi} &= p_e && (1.18)\\ m: \quad \phi(1-\lambda_j)\bar{z}k^{\hat{\theta}}(lh)^{\hat{\mu}}e^{\tau}m^{\varphi-1} &= p_m && (1.19) \end{aligned}$$

conditions for capital and labor are given by equations (1.12), (1.13), (1.14) and (1.15).

If we define V^K as the value of adjusting only capital, V^L as the value of adjusting only labor, V^{LK} as the value of adjusting both labor and capital and V^N as the value of nonadjustment, we can redefine the problem as a continuous choice problem nested in a discrete choice framework. Given the firms decision problem in (1.4), we can express it as $V(\bullet) = max[V^N, V^K, V^L, V^{LK}]$, where firms choose the action that gives it the highest V. That is

- Firms do not adjust if $V^N > [V^K, V^L, V^{LK}]$
- Firms adjust labor if $V^L > [V^N, V^K, V^{LK}]$
- Firms adjust capital if $V^K > [V^N, V^L, V^{LK}]$
- Firms adjust capital and labor if $V^{LK} > [V^N, V^L, V^K]$

As will become clear later in the numerical analysis, the firms follow an (S,s) policy in both capital and labor. An interesting issue left for future work is to prove the validity of this result analytically. The difficulty of this proof comes from the joint determination of capital and labor, making an (S,s) rule dependent not only on the shocks and states but on the choice variables.

The model presented cannot be solved analytically because of the non-convex nature of the decision rules. Therefore, a numerical solution is needed. It is in this sense that the main difficulty associated with the model is the state space: there

$\forall(z, k, l)$ and j = labor, capital, capital and labor (adjustment type) and $\lambda_j = 0$ if there is no adjustment.

are three[40] continuous state variables (shocks, capital and labor) and one discrete choice variable (margin of adjustment). In the next section I show an illustrative calibration, explain the numerical procedure used to solve the model, numerically analyze the decision rules, and explore the quantitative implications that emerge from this model.

1.4 Capital and Labor Adjustment: A Numerical Analysis of the Proposed Model

The purpose of this paper is ultimately to analyze how firms make dynamic joint decisions about capital and employment. Given the evidence and the model presented above, this section describes the firms' decision rules with respect to capital and employment adjustment, and numerically analyzes whether these decision rules are able to generate simulated economies that reproduce the facts observed in the data. Specifically, I look at inaction periods, lumpy adjustment and the dynamic interrelation of capital and labor, and the correlation between factor inputs. Importantly, I want to determine what is the main force generating these behaviors; specifically, whether it is the interaction effects in the adjustment process or the type of the adjustment costs faced by firms.

I use numerical simulations of the model as the main tool to answer to these questions. First, I explain the computational methods used to solve the model numerically. Second, I parameterize the model with adjustment cost parameters that appear to be ex-ante reasonable, illustrating the different behavior the firm-level model exhibits with respect to capital and labor dynamic adjustment when demand

[40] Four if the shocks are differentiated between demand and productivity.

and productivity shocks are the main source of perturbation in the modeled economy. Third, I show and analyze the decision rules that the model implies, presenting time series realizations under several configurations of adjustment costs, in order to give an idea of the ergodic distribution of the state variables and which decision rules the firms visit more often. Finally, I analyze the quantitative response of the model using different adjustment cost configurations.

1.4.1 Numerical Methods

The equation to solve is the Bellman equation given in (1.4). The solution must give the firm's optimal choices for hours, energy, materials, investment and employment given the vector of shocks z, capital k and previous employment level l_{-1}. The optimal level of hours, energy and materials are a function of the state space (z, k, l_{-1}) and this problem can be solved analytically every period as a function of this state space conditional on the disruption cost λ_j as is shown in footnote (39). The variables left to solve are capital and labor, for which a numerical procedure should be used given the dynamic links and non convexities that they exhibit in the model.

In the solution of this equation, three basic choices should be made: (i) the procedure for maximization over the state space, (ii) the procedure to solve the unknown value function $V(z, k, l_{-1})$ and (iii) the procedure to solve for the integral over the shocks that represents the firm's expectation about the future value $V(\bullet)$

For (iii), I integrate using quadrature methods as in Tauchen and Hussey

(1991). This quadrature is solved with Hermite polynomials, which are the best for this situation since the shocks are assumed (and estimated from the data) as AR(1) log-processes with lognormal error terms. I discretize the shock distribution into 3 states for the productivity shock and 2 states for the demand shock. I assume independence of both shocks such that the shock calibrated in the model is the result of the multiplication of those two.

For (ii) I use value function iteration. While I also solved the model with policy iteration, the existence of kinks in the value function did not assure reliable results for the full range of parameters.

The simplest method for (i) would be a grid search, restricting the values that the state space variables can take to the points in the grid; however, this method is very imprecise given the large state space faced in this specific problem. Moreover, since I am looking at inaction periods and spikes in investment and capital adjustment, this grid would need to be very fine, which would soon result in the curse of dimensionality. Instead, I choose a small number of points for the state space (3 for the productivity shock, 2 for the demand shock, 70 for the capital stock and 30 for the number of workers) and use a golden section search method to determine the maximum over the entire state space, bracketing first the optimal region and then using linear interpolation of the optimal values to the values in the grid. This method allows very precise calculations for the value function in each grid point and also allows faster simulation of the model. The code is written in Matlab and C, linking the programs through MEX-files.

1.4.2 About the Parameters: Estimation and Calibration

There are two sets of parameters: those that can be directly estimated without imposing an economic model (reduced form parameters) and those that need to be calibrated or estimated with some simulation procedure (structural parameters). In the first group we have: the production function coefficients χ, α, ξ, and ν for capital, labor, energy and materials respectively; the demand shock process X_{it}; the technology shock process A_{it}; and the elasticity of demand ψ. In the second group we have the adjustment cost parameters (γ_j for the convex cost, F_j for the fixed cost, λ_j for the disruption cost and $\{p_I, p_{sell}\}$ for the price of capital), the discount factor β, the depreciation rate δ and the hours wage elasticity ζ. The dataset does not contain capital prices. Although I can calculate the mean input prices from the data in the case of employment, energy and materials, I choose to calibrate them because of the lack of capital prices in order to put all the factor prices on equal footing. The calibrations come very close to the relative prices calculated from the data for energy and materials. I do not compare the wage calibration with the data, and capital prices are not available.

The estimates for production function coefficients, the demand and technology shock processes and the elasticity of demand are taken from Eslava et al. (2004). They use information on prices to estimate an output-based KLEM production function with demand shift instruments[41] in order to find the production function

[41]They use the Syverson (2005) insight that using demand as an instrument for input factors in production function estimation can get rid of the endogeneity problems that are well known in such situations. They do so by creating downstream demand shift instruments selected with Shea (1997) relevance and exogeneity criteria.

coefficients and the technology shock process. An advantage of their methodology is that the price information allows them to isolate a firm specific price deflator, so that TFP estimations do not use a common price deflator that, as Klette and Griliches (1996) and Foster et al. (2005) illustrate, would bias the estimates of the production function coefficients. The estimations are carried over for all firms in Colombia and are not differentiated by industry as a simplifying assumption, even if the factor shares may differ by industry. The coefficients are 0.213 for capital, 0.303 for labor, 0.176 for materials and 0.2752 for energy. Next, Eslava et al. (2004) take advantage of the price information and estimate a downward sloping demand curve similar to the one assumed here, instrumenting output using the calculated TFP, obtaining the demand elasticity $\psi = 2.28$ and the demand shocks as the residuals of the regression.

In the calibration of the model, I assume that the demand shocks and the technology shocks follow an AR(1) lognormal process such that (with lower case letters meaning logs and dropping the subindex i):

$$a_t = \rho_a a_{t-1} + u_t \tag{1.20}$$

$$x_t = \rho_x x_{t-1} + \varepsilon_t \tag{1.21}$$

Equations (1.20) and (1.21) are estimated as in Eslava et al. (2004) using year effects. The coefficients obtained are $\rho_a = 0.922$, $\rho_x = 0.985$ and $\sigma_a = 0.77$, $\sigma_x = 0.89$. Given that ${\sigma_a}^2 = \frac{{\sigma_u}^2}{1-{\rho_a}^2}$ and ${\sigma_x}^2 = \frac{\sigma_\varepsilon^2}{1-{\rho_x}^2}$, we get $\sigma_u = 0.297$ and $\sigma_\varepsilon = 0.151$. I normalize the mean values of the shocks to one (this normalization also affects the input prices). The discount factor β is set as 0.95, the depreciation rate δ as 0.1 and the hours wage elasticity as 1.1.

Before I discuss the calibration of the input prices, I want to emphasize that even though those prices can be an important source of fluctuations and relative changes in input adjustment, this paper focuses on the firm's responses to demand and productivity shocks. This is the reason to look for an "average" input price in each case, and this guides the calibration of the prices.

Energy and materials prices are calculated by solving the FOCs of the problem without adjustment costs (equations (1.8) and (1.9) respectively). The values for capital, labor, energy and materials plugged into these equations are the means of the actual values. It is interesting to note that the implied prices are very close to those obtained by dividing energy expenditure and materials expenditure by physical amounts. The labor payment parameters w_0 and w_1 are obtained by solving the system composed of the FOC for hours and labor in the problem without adjustment costs (equations (1.6) and (1.7)) and using again mean values. The investment price is obtained by solving the dynamic problem in the case of no uncertainty and no adjustment costs.[42] Finally, I treat investment as reversible, but with the capital resale price equal to 70% of the price of buying capital.

For this illustrative parameterization, I chose the adjustment cost parameters in an arbitrary manner such that the adjustment costs are the same for all types of costs and collectively account for either 4% or 20% of average profit. From this point on, I focus on the congestion effect because it is the one that is later supported

[42] The implicit assumption for the calculation of the prices is that the frictionless FOCs hold "on average".

by the data. Table 1.12 shows the chosen parameters for the adjustment costs and the average adjustment cost as a proportion of the contemporaneous profit. These costs do not increase proportionally from one column to the next because they were obtained with simulations and reflect an approximate rather than exact value. I calculate the policy function under the parameterizations discussed above for later simulations under different realizations of the shocks[43].

Table 1.12: Parameters Adjustment Costs

Adjusted Factor	Adjustment Cost Type	Cost/Π	
		4%	20%
Labor	Fixed (F_l)	0.22	1
	Convex (γ_l)	0.05	0.15
	Disrupt (λ_l)	0.01	0.035
Capital	Fixed (F_k)	0.01	0.044
	Convex (γ_k)	0.0007	0.006
	Disrupt (λ_k)	0.01	0.045
Joint Adjustment (Congestion)	Interaction Effects: Congestion/ Π =30%		
	Fixed (F_{lk})	5	5
	Convex (γ_{lk})	0.11	0.11
	Disrupt (λ_{lk})	0.07	0.07

1.4.3 Decision Rules for Capital and Employment Adjustment

I now present the numerical results for the value function, the decision rules (or policy functions) and its implications for firm behavior, given by the chosen parametrization. The firm has the option to not adjust, adjust only capital, adjust only employment or adjust both capital and employment. The decision rules are presented in a graphical analysis over the space determined by the values of capital

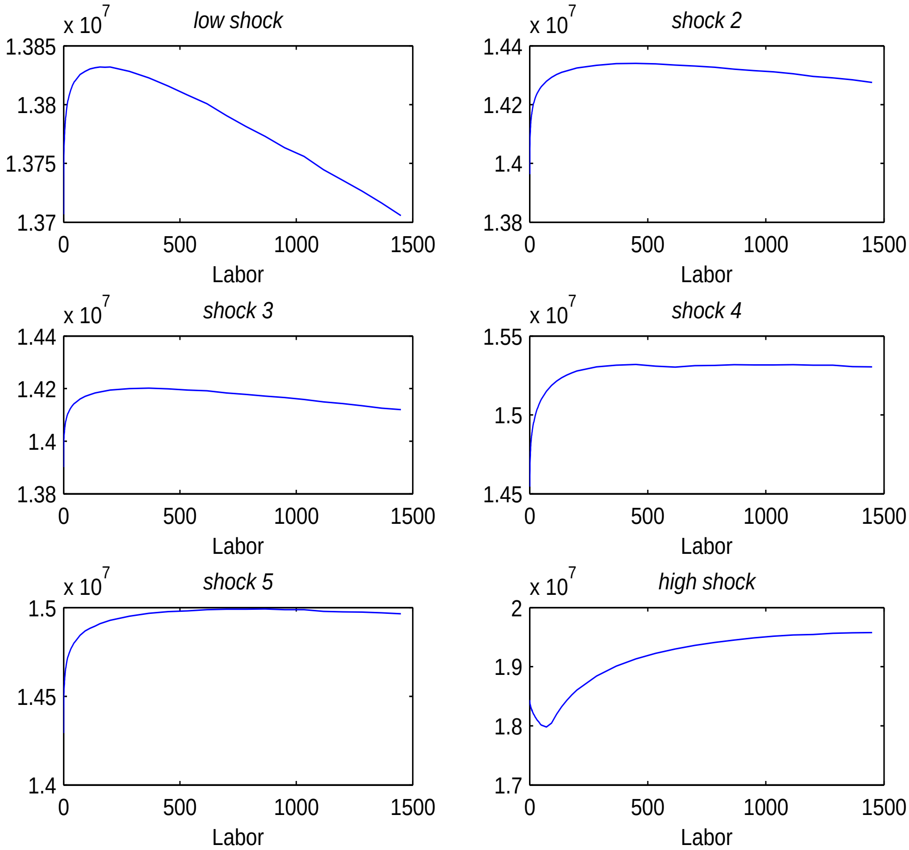
[43]This policy rule is invariant.

and labor. As expected, there is a region of inaction whose size depends on the value of the shocks, on the type of adjustment costs and on the existence or not of congestion effects in adjustment. This region of inaction determines a bi-dimensional (S,s) policy in capital and labor depending not only on the shocks and the other state variables, but also on the other choice variables. However, some regions are more likely to affect firm behavior than others since the ergodic distribution of the state space is an important point to take into account. That is the reason to consider several time series realizations of firm' behavior under different configurations of adjustment costs.

To illustrate the objective functions, figure 1.4 shows that in fact the value function is concave with some kinks at lower values of employment(this is, L_{t-1} on the x-axis). This effect on the value functions is due to the scale of the graph. The decision rules are shown in Figures 1.5, 1.6, 1.7 and 1.8. With these decision rules and the time series realizations, I will analyze the effects of the shocks, the congestion effects and the adjustment costs. Figure 1.5 shows the policy functions for the case where all costs are present for capital and labor (and equal to 4%) and there are congestion effects in adjustment. The first thing to note is that there is an inaction region whose shape and size depends on the shock and the value of both factors. This inaction region defines a bi-dimensional (S,s) policy for capital and labor. The optimal (S,s) policy depends on the shock and the choice of the other variable (either capital or labor).

Even though some adjustment regions for capital and labor are not convex sets, there are defined zones in which it is optimal to adjust only labor and others in

Figure 1.4: Value functions: lateral view, labor.



which it is optimal to adjust only capital, especially for small values of the shock (see figure 1.5). In some of the policy rules there exist disjoint sets in the space capital-labor for a given shock. For example, for the same capital to labor ratio may exist inaction or adjustment depending on the level of capital and labor, opening the possibility of multiple optimal regimes. According to the optimal rule, firms adjust capital and labor together only if the shock is big enough (in this case, above the mean shock). This implies that there is an implicit target for a relationship between capital and labor, and that target changes with the shock.

With just one factor, a standard (S,s) rule would hold, with the shock being the only determinant of the optimal adjustment policy. With the possibility of adjusting capital and labor, firms make decisions depending on where they are with respect to the optimal target of not just one isolated factor but a composite of capital and labor. This is an important improvement over previous models that analyzed just one factor at a time. This result is also related to Eslava et al. (2005), when implement the gap approach by Caballero et al. (1995) and Caballero et al. (1997); their empirical results suggest that firms adjust labor and capital depending on the gap between desired and actual employment and labor. The structural analysis here implies that this gap is implicitly affected by the gap in the other factor, resulting in this bivariate (S,s) policy.

Figures 1.6, 1.7 and 1.8 compare the decision rules implied by the different types of adjustment costs considered one-by-one in the presence (or absence) of congestion effects in the case of a bad shock, an intermediate shock and a good shock.

With respect to the adjustment cost types, the convex cost implies a larger region of adjustment in both capital and employment than the fixed cost and the disruption cost. It is important to note, as the theoretical analysis of the model revealed above, that even with convex costs, there is a region of inaction, though much smaller than the one present under non-convex costs.

The biggest inaction zone corresponds to the disruption cost. The fixed cost implies more staggered adjustment than the disruption cost, under which simultaneous adjustment of both factors is more frequent. The behavior implied by the

Figure 1.5: Decision rules. All costs in K,L.

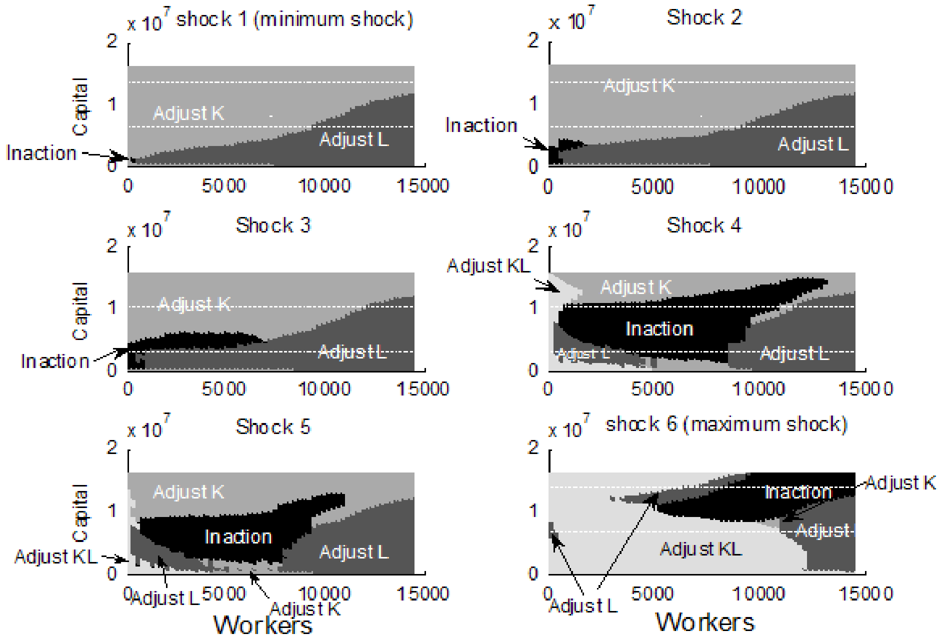


Figure 1.6: Decision rules. Comparison among Adjustment costs. Low shock.

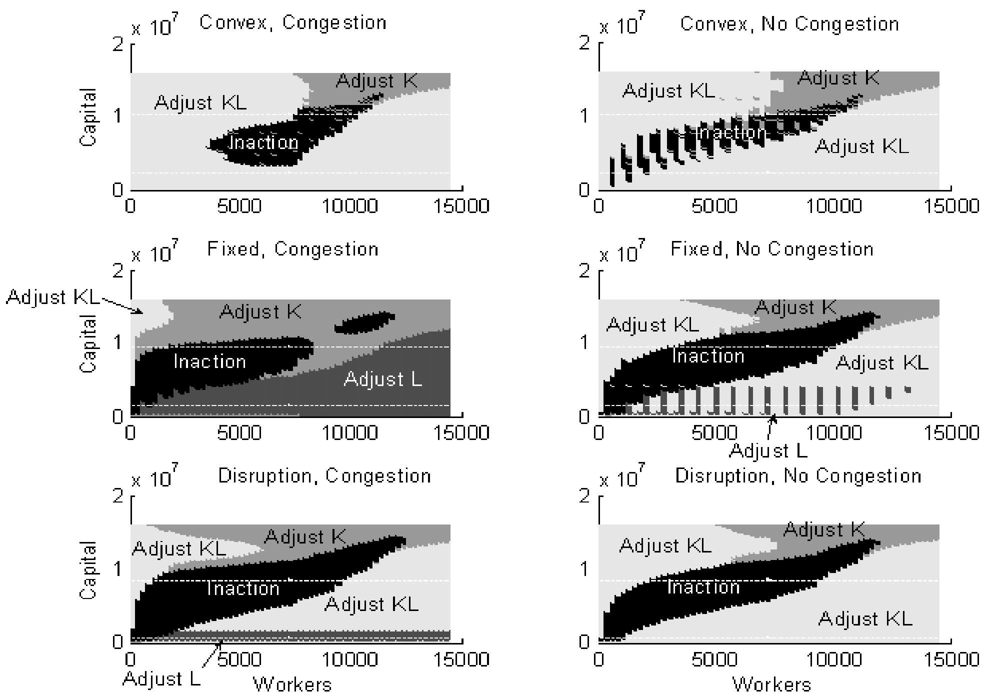


Figure 1.7: Decision rules. Comparison among Adjustment costs. Intermediate shock.

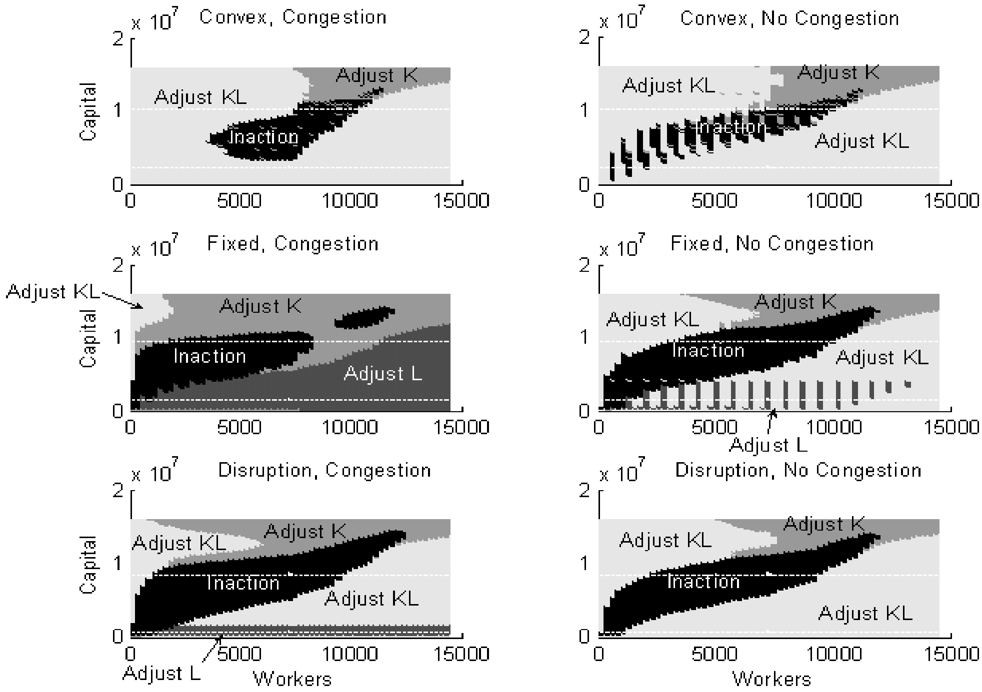
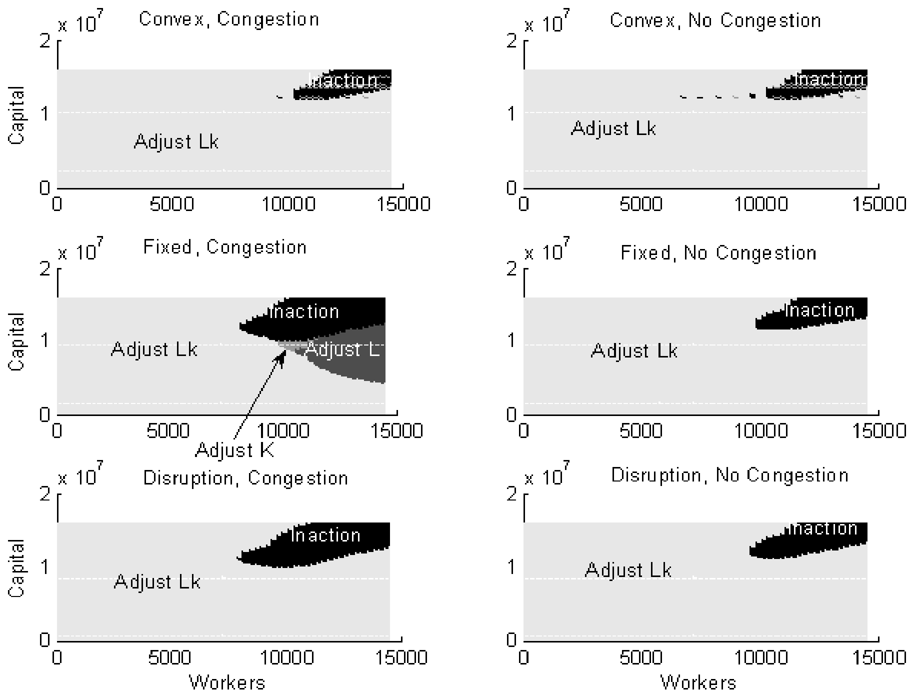


Figure 1.8: Decision rules. Comparison among Adjustment costs. High shock.



disruption cost looks more in line with the empirical evidence, where positive co-movement between capital and employment adjustment is observed.

For low values of the shock (figure 1.6) the behavior under convex or disruption costs does not depend much on the existence of congestion effects, and the only difference between the behavior under convex cost and that under disruption costs is the adjustment of only labor in a small region under convex costs. For the low shock case, fixed costs generate a more differentiated behavior, since there is no joint adjustment of capital and employment in the case of congestion effects.

In the intermediate shock case (Figure 1.7) , we observe that without congestion effects, there is more joint adjustment of capital and employment. This does not necessarily imply a higher correlation of adjustments under this regime, however, since capital and labor can move in opposite directions. The inaction zones are defined as double (S,s) bands. Interestingly, there is more joint adjustment in the convex cost case with congestion effects than without them. The pattern for fixed costs observed in the low shock case repeats itself here: joint adjustment is rare in the presence of congestion effects.

If firms face a high value of the shock (Figure 1.8), there is much more joint adjustment and the behavior under convex costs and disruption costs is very similar, with a larger inaction zone in the disruption case as expected. Again, fixed costs present the most different pattern: in the presence of congestion effects, firms will adjust only labor under certain circumstances.

Other important implications of different configurations of the adjustment costs can be seen plotting the time series realizations that the policy rules imply as a way of visualizing the regions that the firms spend more time in. For example, we could try to find if bigger inaction regions imply less variability of investment, or if bigger inaction regions are compensated by larger adjustments. Figure 1.9 shows the time series realization of one shock series when a firm faces all types of adjustment costs comparing the case of congestion vs. no congestion effects, figure 1.10 shows the labor growth when the firm faces different types of adjustment costs with and without congestion effects and figure 1.11 shows the investment responses of the same.

These time series realizations show that the presence of congestion effects increases the inaction in both capital and labor adjustments in all the cases. In the other hand, fixed costs and disruption costs have the same effect on investment rates when there is congestion effects, even if the decision rules are different. When congestion effects are not present, fixed costs increase inaction and volatility in both capital and labor with respect to the convex and disruption cases. When congestion effects are present and firms face all types of adjustment costs, the volatility of labor growth increases and the volatility of the investment rate decreases; Also, when the congestion effects are present, convex costs increase the volatility of the investment rate and decrease the volatility in labor growth compared with the case when either fixed or disruption costs are present.

The decision rules as presented above do not say anything about the direction of size of the adjustments. For example, capital and labor can move at the same time

Figure 1.9: Time Series: All Costs Present.

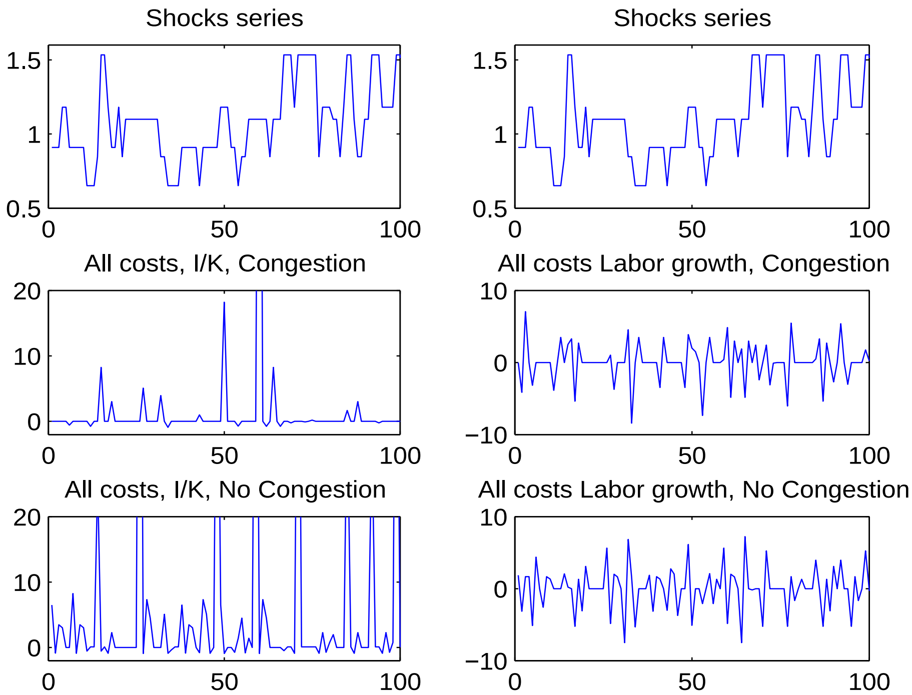


Figure 1.10: Time Series: Investment Rate, Adjustment Costs Comparison

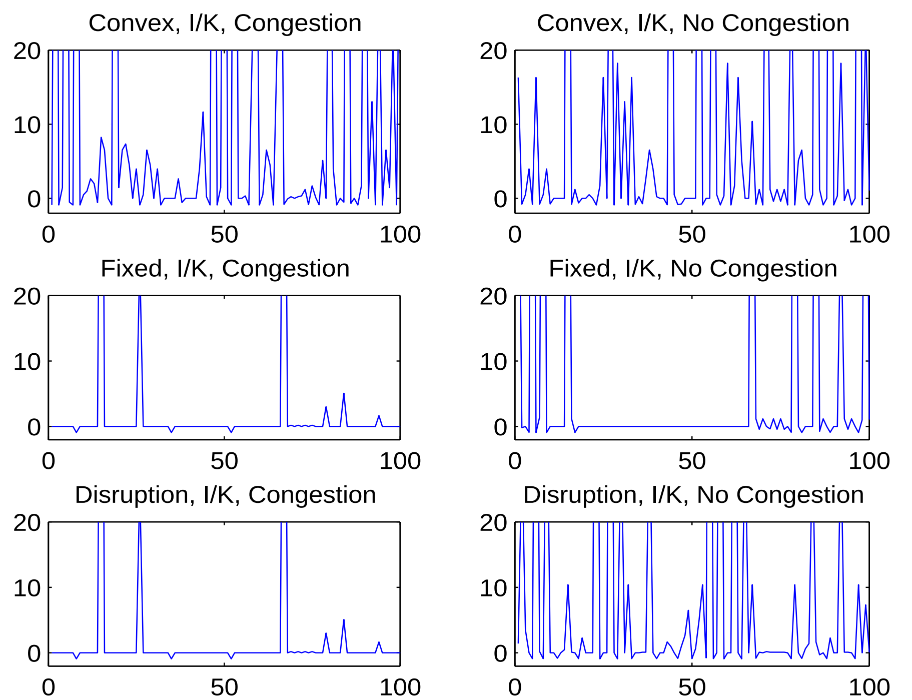
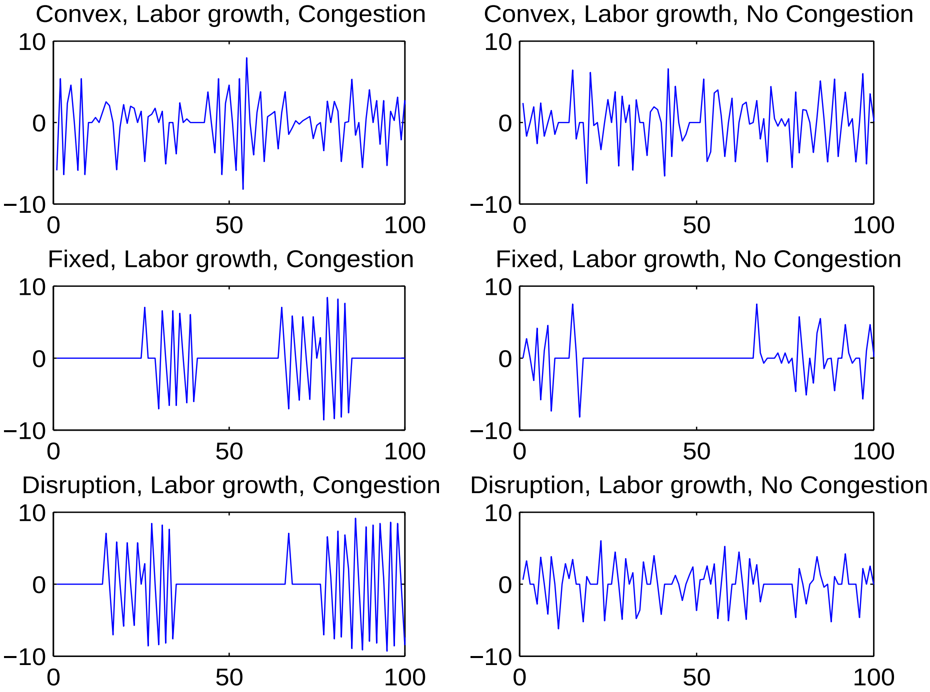
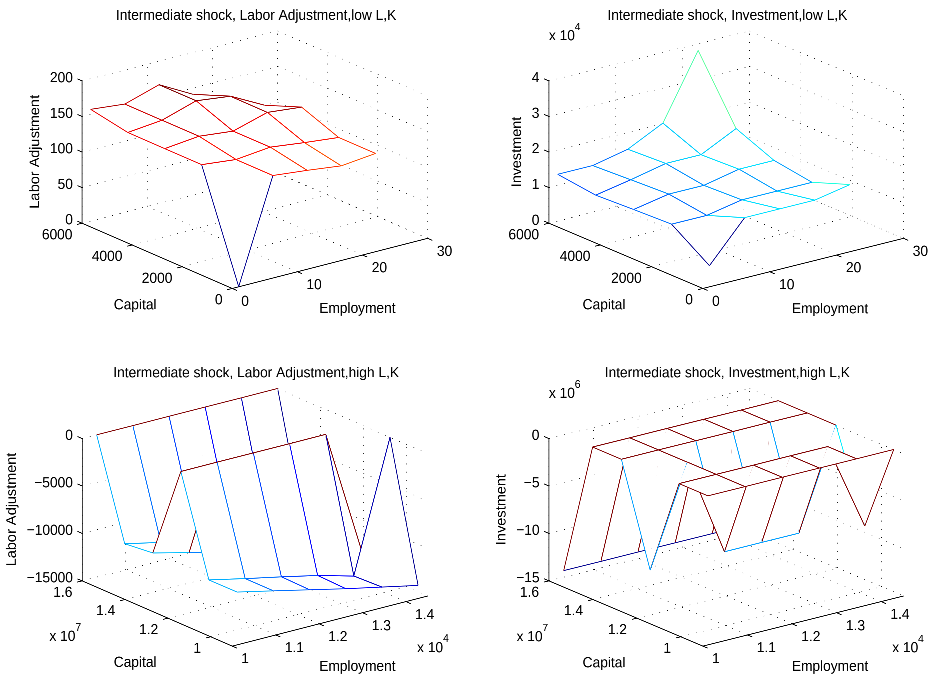


Figure 1.11: Time Series: Labor Growth, Adjustment Costs Comparison



but in different directions. There exist enormous non linearities in the decision rules. Figures 1.12 and 1.13 show the decision rules for labor adjustment and investment for several values for capital and labor and in the case of an intermediate shock with low adjustment costs. From Figure 1.12, we observe that at low values of capital and labor, the adjustments are in the same direction (positive), but for higher values, firms stagger depending on the state of (l, k); that is, under some combinations of capital and labor, firms reduce capital and do not adjust labor, and under other values they do the opposite. Figure 1.13 shows that factors can adjust in opposite directions when the firm has high values of capital and low values of employment or vice versa(higher or lower relative to their frictionless optimum). This means that at low values for both capital and labor the correlation between their adjustments is

Figure 1.12: Labor and Capital Adjustment Levels. Intermediate Shock, High and Low values for Capital and Labor

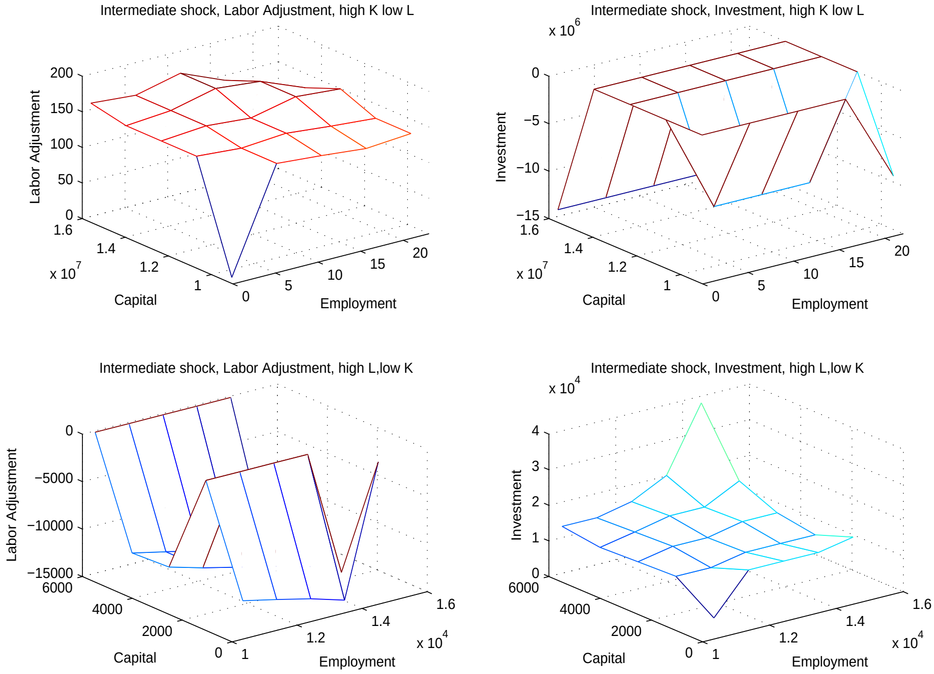


likely to be positive, while at higher values this correlation is likely to be negative.

Thus, we have different possibilities of firm behavior depending on if firms face good or bad shocks, whether they face congestion effects in the adjustment and depending on the type of dominant adjustment cost. In summary, the main features of these decision rules are:

i. The decision rules for capital and employment adjustment exhibit a non-linear pattern with inaction zones, zones of joint adjustment and zones of single factor adjustment. That is, the decision rules present a non linear (S,s) rule in both capital and labor. Adjustment or inaction in capital and labor depend not only

Figure 1.13: Labor and Capital Adjustment Levels. Intermediate Shock, Mix of High and Low values for Capital and Labor



on the states, such as the productivity and demand shocks and the capital to labor ratio, but also on the choices of capital and labor.

ii. Persistent bad shocks and fixed costs lead to a less frequent joint adjustment in capital and employment. Good persistent shocks increase the joint employment and capital adjustment.

iii. In general, the presence of convex costs tends to increase the likelihood of joint adjustment for capital and labor, while the presence of fixed costs tends to reduce this joint adjustment. Disruption costs can accommodate a richer type of adjustment, depending on the capital to labor ratio a firm has. This does not translate directly into measures of correlation since the adjustment of capital and labor can occur in opposite directions.

iv. Under intermediate or high shocks, congestion effects in the adjustment increase the likelihood of joint adjustment. Under low shocks, this is only true if fixed costs are dominant.

v. Even under convex costs, there may be inaction regions. These inaction zones are also present and larger when firms face disruption or fixed costs. However, in the case of fixed costs, inaction zones can present disjoint sets, which opens the possibility for multiple optimal regimes of capital and labor for the same capital to labor ratio. Inaction zones are more important in the case of intermediate shocks, being almost non existent for bad shocks and smaller for good shocks.

vi. Congestion effects increase the inaction in both capital and labor adjustments in all the cases; when congestion effects are not present, fixed costs increase inaction and volatility in both capital and labor with respect to the convex and disruption cases; when congestion effects are present, convex costs increase the volatility of the investment rate and decrease the volatility in labor growth compared with the case when either fixed or disruption costs are present; however, when congestion effects are present and firms face all types of adjustment costs, the volatility of labor growth increases and the volatility of the investment rate decreases.

vii. It is straightforward to conclude that the decision rules presented show a model that can accommodate at the same time smooth, lumpy, and infrequent adjustment, depending on the value of the shocks, the state of the firms in terms of capital and labor, the type of adjustment costs different firms face and the presence or absence of congestion effects. The model is able to incorporate different types of behavior depending on the combination of the variables above.

Since the decision rules imply a wide range of possibilities of adjustment, the next section simulates the response of firms to a specific realization of the technology and demand shocks in order to analyze the types of adjustment observed under the current parameterization.

1.4.4 Congestion Effects and Adjustment Costs: A Simulation exploration

Given the parameters and the average effects they produce in the model, I show in this subsection the results of some simulation exercises for a particular realization of the shocks extending the analysis started in the previous section. I choose to analyze one simple realization because this is not a formal calibration, but instead an example of the different possibilities that the adjustment costs can accommodate with respect to firm behavior. In particular, I look at the inaction zones and spikes in investment and employment adjustment, at the correlation among factor inputs and at the dynamic interrelations expressed in a one-lag VAR across different sets of parameters. The idea behind the numerical simulations is to complement the analysis of the decision rules and to understand, given the model and a specific realization of the shocks, how firms respond to shocks in technology and demand, how input factors move and comove and what is the role of congestion effects. Along the way, we will see how well the model replicates the stylized facts observed in the data.

I do not analyze the behavior of materials, hours and energy because they are not the main focus of this paper. However, the model does a mixed job in replicating the hours, materials and energy movements observed in the data. Inaction in these factors occurs on average 20% of the time and spikes occur 30% of the time, and the correlation between labor and hours is always negative because of the functional form assumed in the model (see footnote (30) for the wage function assumption and footnote (36) for the FOCs for labor and hours in the case of no adjustment costs). The correlation between materials and energy is always above 90% and their VAR coefficients in the investment equation are larger than 100. The other statistics are more reasonable. The positive side of this is that firms in the model adjust along several margins and are not restricted to adjust only capital and employment.

The first simulated statistics are presented in Table 1.13, which shows the percentage of inaction episodes, the percentage of positive and negative spike episodes, and the different responses of capital and employment to shocks. The time series have 500 periods and I drop the first 50. In this table we can see that the congestion effects have an effect on firms' adjustment behavior, making inaction more likely in the case of low adjustment cost value and when costs are high, in most cases, at least for capital. The increase in cost when firms adjust both factors may prevent firms from adjusting either factor as often as they would like.

In general, the model can replicate the basic features of inaction and spikes in investment and labor adjustment. As seen in Table 1.13, the magnitude of the fixed and disruption costs have a greater effect on capital than on employment adjustment. This means that capital is more sensitive to the adjustment costs in the model. Finally, with respect to the response of the variables to shocks, labor growth has a very stable response to shocks when no congestion effects are present, but the response is higher when congestion effects exist. Investment growth responds negatively to shocks in some cases, which may indicate that firms over-invest in some periods, that they replace capital with labor in some good periods or that they simply sometimes disinvest once they receive a bad shock.

It is also interesting to note that even with convex costs, the percentage of simulated observations that display inaction in both capital and labor is positive and high, but not nearly as high as in other cases. This implies that firms have the possibility of staggering adjustment of capital and employment, as discussed before. This is left to future work.

Table 1.14 shows the simulated contemporaneous correlations between labor and capital adjustment. It is interesting to note that the best fit comes from the high congestion effect-low adjustment cost case when all costs are present in capital and labor. It is also important to note that the correlation between labor and capital is negative in the case of high convex costs and low congestion effects, as the analysis of the model predicted as a theoretical possibility. Moreover, when only labor adjustment is costly, this correlation is also negative in the case of low adjustment costs. The correlation between investment and labor growth increases

Table 1.13: Basic simulated statistics

			Investment				Labor			
Adj. Cost Type	C/Π	data	Inaction 0.189	Pos 0.298	Neg 0.018	$\rho(\frac{I}{K}, z)$ 0.10	Inaction 0.134	Pos 0.12	Neg 0.11	$\rho(\frac{\Delta L}{L}, z)$ 0.05
K and L	0.04	NC	0.30	0.25	0.18	-0.03	0.23	0.18	0.11	0.13
		C	0.34	0.29	0.16	-0.09	0.29	0.11	0.10	0.14
	0.2	NC	0.47	0.27	0.14	0.01	0.38	0.08	0.06	0.15
		C	0.60	0.21	0.08	-0.05	0.21	0.17	0.12	0.10
Convex	0.04	NC	0.14	0.07	0.02	-0.11	0.23	0.00	0.00	0.15
		C	0.03	0.12	0.08	0.08	0.00	0.12	0.09	0.21
	0.2	NC	0.09	0.03	0.06	-0.12	0.18	0.02	0.02	0.16
		C	0.09	0.04	0.02	0.07	0.10	0.06	0.05	0.23
Fixed	0.04	NC	0.44	0.21	0.15	0.15	0.31	0.10	0.11	0.16
		C	0.58	0.12	0.09	0.27	0.30	0.10	0.12	0.13
	0.2	NC	0.65	0.08	0.07	0.25	0.35	0.09	0.08	0.17
		C	0.67	0.06	0.06	0.28	0.38	0.07	0.07	0.17
Disrupt	0.04	NC	0.43	0.20	0.15	0.18	0.29	0.13	0.10	0.17
		C	0.64	0.15	0.11	0.21	0.34	0.09	0.10	0.18
	0.2	NC	0.60	0.09	0.11	0.24	0.35	0.08	0.09	0.16
		C	0.55	0.10	0.08	0.26	0.36	0.08	0.08	0.15
K but not L	0.04	NC	0.20	0.30	0.22	0.10	0.28	0.15	0.10	0.19
		C	0.38	0.28	0.17	-0.02	0.25	0.15	0.10	0.14
	0.2	NC	0.48	0.15	0.16	0.07	0.32	0.10	0.11	0.23
		C	0.56	0.18	0.08	-0.10	0.21	0.15	0.13	0.12
L but not K	0.04	NC	0.13	0.28	0.24	0.02	0.26	0.14	0.13	0.11
		C	0.32	0.30	0.20	0.04	0.23	0.16	0.12	0.16
	0.2	NC	0.23	0.26	0.15	-0.08	0.23	0.17	0.13	0.13
		C	0.37	0.26	0.16	0.08	0.26	0.14	0.11	0.13

NC: No Congestion Effects present. C: Congestion Effects present (30%). C/Π: Adjustment cost/Profit

a lot when fixed and disruption costs are present.

Table 1.15 shows the coefficients of a VAR(1) for the investment rate and labor growth. Several parameterizations perform well, among them the one with all costs in capital and labor and with low adjustment costs but high congestion effects. Congestion effects do not seem to have much effect on the convex cost specification, but they do in the other cases, switching the signs at times. This suggests that congestion effects may be important in determining the dynamic behavior of the

Table 1.14: Correlation($\frac{I}{K}, \Delta L$)

Data	0.057			
(Adj cost)/Π	4%		20%	
(Congestion Effects)/Π	4%	30%	4%	30%
All Costs in K,L	0.039	0.054	-0.030	0.005
Convex	0.035	0.203	-0.033	0.385
Fixed	0.205	0.313	0.429	0.466
Disrupt	0.325	0.365	0.421	0.421
Adj. Costs in K, not in L	0.193	0.016	0.107	0.002
Adj. Costs in L, not in K	-0.058	-0.070	0.015	-0.080

Table 1.15: Simulated $VAR(1)$

Data		$C/\Pi = 4\%$				$C/\Pi = 20\%$			
-0.008	-0.008	No Compl.		Compl=30%		No Compl.		Compl=30%	
0.037	-0.147	I/K	ΔL	I/K	ΔL	I/K	ΔL	I/K	ΔL
All Cost	$(I/K)_{-1}$	0.008	0.137	-0.055	0.019	-0.005	-0.005	-0.002	0.002
	ΔL_{-1}	0.013	-0.551	0.048	-0.320	-0.020	-0.387	0.480	-0.077
Convex	$(I/K)_{-1}$	-0.025	-0.061	-0.004	0.000	-0.007	-0.03	0.032	0.000
	ΔL_{-1}	0.017	-0.269	0.012	0.065	0.026	-0.272	0.007	-2.918
Fixed	$(I/K)_{-1}$	-0.005	0.000	0.005	0.000	-0.011	0.001	0.054	0.000
	ΔL_{-1}	1.088	-0.431	-0.465	0.341	0.408	-0.329	-3.812	-0.165
Disrupt	$(I/K)_{-1}$	0.001	0.001	0.006	0.001	0.037	0.000	-0.006	0.001
	ΔL_{-1}	-1.010	-0.644	-0.254	-0.197	-3.496	-0.244	0.324	-0.210
All K	$(I/K)_{-1}$	-0.016	0.000	-0.020	-0.013	0.000	0.000	-0.010	0.009
	ΔL_{-1}	-0.062	-0.233	0.085	-0.111	0.001	-0.239	0.018	-0.028
all L	$(I/K)_{-1}$	-0.005	0.004	0.009	0.000	-0.009	0.024	0.030	-0.006
	ΔL	-0.051	-0.330	0.233	-0.355	0.023	-0.435	0.687	-0.318

firms' factor adjustment. Congestion effects may act by letting the firm adjust one input at a time, creating other types of dynamics in the economy. It is important to note that even if the coefficient on lagged capital is small in the employment equations, very small movements in capital have a huge effect on the number of workers because of scale effects.

What conclusions can we draw from this calibration exercise? First, this parameterization shows that considering capital and labor interrelation in adjustment costs affects the dynamic behavior of labor and capital adjustment. Second, none of the adjustment costs taken alone can completely explain the moments observed in the data, and in fact, it is the combination of these costs that allows one to match the facts. Third, this model also presents a high number of negative investment spikes and. It seems that a higher degree of non-reversibility than the one assumed here is needed to match the rarity of negative spikes in the data. Fourth, even with a model of only convex costs we can have inaction zones due to the existence of other margins of adjustment. Fifth, the combination of parameters that best fits the data is the low adjustment cost-high congestion effects case with all forms of adjustment costs present in capital and labor.

Sixth, the model calibrations show different results if the costs are present in one factor alone; this point is important because it suggests that considering one factor at a time may lead to misleading estimates of adjustment costs, since the estimated costs for one factor may incorporate information on costs from the omitted factors. The estimations of models with one factor which is costly to adjust, may incorporate costs from the other in the productivity shocks or in the estimated parameters. And, finally, congestion effects in adjustment costs are important and they imply, according to the model, different behavior in capital and labor adjustment than that observed when each input is considered separately.

The next section will calculate these adjustment cost parameters in a more formal way. This will give a clearer idea of the questions asked here; this is, if there are congestion effects in capital and labor adjustment and if the nature of this interrelation comes from non-convexities in the adjustment cost process.

1.5 Structural Estimation of the Adjustment Cost Parameters

In this section, I estimate the adjustment cost parameters from the model. Specifically, I use a minimum distance algorithm to match the moments from the data to the moments from a simulated panel generated with the model. My main assumption is that the model is a good approximation of the way firms make decisions about labor and capital. I discuss the methodology and then present the results.

1.5.1 Methodology

The methodology to apply is the Method of Simulated Moments, in the spirit of McFadden (1989), Pakes and Pollard (1989), and (1996) and Hall and Rust (2003) among others. The choice of this estimation method is made for computational feasibility, given that other methods, such as maximum likelihood, would require an enormous amount of computing power.

The parameter set to be estimated is composed of fixed, convex and disruption costs for capital, labor and joint capital-labor adjustment, and the resale price of capital. These are represented by a vector $\Theta = [(F_k, F_l, F_{lk}), (\gamma_k, \gamma_l, \gamma_{lk}), (\lambda_k, \lambda_l, \lambda_{lk}), p_i]$

The algorithm consists of solving the dynamic programming problem given a set of parameters Θ, getting the policy functions for that specific parametrization, simulating a panel of plants, calculating the chosen moments from that panel and comparing them with the moments from the data. The function that depends on the parameters and must be minimized is given by:

$$\min_{\Theta} J(\Theta) = \{\mathbf{M}_{data} - \mathbf{M}_{simulated}(\Theta)\}' W \{\mathbf{M}_{data} - \mathbf{M}_{simulated}(\Theta)\} \tag{1.22}$$

where $\mathbf{M}$ is a vector of moments, W is a weighting matrix and Θ is a vector of parameters to be estimated. To find standard errors, there are two options. The first option is to carry on a Montecarlo simulation, repeating the procedure under different realizations of the stochastic shock. The second option to calculate the standard errors is by obtaining the asymptotic distribution of the estimator, like in Hall and Rust (2003); this is the method that I use which is simpler and much faster. I construct the simulated panels with 1000 plants over 500 periods. At the moment, I set W to the identity matrix in order to estimate the parameters, which gives consistent but not efficient estimates; however, in a second stage, I recalculate W as in Hall and Rust (2003) in order to calculate the standard errors. In future work, I plan to re-estimate the parameters with this optimal weighting matrix to get efficient estimates. See Hall and Rust (2003) for more details; To solve for parameters I use the Nelder-Mead simplex algorithm.

Regarding the moments to match, the main questions are which moments reflect variation in the parameters and which moments are worth matching given their relevance in understanding firm behavior. The empirical evidence in the second section presented characteristic distributions for capital and labor. In particular, the distributions showed highly irreversible capital and lumpy adjustment and inaction zones for both capital and labor. However, given the arbitrary definition of inaction and the implications for different types of capital[44] , I choose not to match this

[44]For example, a hammer, some special cutting tools and a milling machine are capital goods,

feature. Instead, I focus on the lumpiness of the distributions and match the adjustments above the 90^{th} and below the 10^{th} percentile in the distribution of capital and labor adjustment (i.e. the fraction of positive and negative spikes). The VAR(1) illustrates the dynamic interrelations of capital and labor and it is an important feature to consider. On the other hand, the model highlights the importance of shocks in the movements of capital and labor; the correlation between adjustments and shocks is therefore the other important moment. Finally, the correlation between capital and labor adjustment is of prime interest in the paper and it completes the set of moments I attempt to match (11 total).

1.5.2 Adjustment Costs Parameters: Fitting the Data

In order to analyze whether congestion effects in the adjustment for capital and labor are important, I first match the moments assuming that all parameters are present, including the congestion effects parameters $(F_{kl}, \gamma_{kl}, \lambda_{kl})$, and compare the results with those obtained not including the congestion effect terms in the model. In order to analyze which type of adjustment costs are important, I compare the results of the full specification model with the results of models that shut down a particular type of adjustment cost. It is worth emphasizing that since I am not using the optimal weighting matrix but instead the identity matrix, this value is understated. The calculated moments are presented in table 1.16, and table 1.17 presents the calculated parameters with the standard errors for the full specification.

and defining an investment rate lower than 1% as inaction would not considered the investment in small but important units of capital.

Table 1.16: Simulated Moments

MOMENTS		DATA	Simulated Moments: Convex+Fixed+Disruption, Complem.	Simulated Moments: Convex+Fixed+Disruption, No complem.	Simulated Moments: Convex
Positive Spikes	$0.61 < (I/K)$	0.1	0.181	0.3	0.38
(90^{th} percentile)	$0.23 < (\Delta L/L)$	0.1	0.133	0.27	0.25
Negative Spikes	$0 > (I/K)$	0.1	0.152	0.21	0.26
(10^{th} percentile)	$-0.22 > (\Delta L/L)$	0.1	0.105	0.19	0.21
VAR coefficients	bkk	-0.008	-0.009	-0.014	-0.003
	bkl	-0.008	-0.016	0.21	0.065
	blk	0.037	0.068	0.045	0.005
	bll	-0.147	-0.203	-0.073	-0.866
Correlations	$\rho_{(\frac{I}{K},\frac{\Delta L}{L})}$	0.057	0.049	0.139	0.203
	$\rho_{(\frac{I}{K},z)}$	0.1	0.089	0.03	0.074
	$\rho_{(\frac{\Delta L}{L},z)}$	0.05	0.135	0.154	0.297
$J(\theta)$		N.A.	0.022	0.152	0.745

Two important facts emerge from table 1.16:[45] First, the model that considers congestion effects does better in several dimensions than the model that does not. In particular, one of the fitted VAR coefficients in the case without congestion effects has the wrong sign relative to the data, and the contemporaneous correlation between capital and employment adjustment is too high in the case without congestion effects. This suggests that when firms adjust both factors they pay a price instead of having a benefit of adjusting them together. It is important to emphasize that even if the firms pay an extra cost of adjusting capital and labor together, the discounted expected net benefit can still be higher than if firms adjust one factor each period. The second important fact from table 1.10 is that the model that considers convex costs as the only cost faced by firms when adjusting does the worse job in explaining the data moments.

[45]These results should be taken with care, however; the minimization routine is susceptible to getting local minima as solutions. More starting points for the algorithm are needed to confirm the findings presented here.

Table 1.17: Calculated Adjustment Cost Parameters

	Convex+Fixed+Disruption			Convex
	Congestion Effects		No Congestion Effects	
P_{sell}	0.42*pi	(0.7307)	0.57*pi	pi
F_k	0.0002	(0.0021014)	0.0065	NA
F_l	0.007	(0.090392)	0.013	NA
F_{lk}	0.14	(0.40376)	NA	NA
γ_k	0.000006	(0.0000004)**	0.000016	0.092
γ_l	0.0009	(0.0045079)	0.0000571	0.0134
γ_{lk}	0.016	(0.0065368)*	NA	0.024
λ_k	0.0002	(0.0000182)**	0.00065	NA
λ_l	0.0215	(0.0043362)**	0.092	NA
λ_{lk}	0.046	(0.0199720)*	NA	NA

Standard errors in parentheses; **/* significant at 1% and 5%

Table 1.17 has important information about the size of the adjustment costs and about the statistical significance of the estimates.With respect to the size of the estimates, the high degree of irreversibility of the capital in Colombia is observed in the lower selling price of capital for all the models except in the benchmark convex case (by assumption $p_{sell} = p_{buy}$ in this case). This irreversibility is much bigger than the one found by Cooper and Haltiwanger (2005) for the U.S. This degree of irreversibility is consistent with the asymmetric distribution for the gross investment observed in the Colombian census. The high costs of adjusting both factors at the same time are somewhat surprising. However, the functional form for the congestion effects case does not allow for a direct comparison between the individual costs and the congestion cost. The adjustment costs are not large, but ignoring them does not allow a good match of the moments in the data.

With respect to the statistical significance of the estimates, the procedure allows to accept statistically the disruption costs for capital and labor, the convex costs for capital but not for labor and the congestion effect present in the convex cost joint parameter and the disruption cost joint parameter. The low statistical significance of the fixed costs may be due to the fact that the disruption cost takes all its effects. Also, according to the procedure, I can not reject the possibility that the convex costs are present in the Colombian firms when they adjust capital or when they adjust capital and labor at the same time.

1.5.3 Non-formal Tests of Goodness of Fit

After getting the parameters, the following exercises look to determine how well the model can, using the estimated parameters, fit the distributions of adjustment and other moments not considered in the estimation procedure.

Figure 1.13. replicates the distributions of adjustments generated using the model and the estimated parameters. The simulated distributions are more lumpy, but the main characteristics observed in the data are present here. In particular, the continuous adjustment in materials and energy contrast with the lumpy pattern observed in the distributions of adjustments of capital and labor. It is interesting to notice the asymmetry in the capital adjustment distribution and the symmetry in the labor adjustment distribution.

Table 1.18. tries to replicate the logit estimates for the probability of spikes in adjustment or inaction given spikes of adjustment or inaction in the other factor. In order to do so, I generated a panel with 1000 firms and 500 periods using the estimated parameters, dropping the first twenty observations in each simulated

Figure 1.14: Distributions of Factor Adjustments for the Simulated Series. Percentage of observations (y-axis) in a range of adjustments (x-axis).

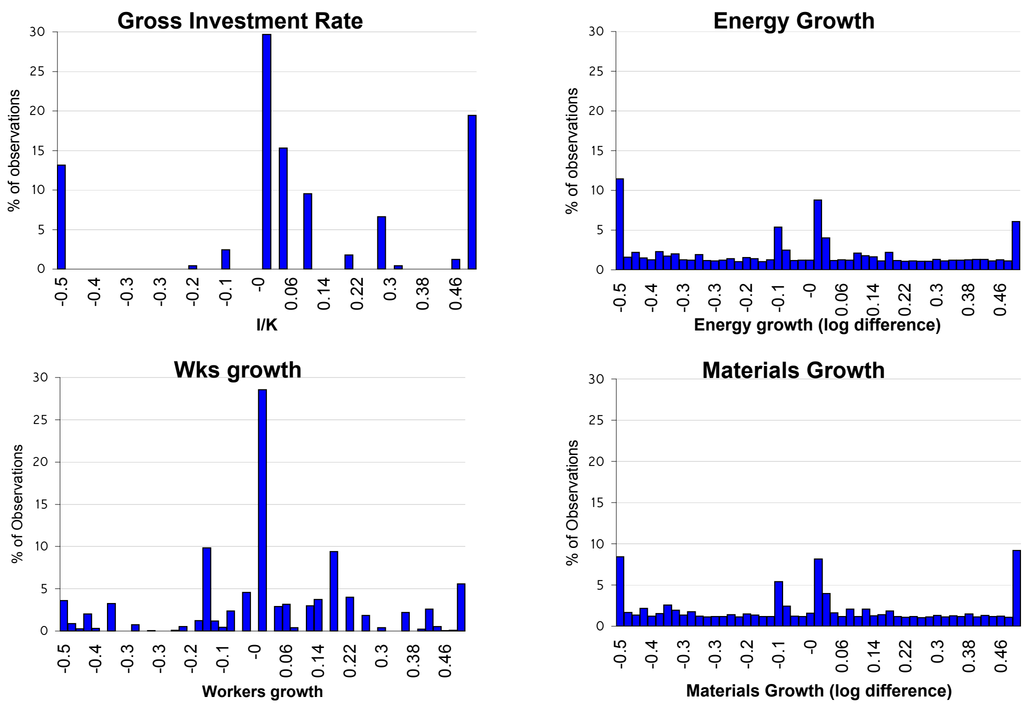


Table 1.18: Probability of inaction/adjustment conditional on Inaction/adjustment of the other factor: Simulated data

Variable x		Investment P(inaction/x)	Investment P(Spike/x)	Employment growth P(inaction/x)	Employment growth P(Spike/x)
Investment	Inaction			0.026 **	-0.021**
				(0.007)	(0.007)
	Spike			-0.017*	-0.001
				(-0.008)	(-0.008)
Employment Growth	Inaction	0.031**	-0.035**		
		(0.008)	(0.008)		
	Spike	-0.003	-0.008		
		(-0.008)	(0.008)		
Observations		49000	49000	49000	49000

†/*/** significant at 10%, 5% and 1%. Shocks in regression
Dummies for inaction are defined as 1 if $abs(x) < 0.01$ and dummies for spikes are defined as 1 if $x > 0.2$

series. The logit estimated using the simulated panel does a mix job matching the empirical coefficients, but it is worth to notice that the definition of small or large adjustment is arbitrary and given the lumpier nature of the simulated panel, these definitions can affect the results. In particular, there is a significant and negative probability of adjusting capital and labor when there is inaction in the other factor, which is not observe in the data. Even if it will be worth to incorporate this set of moments in the estimation, the problem would come from the definition of large and small adjustments. This is left for future work.

1.6 Conclusions

In this paper I have used the Census of Manufacturing Firms in Colombia to analyze if labor and capital adjustments are interrelated, whether there are congestion effects in the adjustment process, and what is the nature of the adjustment costs.

Empirically, firms adjust employment and capital in an interrelated way, using several margins of adjustment in the process. As is the case for U.S. firms, there is a distribution of adjustment that is at the same time lumpy and infrequent for capital and labor, being more frequent in the case of materials and energy. These patterns suggest that to understand the effect of policies such as tax investment incentives or reductions in the firing/hiring costs, a model of joint capital and labor adjustment is needed.

I argue that these patterns can be explained with a dynamic model in which labor and capital are costly to adjust. The adjustment cost structure is chosen to match some facts observed in the data, such as the decrease in output after the adjustment, the cost of hiring and firing workers, the cost of installing capital and a convex component to capture the mix of smooth and lumpy adjustment.

The proposed model is first calibrated taken the adjustment costs parameters in an arbitrary way to serve as example and then estimated with a minimum distance procedure. The analysis of the decision rules for firms' capital and labor adjustment shows that the adjustment patterns are highly nonlinear and they can be characterized as a bidimensional (S,s) policy where adjustment depends not just of the states of the system but also on the choices. The calibrated model is able to replicate some features from Colombian firms' adjustment patterns, but none of the different adjustment cost types fit the data when considered alone. We also observe that a model with adjustment costs only in capital or in labor predicts different behavior. Importantly, models with high congestion effects more closely resemble the data.

Finally, I estimate the deep parameters of the model using a structural approach with a minimum distance algorithm. This method reveals that a model that incorporates congestion effects fits the data best and the structural methodology allows me to reject statistically the existence of fixed costs and to accept the existence of disruption costs for capital and labor, the existence of convex costs for capital but not for labor and the existence of congestion effects.

The main conclusion is that labor and capital adjustment should be analyzed together. This is supported both by theory and by facts. The data show an interrelated adjustment pattern. Moreover, a model that incorporates adjustments for both capital and labor, generates sharply different predictions if adjustment costs are assumed for one factor alone.

The main advantage of the type of methodology proposed in this paper is that several policy experiments can be analyzed. The effects of taxes on capital and employment and the aggregate effects of these policies are among the main ones. Also, Colombia undertook several market liberalization reforms at the beginning of the 1990s, so it would be interesting to use this structural framework to explore how the reforms affected firm behavior in terms of factor adjustment. And finally, it may be worth exploring sectoral differences in firm behavior, especially since the parameters and functional forms may not be the same for all types of industries. This paper took an aggregate approach to this problem, but a more micro-level analysis may prove useful, particulary if micro level behavior is the key to understanding aggregate responses.

Chapter 2
Costs of Adjusting Production Factors: The Case of a Glass Mould Company

2.1 Introduction

In chapter 1, I proposed and estimated a model to explain the main empirical findings observed in the distributions of factor adjustments for the Colombian Census of Manufacturing Firms. This explanation relied on the existence of a wide range of adjustment costs for capital and labor and in the interrelation of such adjustments. The present chapter presents direct evidence for the adjustment costs proposed in chapter one, in order to relate these rather abstract concepts about adjustment costs and interrelation to a concrete firm. The approach of this chapter is simply to observe the internal records of a firm and determine directly how much this firm has to pay for adjusting production factors[1]. Using these observed adjustment costs, the chapter also evaluates how well the generic model presented in the previous chapter can fit a specific firm.

Ever since the work of Holt, Modigliani, Muth and Simon (1960), economists, under the profit maximizing agent paradigm, have tried to derive optimal production decision rules and to test these rules with actual data from operating plants. Despite their effort, the number of different production factors, the heterogeneity in different

[1] In some cases, the adjustment costs analyzed in the previous chapter are not directly observed, but the numbers presented in this section are either directly observed or part of a reduced form data analysis; in the former case, the reduced form analysis does not pretend to uncover the structural parameters because of endogeneity problems, and are simply aimed to illustrate the concepts developed in chapter one.

production processes and the mathematical complexities of the problem, in addition to the difficulty in accessing the data, have been and still are a big challenge for economists.

Production decisions are taken in an uncertain and dynamic environment where decisions today affect the decision tomorrow. At the firm level, the usual approach to the problem of deriving optimal decision rules for production factors was to specify a quadratic cost function and derive the optimal decision rules. The choice of a quadratic function was to simplify the mathematical problem. At the aggregate level, this quadratic function was implemented to fit the smooth series observed in the data capturing the fact that it takes time to adjust production factors.

Despite its simplicity, the quadratic adjustment cost implies continuous adjustment, a feature that is not observed in the adjustment of many production factors at the firm level, and in particular, not observed in the adjustment of employment and capital. Instead, at the micro level, we observe infrequent and lumpy adjustments. The main explanation for this firm behavior is that there are non-convex costs of adjusting production factors, which translate into discrete payments or costs, like the cost that a firm has to pay to hire or fire a worker, or the resources in time and money that a firm has to allocate to adjust capital.

Adding to the debate, this chapter presents direct and detailed evidence of the type of costs a firm has to pay when hiring/firing a worker or when adjusting capital, using detailed monthly data from a glass container mould firm in Colombia. At this frequency, we observe a fixed cost when the firm hires or fires workers and an adjustment cost that comes from the disruption in the production process during periods of adjustment, which increases when the adjustment is simultaneous in capital and employment. These adjustment costs are directly related to the ones proposed in chapter one's model and are specific examples of such adjustment costs. It is important to emphasize that the adjustment costs present here are not estimated as in the previous chapter uncovering the structural parameters, but instead they are directly observed and analyzed using reduced form equations.

The observed magnitudes of the adjustment costs are important. Hiring a new worker costs $\$1,320$ US dollars and firing an existing worker costs $\$53,000$ US dollars, a striking asymmetry. The existence of a powerful union increases the cost of adjusting the number of workers through contractually established fees for firing in addition to high legal costs. With respect to the disruption costs, hiring a worker increases the production time by 1.02% a month and installing new units of capital requires on average 1,417 hours a month, which correspond respectively to 0.073% and 1.6% of total monthly sales. The disruption cost of installing capital is increased by 0.86%, to 1.614% of total sales, when there is simultaneous adjustment of capital and employment.

Besides presenting direct evidence on the different types of adjustment costs, this paper examines the pertinence of using the model developed in the previous chapter that fits the average factor adjustment behavior of firms in Colombia, to describe and predict the actual decision rules for this particular firm. In order to do so, I use the available data on production and adjustment costs for this firm to calibrate the model.

The model matches many of the qualitative features of the data and provides a good fit quantitatively in other dimensions. Specifically, it is able to closely match the correlation between capital and employment adjustment and productivity shocks. However, it falls short in explaining the effects of employment growth in investment. There are some conceptual issues described later with respect to the type of production process the model in the previous section describes compared to the production process in this specific firm, but in any case it is useful to link the direct evidence of adjustment costs obtained in this firm with a generic model that fits the macro level. Overall, the level of detail and the quality of the data, together with the particularities of the firm, help us understand, on the one hand, the nature of the adjustment costs observed at the firm level, and on the other hand, the the ability of a model estimated at the macro level to fit the data for a micro level firm

The paper has 5 sections. Section 2 describes the firm and the production process. Section 3 presents the data and calculates adjustment costs, while section 4 describes the model, estimates the remaining parameters needed for the simulation and presents the results, discussing the validity of simulating the model from the previous chapter without any modifycation. Section 5 concludes and gives directions for future research.

2.2 Description of the firm and the production process

2.2.1 History of Moldes Medellin

The firm used in this study is a glass mould company called Moldes Medellin. This firm is a subsidiary of Ross Mould International and it is located in Medellin, Colombia. Ross Mould International is the largest glass bottle mould company in the world, owning plants in Colombia, England, Hungary, South Africa and U.S.[2]

Moldes Medellin started operations in 1999. Before that, it was called Metalicas Peldar and it was a division of Peldar, a subsidiary of Owens Illinois located in Medellin and Bogota. Peldar (Owens Illinois) sold Metalicas in 1999 to Ross Mould International, a long term US Owens Illinois' supplier.[3] Ross Mould made a big initial investment, represented not only by machinery and land but also in the form of knowledge of the production process (embodied in local labor with years of experience); since then, no other big investments have been made.

The main customers for Moldes Medellin and for Ross International are the two worldwide leading companies in the glass industry: Owens Illinois and Saint Govain. Owens Latin America (Colombia, Peru, Venezuela, Ecuador, Dominican Republic and Puerto Rico) has an special agreement with Moldes Medellin to supply 90% of their needs for the next 10 years[4]. As a consequence, the firm's investment in

[2]Ross Mould International has four US subsidiaries: Ross Mould, Penn Mould, OMCO mould and Brockway Mould. Together, these operations design and built moulds for virtually every glass bottled product on the U.S. market, including those for leading food, beverage, cosmetics manufacturers such as Kraft, Gerber, General Foods, Coca Cola, Avon, and many others.

[3]The Glass industry requires high levels of capital. These industries used to be vertically integrated with their supply chains, and it was common to find units within the firms in charge of supplying the moulds required for glass production.

[4]Ross International has similar agreements with Owens all around the world.

publicity and marketing is almost zero, allowing the company to focus on production and service.

It is important to point out that Ross Mould does not have competitors in Colombia and there are very few companies in Europe and America able to manufacture this kind of product[5]. As a result, it is very difficult to find qualified labor and the company needs to provide most of the specific training for new workers.

2.2.2 The Production Process

Moldes Medellin produces moulds primarily for glass container companies. A glass mould consists of several parts, each creating a stage in glass container manufacturing process, giving the shape to the containers in a progressive way. Glass moulds require high precision in the dimensions and high technology both in design and manufacturing.

This company uses machine tools directed by computer programs which are adapted for each batch. The operator of the machine tools has to do a special mounting for each job, then charges and proofs the programs and measures the final result. Maintenance also plays a very important role since a production disruption caused by a machine breakdown can have a considerable impact on service costs and time.

Manufacturing the moulds has two phases: planning and production. The planning phase starts with the designing of the mould using CAD (Computer As-

[5]PEREGO and CISPER are perhaps the most significant competitors that Ross Mould has to face in Europe and America.

sisted Design). Once the design is done, the engineers program the production process and write codes to program the machines for each step in the process, using special engineering programming software (CNC- Computer Numerical Control and CAM -Computer Assisted Machining). The next step is to assign the tools and cutting conditions.

The production phase starts with an initial machining to the raw cast iron material, and then a special welding process is applied to a part of the mould. Depending of the shape of the mould, different machining processes are applied afterwards. In order to guarantee the precision of the product, a Coordinate Measure Machine is used during the process to measure results. Each piece is analyzed by this machine and the dimensional report is sent directly to the customer.

For each batch, the machine tools have to be set using different tools depending on the job. These tools last between 6 to 12 months and are very expensive. Also, there are special additional elements added to the machine tools in order to execute special processes which are called fixtures.

In the next subsection I will describe the type of adjustment costs the company faces when adjusting machines for new jobs and when hiring new workers. Later, these costs are quantified with first-hand data on costs from the internal records of the firm.

2.3 Data: Production process, Factor Adjustment Dynamics and Adjustment Costs

2.3.1 Data

I have three years of monthly data from Moldes Medellin, from January 2003 until December 2005. The data set has information on production (sales in US dollars and quantities by item), investment (book values in Colombian pesos, calculated as in Eslava et al (2004)), energy (quantities and prices), materials (prices and quantities by job), labor hours and number of workers (production and non production), and total labor costs in US dollars[6]. There is also data on setup times in man-hours. I consider setup times are to be an adjustment cost for reasons I will discuss later. All prices are converted to December 2005 US dollars using the official exchange rate and the US CPI series from the BLS.

My measure of capital consists of two parts. The first part is the book values of capital excluding land and vehicles. The second component consists of the tools that the company uses to produce the moulds which have an approximate lifetime of 6 months in Moldes Medellin and are not including in the book value measure of capital[7].

[6]The calculation of labor costs is done by the plant manager day by day, converting payments in colombian pesos to dollars using the daily official exchange rate

[7]These two types of capital have different depreciation rates. The depreciation rate for the first type, following Oliner (1996), was set equal to the 9.5% annual depreciation rate for numerically controlled machine tools In the second type, the depreciation taken was 35% monthly, implying a scrap value of 12% in 6 months and a zero value in 12 months. The average selling price Moldes Medellin gets is 12%.

2.3.2 A First look at the Production and Factor Adjustment Dynamics

This section explores how Moldes Medellin adjusts its input factor choices when production changes. Specifically it looks at the behavior of production in sales and units, the number of production and non production workers, production labor hours and the costs and units of materials and energy.

I start by describing basic statistics and graphing time series, then discuss volatility and comovement among the variables in levels and in percentage terms. Although the sample size is very small (36 observations), it is still useful to look at these numbers to get an idea of the behavior of the firm.[8] Table 2.1 shows the mean and standard deviation of the levels and growth rates of these variables. We can see from this table that Moldes Medellin is not a very big firm. Monthly sales are less than a million dollars on average and there are only 82 workers with a capital stock of 7.5 million dollars. Almost all the capital consists of machine tools, 23% of the total workers are engineers and 89% of the production workers are high skilled workers. The firm does not hold inventories because all jobs made made to order. It is also worth noticing that the plant was underutilized during the entire sample period which indicates no shortage of capacity. Finally, the company had an interesting downsizing process in December 2003 in output and labor, since the management started to build another plant to get rid of the financial burden imposed by the union; this can be seen in figure 2.1. This regime change plays an important role

[8] A small sample size can affect the standard deviation of the variables and the statistical significance of the correlations.

Table 2.1: Basic Statistics. Monthly values

	Levels		Growth	
	Mean	Std	Mean (%)	Std
Sales	906	229	1.84	0.21
Production Workers	53	2	0.02	0.02
Nonproduction Workers	29	2	-0.34	0.03
Total Workers	82	3	-0.12	0.02
Energy	8.4	2.0	7.23	0.34
Materials	306	115	3.96	0.30
Units produced	7.8	1.9	4.18	0.30
Hours	7.2	1.8	2.79	0.22
Energy (thousand Kw)	125	9	1.19	0.08
Capital	7571	420		
Capital Tools	65	26		
Investment	59	80		
Investment Tools	23	19		
Investment Rate (I/K)			0.80	0.01
Inv. Tools/ Capital			0.30	0.00
Inv.Tools/Capital Tools			33.88	0.11

Sales, Capital, Investment, Energy and Materials in thousand of 2005 US$ dollars.
Hours and Units produced in thousands

and it is considered later in the estimations.

Figure 2.1 shows the series for employment and labor hours, investment and capital, energy in units (Kw) and monetary values, materials, total costs, total sales and total units produces. Figure 2.2 shows the factor adjustment graphs at a monthly frequency. The peaks observed in production and non production workers adjustment and the lumpiness in their adjustment suggest the presence of non-convex adjustment costs to change the number of workers. Hours, energy and materials, move much more often than employment. Total investment has some inaction months mixed with some peaks. In the case of the long term tools, which depreciate quickly, investment is always positive, with a peak that represents a special fixture the company bought to produce a special mould part.

Figure 2.1: Production Factors Series

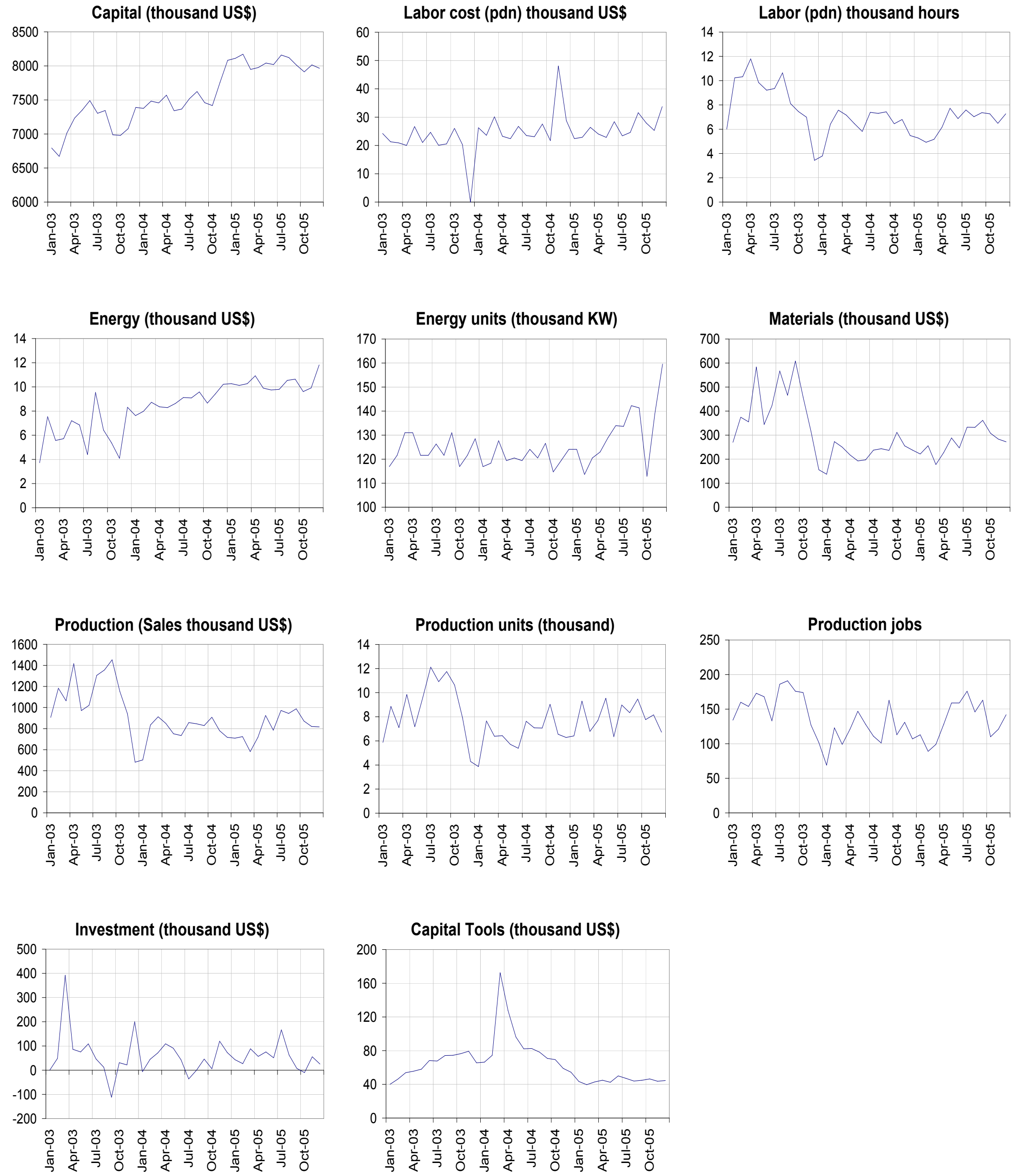


Figure 2.2: Production Factors Adjustment

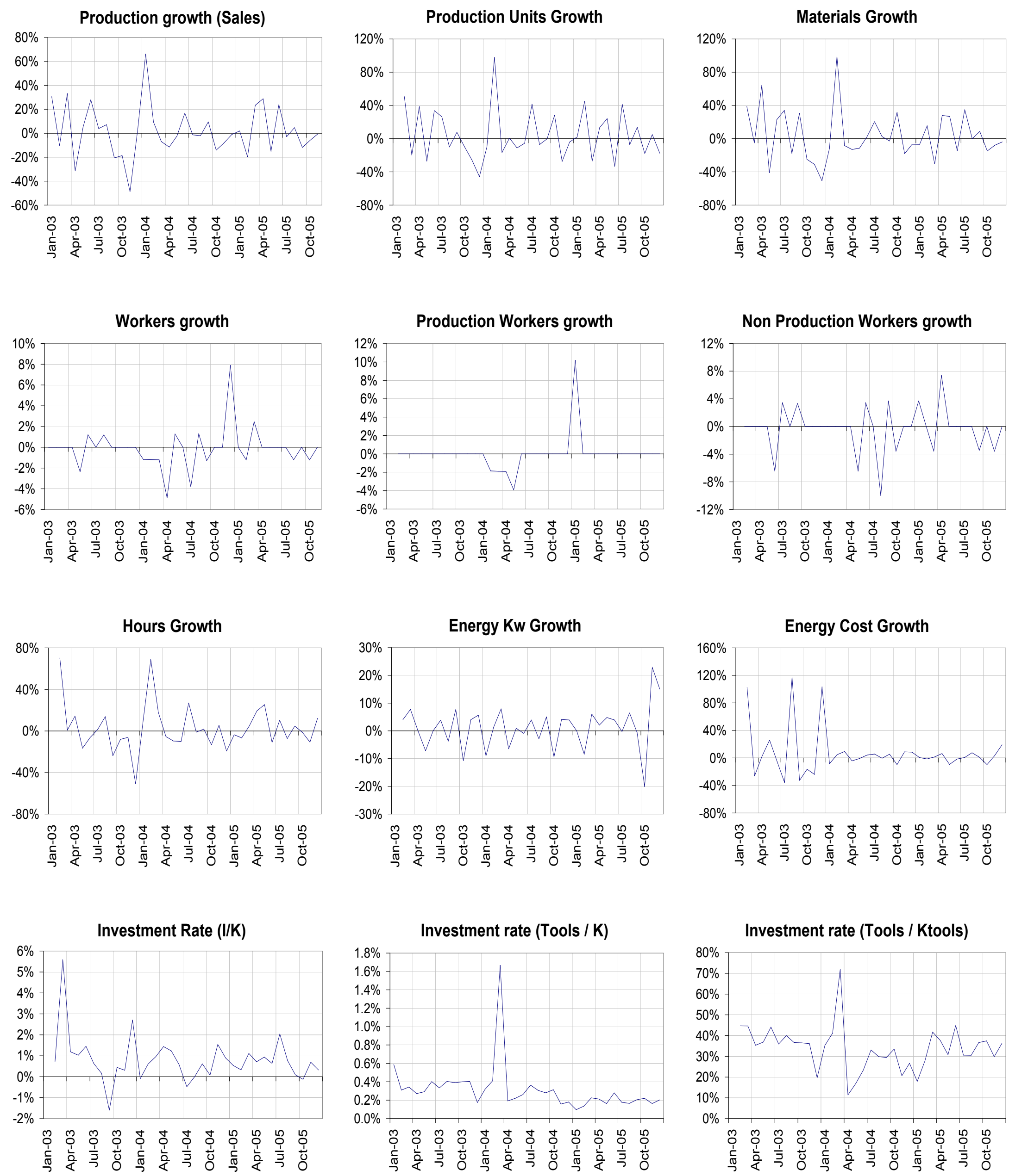


Table 2.2: Correlation among the levels of the variables

	Sales	Pdn Wks	Nonpdn Wks	Total Wks	K	K Tools	Energy	Materials	Units pdn
Sales	1.00								
Pdn Workers	0.26	1.00							
Nonpdn Wks	0.36	0.32	1.00						
Total Wks	0.37	0.87	0.75	1.00					
K	-0.46	0.01	-0.71	-0.36	1.00				
K Tools	0.06	-0.41	0.38	-0.09	-0.32	1.00			
Energy	-0.47	-0.18	-0.69	-0.49	0.83	-0.19	1.00		
Materials	0.95	0.37	0.29	0.41	-0.37	-0.07	-0.48	1.00	
Units pdn	0.82	0.32	0.04	0.25	-0.10	-0.14	-0.21	0.87	1.00
Hours	0.86	0.18	0.30	0.28	-0.38	0.05	-0.34	0.76	0.61

Table 2.3: Correlation among the Growth of the variables

	Sales	Pdn Wks	Nonpdn Wks	Total Wks	$\frac{I}{K}$	$\frac{Itools}{K}$	$\frac{Itools}{Ktools}$	Energy	Mat.	Units pdn
Sales	1.00									
Pdn Wks	-0.07	1.00								
Nonpdn Wks	0.17	0.30	1.00							
Total wks	0.05	0.82	0.79	1.00						
$\frac{I}{K}$	-0.21	-0.08	-0.05	-0.08	1.00					
$\frac{Itools}{K}$	0.13	-0.26	-0.01	-0.17	-0.03	1.00				
$\frac{Itools}{Ktools}$	0.26	-0.19	0.00	-0.13	-0.01	0.75	1.00			
Energy	-0.11	-0.01	0.00	0.00	0.08	-0.01	0.01	1.00		
Materials	0.94	-0.09	0.11	0.00	-0.16	0.01	0.17	-0.18	1.00	
Units pdn	0.87	-0.04	0.03	-0.01	-0.19	-0.05	0.07	-0.08	0.91	1.00
Hours	0.78	-0.10	0.09	-0.01	-0.09	0.19	0.38	0.16	0.63	0.64

Table 2.2 shows the correlation among variables and Table 2.3 shows the correlation among adjustments. It is interesting to notice the positive and strong correlation between hours growth and investment in long lived tools and between hours and energy and materials. This firm chooses to adjusts hours rather than workers since workers adjustment is very costly.

The dynamic correlations between adjustments are presented in Table 2.4, which shows a VAR of factor adjustments. Having in mind the small sample size and the fact that this is just an empirical exercise, the only statistically significant correlations are between lagged hours growth and investment in long lived tools, and between hours growth and lagged energy growth. The same interrelation between capital and labor is observed at the aggregate level in other studies using the number

Table 2.4: VAR for Growth of the variables

	$\frac{Itools}{Ktools}$	$\frac{\Delta M}{M}$	$\frac{\Delta e}{e}$	$\frac{\Delta h}{h}$
$(\frac{Itools}{Ktools})_{-1}$	-0.192	0.009	-0.186	0.001
	-0.169	-0.238	-0.176	-0.165
$(\frac{\Delta Materials}{Materials})_{-1}$	0.228	-0.288	-0.138	0.181
	-0.173	-0.244	-0.18	-0.169
$(\frac{\Delta Energy}{Energy})_{-1}$	0.096	0.082	-0.505	0.017
	-0.149	-0.21	(0.156)**	-0.146
$(\frac{\Delta Hours}{Hours})_{-1}$	0.632	0.402	0.239	0.016
	(0.276)*	-0.389	-0.288	-0.27
$(\frac{\Delta TFP}{TFP})_{-1}$	-2.34	-0.541	-0.36	-0.98
	(0.767)**	-1.08	-0.8	-0.75
Constant	0.395	-0.009	0.074	-0.007
	(0.059)**	-0.083	-0.061	-0.058
Observations	34	34	34	34
R-squared	0.4	0.09	0.29	0.1

of workers. It is possible that at this frequency and with the high adjustment costs in employment this firm faces, the utilization of labor, reflected in the production hours, is more closely related to investment than the number of workers.

This descriptive evidence suggests that given the constraints this firm faces on adjusting workers or the capital stock, it instead uses intensively other margins of adjustment such as hours, materials and energy. The low capacity utilization gives the firm larger cushion to adjust these factors both upwards and downwards. With respect to investment, even if Moldes Medellin faces high costs of capital adjustment due to setup costs for its tools, it still invests almost continuously, but in a lumpy way as seen in figure 2.2. The next section presents direct evidence on the costs that this firm has to pay when adjusting capital and labor.

2.3.3 A Description and Calculation of the Adjustment Costs faced by the Company

This section discusses the type of adjustment costs that Moldes Medellin faces, at a monthly frequency, when it decides to change its production factors, specifically capital and employment in response to changes in demand. The methodology used in this section is descriptive, meaning that the adjustment costs are directly observed as payments or increases in costs that the firm incurs when adjusting. I use some reduced form regressions to isolate individual effects of the adjustment costs.

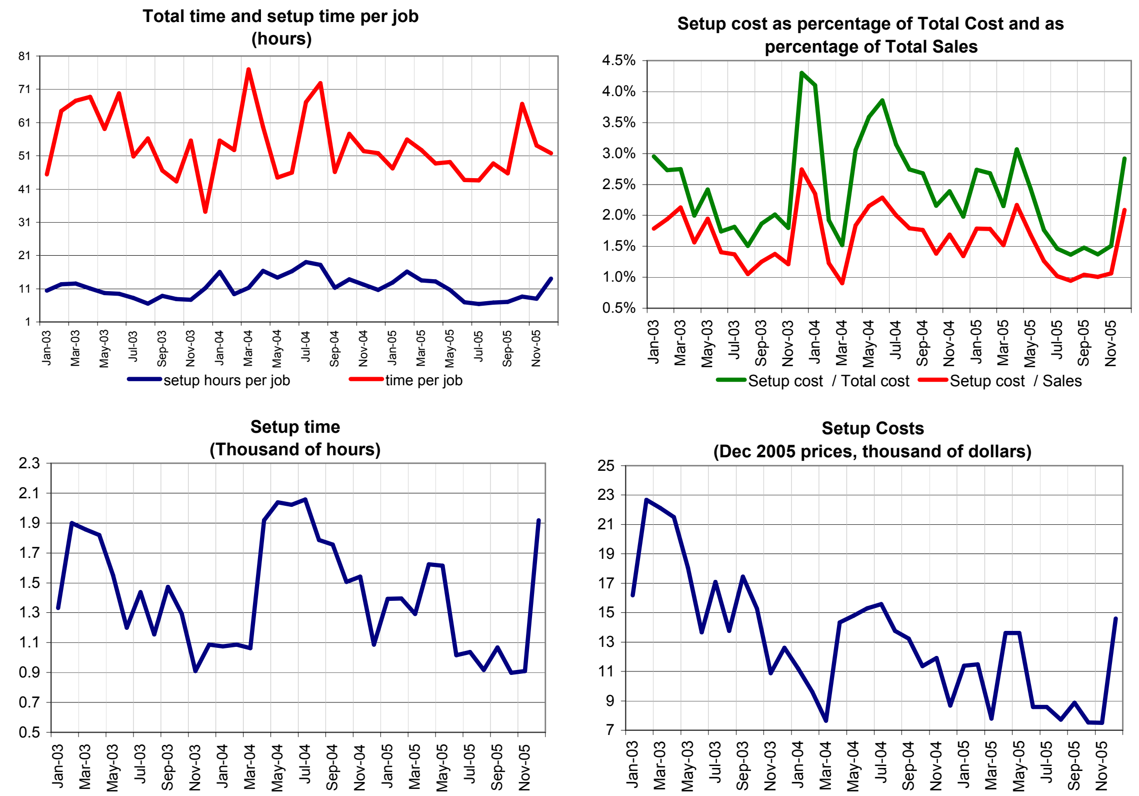
Adjustment Costs in Capital

When Moldes Medellin has to manufacture a batch of moulds, it must set up the machine tools for that specific job. Setting the machines involves three stages: the first stage is to charge the programs into the machine's computer; the second stage consists of adding elements and structures to the machine in order to position the pieces (known as "fixtures") and the tools in the process; and the third stage is to set up the specific tools for the job.

These fixtures and tools should be considered as investments because they are used in several jobs to produce several pieces, and are literally interchangeable parts of the machine. They have a lifetime of around six months. They are not materials and are not counted as materials.

This setup process takes a considerable amount of time and disrupts the production process. In Moldes Medellin all these steps are timed and they represent between 10% to 35% of the total time in man-hours depending on the month and on the past and current job, and between 1% to 3% of the total sales in a month (1.6% on average). Figure 2.3 shows the total setup time in hours and the average setup time per job, the setup time as a percentage of the total time, and the setup time as a percentage of the total sales and the total costs. Around 20% of the total time it takes to produce a mould in the plant is devoted to installing the new capital required for the production; it is clearly observed in this figure that the fluctuations are not generated only by fluctuations in sales or total costs.

Figure 2.3: Setup Costs



The fact that the disruption in the production process due to the machine setup is quantified, and that it can be translated into forgone profits due to the adjustment, gives first hand support for the modeling mechanism adopted in the literature of adjustment costs in which a decrease in productivity is observed during the adjustment of capital or labor, which translates into longer production times.

It is important to notice that the setup costs in capital presented here are an upper limit for the disruption costs caused by adjustment in capital, since some jobs require only to re-align a set of tools without buying any new tools. However, the short life of the tools and the specificity of the jobs make this disruption costs to be associated very often with investment episodes. In a related matter, sometimes it is enough for the firm to change the computer programs but not necessarily the tools it operates when a new job arrives, and in other cases it is necessary to change the programs and the tools. This relates to the ideas of fixed costs of adjustment and "disruption costs", but these are more like job specific investments, or fixed costs. This is an important difference with the model in chapter one, since that model really does treat investment as an addition to long term capital stock, and not as a job specific investment or short run fixed cost of production.

Adjustment Costs in Employment

There are 3 types of observable adjustment costs in employment: (i) the direct costs that firms have to pay to hire and to fire a worker and (ii) the costs of shifting resources from other workers to train the new ones, and (iii) the lower productivity

Table 2.5: Legal Firing Costs in the Colombian Legislation

Contract Type	Firing Fee
Fixed term contract	Time left to expiration
Contracts for the duration of the job	Maximum between the time left to expiration or 15 days
Workers with less than 1 year of continuous service	45 days
Workers with more than 1 year and less than 5 years of continuous service	45 days and 15 more for every year after the first year and proportional for each fraction of year
Workers with more than 5 years and less than 10 years of continuous service	45 days and 20 more for every year after the first year and proportional for each fraction of year
Workers with more than 10 years of continuous service	45 days and 40 more for every year after the first year and proportional for each fraction of year

of the new workers compared with the old ones[9].

The first type of costs have received the most attention in the literature since they are more directly observable. They are typically modeled as fixed costs. The second type of costs are known in the literature as disruption costs.

The average payment to fire a worker in Moldes Medellin is around US$ 53,000, which includes legally mandated firing costs and the union agreement cost. Because of the strength of the union, the firing cost is more than four times the legally mandated payment for laying off a worker. Table 2.5 shows these legal fees. In the case of Moldes Medellin this translates into 71 dollars per day of legal payment (assuming an average hourly wage of US$8.9) which means that, accounting for the average tenure time of 6 years, the average legally mandated firing cost is about US$10,300. The rest of the firing cost (US$42,700) comes from the union agreements.

In order to hire a worker, the firm pays around US$1,320. This money is spent on medical and psychological examinations, training costs and increases in production times (reduction in productivity) while the new worker learns the job. The training costs are a form of disruption costs since the firm shifts resources to

[9]The main hiring costs are psychological, medical and ability tests, and the firing costs are the legal firing costs and the union agreement fees.

train new workers using old workers; in total, this training takes 6 shifts of 8 hours each. Given the average hourly rate (US$8.9), the total training cost has been quantified to be US$427[10]. The increase in the production time is calculated to be 2% during the first month after a new worker is hired according to the manager of the firm; to test this number, I ran a regression in logs of the production hours on the number of workers and controlling for the number of units produced, which confirmed the manager's estimate: an increase of 1% in the labor force increases the total production time by 1.02%[11]. Given the average production hours per month (7,240), this represents a cost of US$657 assuming that the worker is fully productive after the first month. Finally, the medical and psychological examinations cost US$240 according to the company records.

Summarizing, there are two important points with respect to employment adjustment in this firm. The first one is that the disruption cost is the most important adjustment cost that firms face when hiring. The fixed cost of hiring is per-se relatively very low. The second point is that there exists a big asymmetry between the hiring and the firing cost. In the case of Moldes Medellin this asymmetry is even bigger because of the existence of the union, but in any case, the legally mandated firing cost is much higher than the hiring cost[12].

[10]This number is just an approximation, since during some periods the worker's marginal productivity may be higher (or lower) than the wage, causing a higher (or lower) disruption cost.

[11]This regression controls for tfp (the solow residual, which is calculated and explained later in the paper) and the level of capital. It also controls for the change in regime observed in December 2003 using a dummy variable. The standard deviation of the coefficient is 0.27, meaning a statistical significance of 1%

[12]The hiring cost is about 2.5% of the firing cost or 12.9% if we consider only the legal payments.

Interaction Effects in the Adjustment Costs

Besides the individual adjustment costs that Moldes Medellin has to pay when adjusting capital or employment, it is worth investigating whether the cost of adjusting capital increases or decreases when the firm adjusts employment simultaneously. As it was analyzed in chapter one, I call this interaction effects, which could be positive (complementarities) or negative (congestion effects). In chapter one, the parameters governing this interaction effect were uncovered with a simulation procedure. In this section, the approach is different and a reduced form regression is ran in order to illustrate the effects. This reduced form analysis does not pretend to uncover the structural parameters governing the interaction effects, since there are some endogeneity problems; instead, the empirical analysis of the interaction effects is aimed to clarify the concepts presented in chapter one and give first-hand empirical support for the existence of interaction effects. Although I do not have a series of the employment adjustment costs, I have the series for the setup costs paid by the firm every month when adjusting capital, which, as was mentioned above, gives an upper limit for the disruption adjustment costs.

In order to find out if employment growth affects the disruption adjustment costs for capital (i.e. if the disruption adjustment costs are higher or lower than average during periods of worker adjustment), I ran regressions of the logs of capital set-up costs and capital set-up hours on the change in employment level. The coefficient should be interpreted as the effect of employment growth on disruption cost growth (set-up cost or set-up time growth). If it is cheaper to adjust both

Table 2.6: Effect of a Change in the Number of Workers on the Capital Disruption Adjustment Cost

	Dependent Variable			
	log Set-up costs		log Set-up time	
Δ Workers	1.17 (2.04)		0.255 (2.174)	
Δ Non Pdn Workers		1.128 (1.323)		0.579 (1.412)
Δ Pdn Workers		-0.173 (2.123)		-2.226 9.661
R-squared	0.51	0.52	0.31	0.31

Other Controls: tfp, lagged tfp, dummy at Dec 2003 (regime change) and log of units produced. Standard errors in parenthesis

capital and employment at the same time, this coefficient will have a negative sign and it will be positive otherwise.

Table 2.6 shows the results of this regression. With respect to the sign of the effect, we can see from this table that an increase in the number of workers increases the adjustment costs for capital, suggesting the existence of congestion effects in the adjustment costs (an extra cost of adjusting both factors together). Moreover, we can see that it is the increase in the number of non production workers that increases the setup costs. The same happens in the case of the set-up time. However, the the coefficients are not statistical significant. Overall, this result may be due to the small variation on the number of nonproduction workers or due to the nature of the production process. In this particular production process the set-up of the machine tools depends on the planning made by the non production workers: the engineers have to plan the times and the specific ways the tools and fixtures are placed.

I have shown the factor adjustment behavior of Moldes medellin and the cost that it has to pay when adjusting. The next section explores to what extent a model that closely matches the factor adjustment moments of the whole Census of Manufacturing firms in Colombia is able to reproduce the adjustment of production factors in Moldes Medellin.

2.4 How Well the Model from Chapter One Can fit this Particular Firm?

The objective of the previous section was to illustrate with a concrete example the adjustment costs definitions proposed in chapter one. In particular, we could observe in the data the costs that Moldes Medellin has to pay when hiring or firing a worker (fixed costs), the increases in production time and the reallocation of resources that the firm has to make when adjusting capital and labor(disruption costs), and the increase in capital setup time when the firm adjust at the same time the number of workers (congestion effects). This section looks to link the generic model fitted for the Colombian firms to the particular production process that Moldes Medellin has. As in chapter one, the objective of this model is to understand the existence of infrequent and lumpy adjustment across input factors and especially in labor and capital. The explanation given for this behavior lies in the different adjustment costs a company faces when adjusting production factors. The model also captures the observed interrelation between capital and labor adjustment. The parameters for the adjustment costs are taken directly from the evidence collected from Moldes Medellin. The other parameters needed to simulate the model, such as the production function elasticities and the productivity shocks, are directly estimated from the data using the same methodology I applied in chapter one.

2.4.1 Model

The model is a dynamic firm problem with adjustment costs in employment and capital, where firms decide how much input factors to use in response to changes in demand and productivity. The main difference with previous adjustment cost models in the literature is the existence of a complementarity effect which makes the joint adjustment of capital and labor more expensive (or cheaper, since no restriction is imposed) than the individual adjustments. What motivates the firm to adjust capital and employment together is the gain of the joint adjustment compared with the opportunity cost of adjusting only one or no factors.

Equation (2.1) describes the general problem. In this equation $I_t = k_{t+1} - (1-\delta)\,k_t$ represents investment and δ represents depreciation. $C(\bullet)$ is the cost of adjustment, which takes different parameter values depending on whether the firm adjusts employment, capital or both. β is the discount factor and the integral term represents the expected value of the firm subject to shocks z. This shock distribution $f(z'/z)$ is parameterized as an AR(1) process estimated using the Solow residual from the production function estimation. For notation reasons, this shock includes materials and energy, which are chosen optimally every period in a static fashion[13].

$$\begin{aligned} V\left(z,k,l_{-1}\right) &= \max_{k',l}\left\{\Pi(z,l_{-1},l,k,k') + \beta\int V(z',(1-\delta)k+I,l)f(z'/z)dz'\right\} \\ &= \max_{k',l}\{zk^{\theta}l^{\mu} - w(l) - C(z,l_{-1},l,k,k') \\ &\qquad +\beta\int V(z',(1-\delta)k+I,l)f(z'/z)dz'\} \end{aligned} \tag{2.1}$$

[13] For more details on the model, see chapter one.

The cost of adjustment $C(\bullet)$ potentially includes disruption costs, fixed costs and convex costs. The following is the functional form assumed for the adjustment costs when firms adjust l (labor), k (capital) or kl (capital and labor):

$$C\left(z,k,I,l,l_{-1}\right)=\begin{cases} C^{l} &= \lambda_l R(\bullet)+F_l l_{-1}+\frac{\gamma_l}{2}\left(\frac{\Delta l}{l_{-1}}\right)^2 l_{-1} \qquad if \quad \Delta l\neq 0 \\ C^{k} &= \lambda_k R(\bullet)+F_k k+\frac{\gamma_k}{2}\left(\frac{I}{k}\right)^2 k+p_I * I \quad if \quad I\neq 0 \\ C^{lk} &= C^l+C^k+\lambda_{lk}R(\bullet)+F_{lk}\sqrt{l_{-1}k} \\ & \quad +\frac{\gamma_{lk}}{2}\left(\frac{I}{k}\right)\left(\frac{\Delta l}{l_{-1}}\right)\sqrt{l_{-1}k} \qquad if \quad \Delta l * I\neq 0 \end{cases} \tag{2.2}$$

In the case of labor or capital adjustment, (C^l and C^k respectively) the first term $\lambda_j R(\bullet)$ represents the disruption cost, the second term involving F_j represents the fixed cost and the third term involving γ_j represents the convex cost, with j=k(capital) and l(labor). In the case of capital adjustment, there is an extra cost which represents the investment price, which can take values of $p_I = \{p_{buy}, p_{sell}\}$ depending on if the firm buys or sells capital, having the selling price a negative value. The asymmetry in the price for buying and selling capital implies that capital is not fully reversible.

The convex cost term is the benchmark used in the cost function estimation literature and it also appears also in this general model. In this paper, however, I do not fit with a quadratic function the observed adjustment costs. In fact, the data does not show a quadratic shape. Neither do I use a fixed capital adjustment cost, since I do not have data on it.

In the model, if the firm adjusts capital and employment at the same time, the adjustment cost is the sum of the cost of adjusting capital (C^k), plus the cost of adjusting employment independently (C^l), plus a collection of terms that represent the extra cost of the joint adjustment. The parameters to be inserted in the model are the observed ones: $\{\lambda_k, \lambda_l, \lambda_{kl}\}$ for the disruption cost, F_l for the fixed cost, and p_I for the investment price.

There are important differences between the production process represented in the generic model in chapter one and the production process in Moldes medellin. For example, Moldes Medellin “produces to order” and stochastic arrivals of orders or ”jobs” seems like the appropriate way to model the glass mould factory. However, the production function chosen for the generic model can be interpreted this way if the shock processes are taken as demand shocks, or demand fluctuations that trigger the production factor adjustment every time they arrive. Also, many of the adjustment costs that the glass mould company incurs are related to retooling from one job to another, as it was said above. In this sense, the adjustment costs should be seen as an upper limit.

2.4.2 Calibration/Estimation of the Parameters

The existence of a disruption cost takes the form of lower productivity and can be also thought as the shift of resources in order to adjust the other factor. In the previous section, this cost was observed to fluctuate between 1% and 3% of the total sales, with an average of 1.6% in the case of capital and of 1.02% increase in the production time in the case of labor, or 0.073% of the total sales.

The fixed adjustment cost represents the installation costs (in both time and resources) in the case of capital and firing and hiring costs in the case of labor. I only observe the fixed labor adjustment cost, which is calculated to be \$53,000 US for firing and \$240 US for hiring (out of the total of \$1320 of hiring costs). This translates into 5.8% of total monthly sales in the case of firing costs and 0.026% in the case of hiring costs. Since my benchmark model assumes a symmetric adjustment cost in employment, I use the average between the hiring and firing costs to be the fixed cost parameter in the model. This cost (US\$26,620) is scaled in the model by the employment level. To get the parameter value, I consider the average number of employees (80) as the scale value, getting a adjustment cost parameter of 333 or 0.333 in thousand dollars.[14]

With respect to the selling price, this firm sells the used tools after a couple of months for a recovery price which fluctuates approximately between 10% and 20% of the original price with an average of 12%.

Congestion effects in the adjustment costs are also observed in Moldes Medellin, specifically in the capital disruption cost when the firm increases the number of workers. The estimations above suggest that a 1% increase in the number of workers increases the cost of adjusting capital by 1.17%. Table 2.7 summarizes the adjustment cost parameters to be introduced in the model.[15]

The values for the adjustment cost parameters calculated for Moldes Medellin are consistent with the ones found in Chapter one using the generic model for the Colombian firms. For example, the disruption cost parameter was 0.046 compared to 0.01693 for Moldes Medellin. The fixed cost parameter is much higher for Moldes

[14]In future work, I intend to incorporate the asymmetry of these costs into the model and change the scale value for the increment.

[15]In order to make the parameters comparable with the ones in the previous chapter, I consider capital and sales to be thousands of dollars.

Table 2.7: Adjustment Cost Parameters

	Capital	Employment
Disruption	0.016	0.00073
Fixed		0.332
Complementarity (disruption)	$0.016 + 0.00073 + 0.0002 = 0.01693$	

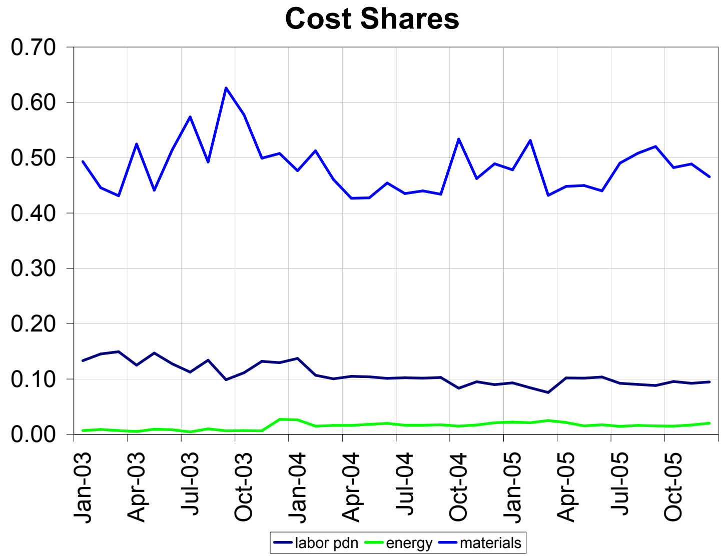
Medellin than for the average firm in Colombia according to the estimates in chapter one (0.332 vs. 0.007), but this may be due to several causes like the very high cost imposed by the contractual obligations with the union, to the long tenure of the workers in Moldes Medellin (the longer the tenure, the higher the firing cost), and the failure of the model in capturing the asymmetry between hiring and firing costs. On the other hand, the capital in this glass mould firm is very irreversible compared with the typical Colombian firm (0.12 vs 0.42 times the buying price); this is reasonable since we are dealing here with a form of capital that depreciates very fast and is specific for the process.

The next step is to estimate the other parameters needed to simulate the model in the case of Moldes Medellin. These parameters are the production function elasticities, the wage equation parameters and the productivity shocks that will drive the adjustment of the production factors.

What Function Can Describe the Production Process?

There may be many functional forms that can describe the production process in Moldes Medellin. Since the objective of this section is to compare the performance of the model proposed in the previous chapter, the natural choice is to fit a Cobb-Douglas production function. However, a closer look at the production process suggests that such a choice is not a bad one. The main characteristic of the Cobb-Douglas production function is that the cost shares remain constant. Figure 2.4 shows this value for Moldes Medellin. We can see that the cost shares do not fluctuate much, giving some support for the assumption of the Cobb-Douglas production function. Table 2.8 shows the OLS estimates of the Cobb-Douglas pro-

Figure 2.4: Cost Shares



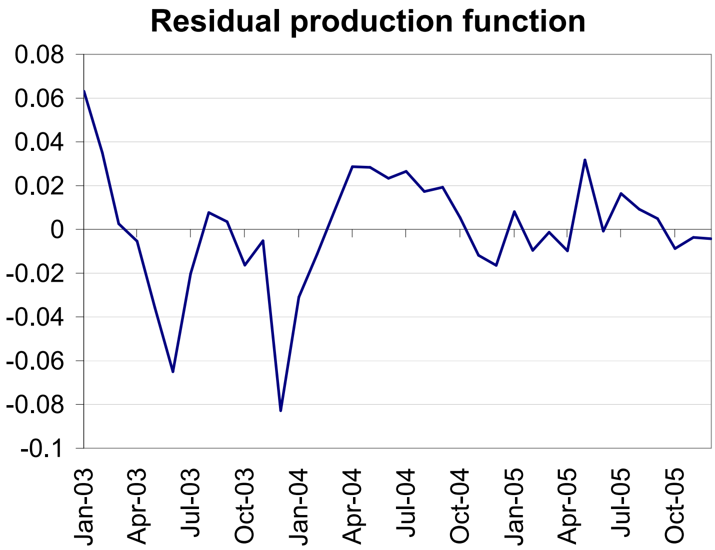
duction function relating sales to capital, labor costs, energy cost and materials cost. Even if the OLS coefficients may be biased, the fact that the observed cost shares are similar to the coefficients estimated with the OLS suggest that this functional form and these coefficients are reasonable. The cost shares are on average 0.15 for labor (total hours), 0.48 for materials, 0.02 for energy and 0.04 in the case of the capital (long lived tools). The cost shares for labor and materials are very close to the OLS estimates but the energy and the capital costs are not. This may be because variation in capacity utilization occurs through capital (energy) more than other factor and the existence of other type of capital. Figure 2.5 shows the

Table 2.8: Production Function Estimates

	Coefficient.	Stdandard Error
Capital	0.116	0.034
Energy	0.085	0.046
Materials	0.560	0.061
Labor	0.175	0.061
F(4,31)=126.14		
Adj R-squared=0.9346		
Number of obs=36		

residual from the previous production function estimation. The big jump between January and April 2004 is associated with the change in the plant management and the downsizing of the plant in order to control the union. From this residual, I esti-

Figure 2.5: Residual Production Function



mate an AR(1) process $tfp_t = \rho_{tfp} tfp_{t-1} + \nu_t$ getting an autocorrelation coefficient of 0.487 (std=0.134) and a $\sigma_\nu = 0.021$ which in turn implies that $\sigma_{tfp} = 0.024$.

The wage function is taken as $wage = w_0 * e + w_1 * e * h^(\psi)$ and estimated directly from the data on wages and hours.[16] The elasticity of wages with respect to

[16]The numbers are given in thousands of December 2005 dollars.

hours is taken as 1.1, as in the previous chapter. The results from an OLS estimation of this equation are $w_0 = 1.11(std = 0.58)$ and $w_1 = 0.12(std = 0.000)$.

The energy price is calculated as the average kilowatt price paid by the firm across all sample months and is equal to 0.067US$. The materials price is the average across months of the ratio of total cost to quantities (measured in pounds of casting per unit produced) and equal to 1.4 US$. The buying price of capital is normalized to 1. The selling price of capital is calculated as follows: The lifetime of the tools is one year. However, they are sold when they are 6 months old by around 12% of their value. This implies a monthly depreciation of 35%. Finally, the discount rate is taken as 0.95 per year which implies a discount rate of 0.996 per month.

Benchmark Moments

At this frequency, some of the variables are not as relevant to this particular company as they are to the average Colombian firm observed in the annual Census of Manufacturing firms. These variables are the employment growth and the investment rate. On the other hand, some variables that are not observed in the census play a key role describing the behavior of Moldes Medellin, like labor hours and the investment rate in long lived tools. That is the reason why the benchmark moments taken from the census can be compared with the moments for Moldes Medellin for energy and materials, but not in capital and labor. Table 2.9 summarizes the moments that are taken as benchmarks to compare with the simulations of the model.

Table 2.9: Benchmark Moments (Monthly Values From the Data)

	Wks Growth	Hours Growth	$\frac{T}{KTools}$
90^{th} percentile	0.013	0.229	0.444
10^{th} percentile	-0.013	-0.153	0.200
$\rho(\frac{T}{KTools}, x)$	-0.1277	0.38372	
$\rho(x, tfp)$	-0.0133	0.42224	-0.0711
VAR Coefficients	$\frac{I}{K}$	$\frac{\Delta Wks}{Wks}$	$\frac{\Delta Hours}{Hours}$
$(\frac{I}{K})_{-1}$	-0.191	0.021	0.002
$(\frac{\Delta Wks}{Wks})_{-1}$	0.038	-0.075	0.019
$(\frac{\Delta Hours}{Hours})_{-1}$	0.631	-0.068	0.016

2.4.3 Simulations Results

Table 2.10 shows the simulation results using the model and the calibrated parameters. A quick view of the results reveals that the model does not get a perfect fit, but is able to reproduce some qualitative features of the data. In particular, although it does not match exactly any moment exactly, it does yield the correct sign in most cases. In particular, the model predicts the correct signs in the case of the percentiles of workers growth, hours growth and the capital growth.

The model matches the qualitative behavior for the correlation between workers, hours and investment with productivity shocks. With respect to the VAR, the model is not able to explain the effect of lagged employment and hours growth on capital, but it does a better job in explaining the effect of investment on employment growth and hours growth. The best match is the correlation between the investment rate and the productivity shock.

The lack of a good match between the simulated moments and the moments from the data may come from different explanations. First, it is possible that the model does not reflect all the variables management considers when adjusting factors. With respect to this first argument, it is true that the existence of the union imposes intangible restrictions, such as political fights inside the firm, that the management tries to avoid, or long processes which retard the response of the firm to shocks in demand or productivity. It is also hard to consider in one single model all the factors that the management weighs when making decisions. Second, it is possible that the firm does not act completely as profit maximizing agent. With respect to the second argument, if it is true that the firm is not acting as a profit maximizing agent, it must be true that it is in its best interest to modify its behavior. For example, the model suggests that the firm should respond much more adjusting workers, hours and investment despite the high adjustment costs; it also suggests substitution between hours and capital instead of substituting workers and capital.

I do not view the results of the simulations as a failure. Instead I regard them as very promising, considering this model is taken directly from a model fit to the average behavior of all firms in Colombia[17].

Some modifications to the model regarding the observed asymmetry in the fixed costs of adjusting labor, or the modeling of different types of workers (i.e. production and non production), or different types of production functions, could significantly improve the fit of the model to the data. The final goal is to deliver a model that can assist the managers of Moldes Medellin in their decision making process.

[17]The only modification made was a different calibration/estimation of the parameters.

Table 2.10: Simulations Results

	Wks Growth	Hours Growth	$\frac{T}{KTools}$
90^{th} percentile	0.037	0.49	0.710
10^{th} percentile	-0.037	-0.31	0.000
$\rho(\frac{T}{KTools}, x)$	-0.017	-0.059	
$\rho(x, tfp)$	0.384	0.115	-0.027
VAR Coefficients	$\frac{I}{K}$	$\frac{\Delta Wks}{Wks}$	$\frac{\Delta Hours}{Hours}$
$(\frac{I}{K})_{-1}$	-0.1632	0.029	0.081
$(\frac{\Delta Wks}{Wks})_{-1}$	-0.033	-0.0048	0.089
$(\frac{\Delta Hours}{Hours})_{-1}$	-0.039	-0.006	0.103

2.5 Conclusions and Future work

In this paper, I have presented direct evidence of the costs that a glass mould firm has to pay when adjusting input factors using detailed production monthly data. The observed adjustment costs come on the one hand from the disruption in production when adjusting capital and employment, resulting from the resources diverted to adjust these factors, and on the other hand from the fixed costs that the firm has to pay when hiring or firing a worker. I presented also direct evidence of the existence of an additional cost for the firm when adjusting both factors at the same time, since the disruption cost is higher during these periods. The most salient features of the adjustment costs are the high asymmetry between the firing and the hiring cost and the high disruption cost in both capital and employment adjustment.

These observed adjustment costs were introduced in a model that fit the average behavior of the manufacturing sector in Colombia. In that case, the parameters were estimated and not observed, in contrast with this paper, where the costs are observed and not estimated.

With this direct calibration, the model is able to reproduce many qualitative features from the Glass Mould firm behavior, and in some cases, the qualitative results match the data, as in the response of investment and labor hours to shocks in productivity, or in the case of the extreme percentiles (10^{th} and 90^{th}) of labor hours growth. However, the overall quantitative fit, and some qualitative features like the dynamic relationship between capital and employment, are not good. The explanations for this could come from misspecification of the model or from suboptimal behavior of the firm.

The model can be improved by incorporating features like the asymmetry of the fixed employment adjustment costs or other constrains that the management faces because of the union. But if the model is a good approximation of the production process in Moldes Medellin, it suggests that despite the high adjustment costs, the firm should adjust employment, hours and investment more frequently and use more the substitution margin between capital and workers.

In the future, I plan to carefully consider a specific model that can fit the operation of Moldes Medellin, introducing elements like those mentioned above. The final goal is to show to the management and the owner how they can improve their profits with modifications to the production choices suggested by an economic model.

Chapter 3

Conclusions and Final Thoughts

In analyzing input factor decisions using the unique data sets presented in chapters two and three, this dissertation makes three main contributions. First, it reveals the fact that it is more costly for firms to adjust capital and employment at the same time, an effect called congestion. This effect is important in explaining the observed interrelation between capital and employment growth. Second, it provides direct evidence of the existence of adjustment costs using data from a particular firm; these adjustment costs take the form of disruption in the production process and reallocation of internal resources to adjust the input factors, fixed costs of adjusting factors and complementarities in the adjustment costs as defined before. And third, it proposes a model that is able to explain the empirical evidence about capital and employment adjustment, namely the mix of smooth and lumpy adjustments, the mix of inaction, small and large adjustments and the interrelation in capital and employment adjustment. The key for the success of the explanation lies in the joint analysis of dynamic capital and employment decisions with a very complete and realistic structure of adjustment costs.

In the first chapter I have used the Census of Manufacturing Firms in Colombia to analyze if labor and capital adjustment are interrelated, whether there are interrelations in this process, and what the nature of this adjustment is. The data shows the same patterns observed in other data sets: mix of smooth and lumpy adjustments in capital and employment, mix of inaction, small and large adjustments, continuous adjustment in energy and materials and interrelation between capital and employment adjustment.

I argue that these patterns can be explained with a dynamic model in which labor and capital are costly to adjust. The adjustment cost represents some facts from the data, such as the decrease in output after the adjustment, the cost of hiring and firing workers, the cost of installing capital and a convex component to capture the mix of smooth and lumpy adjustment. The model also incorporate the fact that the adjustment is more costly when done simultaneously in capital and employment. The decision rules for firms' capital and labor adjustment show that the adjustment patterns are highly nonlinear and they can be characterized as a bidimensional (S,s) policy where adjustment depends not just of the states of the system but also on the choices. Importantly, the model with high complementarities more close resemble the data statistics.

The main conclusion from the first chapter is that labor and capital adjustment should be analyzed together when considering a dynamic model of adjustment dynamics with convex and non-convex costs. This is supported by an empirical reason as well as a theoretical one. The data show an interrelated adjustment pattern. Moreover, in a model that incorporates adjustments for both capital and labor, the conclusions about factor movements are different if adjustment costs are presented in one factor alone. The structural methodology allows me to reject statistically the existence of fixed costs and to accept the existence of disruption costs for capital and labor, the existence of convex costs for capital but not for labor and the existence of congestion effects.

The main advantage of the type of methodology proposed in this paper is that several policy experiments can be analyzed. The effects of taxes on capital and employment and the aggregate effects of these policies are among the main ones. Also, Colombia undertook several market liberalization reforms at the beginning of the 1990s, so it would be interesting to explore with this structural framework, how the reforms affected the firm behavior in terms of factor adjustment. And finally, it may be worth exploring sectoral differences in firm behavior, especially since the parameters and functional forms may not be the same for all types of industries. This paper took an aggregate approach to this problem, but a more micro-level analysis may prove useful, particulary if micro level behavior is the key to understanding aggregate responses.

In the second chapter I have presented direct evidence of the costs that a glass mould firm has to pay when adjusting production input factors using detailed production monthly data. The evidence presented confirms part of the adjustment cost structure proposed in chapter one. The observed adjustment costs come on the one hand from the disruption in production when adjusting capital and employment and from the resources used to adjust these factors, and in the other hand from the fixed costs that the firm has to pay when hiring or firing a worker. I presented also direct evidence of the existence of an additional cost for the firm when adjusting both factors at the same time since the disruption cost is higher during these periods. The most salient features of the adjustment costs are the high asymmetry between the firing and the hiring cost and the high disruption cost in both capital and employment adjustment.

The observed adjustment costs where introduced in the model from chapter one. In chapter one, the parameters were estimated and not observed, in contrast with chapter two, where the costs are observed and not estimated.

With this direct calibration, the model is able to reproduce many qualitative features from the Glass Mould firm behavior, and in some cases the qualitative results get close to the data as in the response of investment and labor hours to shocks in productivity, or in the case of the labor hours growth extreme percentiles (10^{th} and 90^{th}). However, the overall quantitative fitting and some quantitative features like the dynamic relationship between capital and employment are not good. The explanations for this can come from the misspecification of the model or from the suboptimal behavior of the firm.

The model can be improved in features like the asymmetry of the fixed employment adjustment costs or the production function or incorporating some other constrains that the management faces because of the union. But if the model is a good approximation of the production process in Moldes Medellin, it suggests that despite the high adjustment costs, the firm should adjust more employment, hours and investment and use more the substitution margin between capital and workers.

In the future, I plan to carefully consider a specific model that can fit the operation of Moldes Medellin, introducing elements like the mentioned above. The final goal is to show to the management and the owner how they can improve their profits with modifications to the production choices suggested by an economic model.

Appendix 1
Appendix Chapter 1: Complementary Analysis of the Variables Around Spikes in Capital and Employment

This appendix has three main goals. The first one is to analyze how the adjustments of capital and employment and the levels of energy, materials, output and productivity are interrelated before, during and after a spike in investment or employment. The second goal is to show that the patterns of adjustment have a mix of lumpy and smooth elements as argued in previous sections. And the third goal is to show that TFP and output decrease after episodes of large adjustments specially in capital, suggesting the presence of adjustment costs in the form of forgone profits.

Following a similar methodology to Sakellaris (2004) and Letterie et al. (2004), I analyze the conditional expected values of the variables of interest around the spikes in investment and employment adjustment. Specifically, I create a dummy variable for the investment spikes if the investment rate is greater than 20% and was lower than 20% in the previous period; that is $\frac{I_t}{K_t} > 0.2$ and $\frac{I_{t-1}}{K_{t-1}} < 0.2$. In order to make a comparison with the existing literature, and given the arbitrary nature of the definition of thresholds for "large" adjustments, I also construct a dummy variable signalling the job creation bursts if the adjustment is bigger than 10% in t but less than 10% in absolute value in $t-1$. Job destruction bursts are determined by the same rule on the negative side (less than -10% labor adjustment in t and more than 10% in $t-1$). An important assumption is that two years of consecutive large adjustment correspond to the same episode. Consequently, I analyze 5 years around the investment episode.

The analysis is based on the following regression:

$$X_{is} = \mu_i + v_s + \sum_{j=-2}^{j=2} \beta_j * EVENTD_{is}^{t+j} + \epsilon_{st} \qquad (1.1)$$

X_{is} is the variable of interest for firm i in period s. μ_i stands for plant effects to control for unobserved heterogeneity and ν_s stands for year effects to control for aggregate effects in the variable; $EVENTD = 1$ if the event D happens in time s, where D can be an investment spike, job creation burst or job destruction burst.

The reported coefficients in tables A1, A2 and A3 are the β_j's of equation (1.1). They account for the conditional expected values of the adjustments in capital and employment and the levels of energy, materials, output and productivity in the time window composed by the two periods before and two periods after the episode of large adjustment in capital and employment.

We should expect a statistically significant coefficient on capital and employment growth around the spikes of the opposite factor if there is an interrelation between capital and labor adjustment. Also, if there is smooth adjustment, we should observe a constant increase or decrease in the coefficients before or after the episodes; in contrast, lumpy adjustment would be seen as jumps in these coefficients. If there is evidence of a disruption cost, we expect productivity and output to decrease after the spikes.

In fact, as expected, the most relevant facts drawn from the tables A1, A2 and A3 are that there is interrelation in the adjustment, that there is evidence of disruption costs, especially after capital adjustments and that firms adjust with mix

Table A1. Conditional Expected Values during Investment spikes episodes

	I/K	$\Delta L/L$	$log(y)$	$log(k)$	$log(L)$	$log(E)$	$log(M)$	$log(TFP)$
t+2	0.092	0.003	0.043	0.384	0.044	0.033	0.045	-0.107
	(0.013)**	0.005	(0.009)**	(0.014)**	(0.007)**	(0.010)**	(0.009)**	(0.008)**
t+1	0.195	0.008	0.052	0.401	0.052	0.026	0.05	-0.107
	(0.014)**	0.005	(0.010)**	(0.015)**	(0.008)**	(0.011)*	(0.010)**	(0.009)**
I/K spike	0.615	0.026	0.052	-0.262	0.052	0.014	0.061	0.088
t	(0.014)**	(0.005)**	(0.010)**	(0.015)**	(0.007)**	0.011	(0.010)**	(0.009)**
t-1	-0.071	0.008	0.036	-0.204	0.025	-0.001	0.05	0.071
	(0.014)**	0.005	(0.009)**	(0.015)**	(0.007)**	-0.011	(0.010)**	(0.009)**
t-2	-0.021	0.003	0.013	-0.167	0.013	-0.02	0.026	0.052
	-0.013	0.005	0.009	(0.015)**	0.007	-0.011	(0.010)**	(0.009)**
Obs.	20093	27835	26578	27946	28068	28132	26060	24410
R^2	0.13	0.01	0.18	0.25	0.03	0.08	0.23	0.1

Standard errors in parentheses* significant at 5%; ** significant at 1%

of smooth and lumpy adjustment. These coefficients are particular for the episodes of capital and employment spikes, but the analysis in the main text supports the results found here

Table A2. Conditional Expected Values during Employment growth spikes

	I/K	$\Delta L/L$	$log(y)$	$log(k)$	$log(L)$	$log(E)$	$log(M)$	$log(TFP)$
t+2	0.006	-0.012	-0.054	-0.068	-0.123	-0.06	-0.05	0.017
	0.005	(0.003)**	(0.007)**	(0.012)**	(0.005)**	(0.008)**	(0.008)**	(0.007)**
t+1	0.01	-0.024	-0.037	-0.066	-0.166	-0.05	-0.024	0.034
	0.005	(0.003)**	(0.007)**	(0.011)**	(0.005)**	(0.008)**	(0.007)**	(0.007)**
L spike=t	0.042	0.34	0.058	-0.045	0.175	0.019	0.058	0.014
	(0.005)**	(0.003)**	(0.007)**	(0.011)**	(0.005)**	(0.008)*	(0.007)**	(0.007)*
t-1	0.035	-0.023	0.075	0.035	0.13	0.041	0.076	0.008
	(0.005)**	(0.003)**	(0.007)**	(0.011)**	(0.005)**	(0.008)**	(0.007)**	-0.007
t-2	0.016	-0.008	0.074	0.093	0.11	0.037	0.07	-0.002
	(0.005)**	(0.003)**	(0.007)**	(0.012)**	(0.005)**	(0.008)**	(0.008)**	-0.007
Obs.	19770	27800	26578	27946	28068	28132	26060	24410
R^2	0.03	0.43	0.19	0.19	0.16	0.09	0.24	0.09

Standard errors in parentheses* significant at 5%; ** significant at 1%

Table A3. Conditional Expected Values during Negative Employment growth spikes

	I/K	$\Delta L/L$	$log(y)$	$log(k)$	$log(L)$	$log(E)$	$log(M)$	$log(TFP)$
t+2	0.002	0.005	0	0.005	0.086	0.019	0.013	-0.028
	0.005	0.003	0.007	0.012	(0.005)**	(0.008)*	0.008	(0.007)**
t+1	0	0.016	-0.02	0.027	0.124	0.009	-0.01	-0.053
	0.006	(0.003)**	(0.007)**	(0.012)*	(0.005)**	0.008	-0.008	(0.007)**
-L spike	-0.017	-0.36	-0.11	0.036	-0.243	-0.07	-0.103	-0.026
t	(0.006)**	(0.003)**	(0.007)**	(0.012)**	(0.005)**	(0.009)**	(0.008)**	(0.007)**
t-1	-0.02	0.033	-0.101	0.005	-0.176	-0.078	-0.107	-0.019
	(0.006)**	(0.003)**	(0.007)**	-0.012	(0.005)**	(0.009)**	(0.008)**	(0.007)**
t-2	-0.006	0.015	-0.087	-0.034	-0.139	-0.071	-0.084	-0.011
	-0.006	(0.003)**	(0.008)**	(0.013)**	(0.006)**	(0.009)**	(0.008)**	-0.007
Obs.	19770	27800	26578	27946	28068	28132	26060	24410
R^2	0.02	0.42	0.19	0.18	0.17	0.09	0.24	0.09

Standard errors in parentheses* significant at 5%; ** significant at 1%

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