Adjustment Cost in Capital and Labor*

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Abstract

This paper proposes a new method to estimate adjustment costs for capital and labor using standard firm level production data. Our approach is based on the empirical framework developed by De Loecker (2011) and De Loecker and Warzynski (2012) which recovers markups from a wedge between an input's revenue share and its output elasticity. Our methodology allows for various returns to scale, flexible production technologies and different price setting models. We rely on our method to estimate adjustment costs of capital and labor using Belgian firm-level data. Our results suggest that, for labor, the adjustment costs are substantial and asymmetric. More specifically, firing costs exceed hiring costs in Belgium, which is consistent with some evidence found in other studies for Europe. Whereas the methodology does not provide reliable estimates for capital adjustment costs because of the absence of comprehensive micro data on the rental price of capital faced by individual firms.

Keywords: Adjustment cost; Markups; Control function

JEL Classification: D24; E22; J23; L11

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1 Introduction

A huge literature has studied the dynamics of capital and labor demand based on the costs of adjustment facing firms. Adjustment costs determine the dynamics of the response of a firm's output to a shift in demand. An increase in adjustment costs slows a firm's reactions to changes in output demand and reduces investment and employment variability. The investigation of adjustment costs is vital to understand firms' investment and employment behavior, for example, to understand the way in which changes in relative factor prices (e.g. interest rates, investment tax credit and minimum wage legislation) and changes in aggregate output affect investment and employment over time. In this paper, we provide a simple empirical framework to estimate adjustment costs of capital and labor. Our approach is based on the empirical framework developed by De Loecker (2011) and De Loecker and Warzynski (2012) which recovers markups from a wedge between an input's revenue share and its output elasticity. The methodology in this paper relies on the insight that the wedge between output elasticity and revenue share for quasi-fixed inputs, which are subject to adjustment costs, is higher than that for variable inputs free of adjustment costs.

Dynamic optimization models, developed by Lucas (1967), Uzawa (1969) and Treadway (1969, 1970), incorporate costs of adjustment and treat investment function as the capital demand of firms[1]. Most previous empirical studies are based on highly aggregated data at the sectoral or macroeconomic level. Chirinko (1993) and Caballero (1999) provide surveys on work on aggregate investment, and Hamermesh (1993) provides a survey of work on aggregate employment. This situation is changing as the access to firm- or plant-level data increases. For instance, Caballero, Engel, and Haltiwanger (1995), Cooper, Haltiwanger, and Power (1999) investigate the lumpiness of plant-level investment using the plant-level data on investment.

There are two most popular structural dynamic models in the literature, namely the Q model of investment and the Euler equation models which have been applied in both

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[1] See Berndt, Morrison, and Watkins (1981) for a survey of dynamic models of production.

the investment and employment literature. The Euler equation approach introduced by Abel (1980) uses the first-order condition for factor demand (Chirinko, 1993; Hall, 2004; Shapiro, 1986). The adjustment costs of capital provided by Chirinko (1993) and Shapiro (1986) are substantial. However, Hall (2004) estimates adjustment costs for labor and capital and he finds that adjustment costs are small for both capital and labor inputs. Cooper and Haltiwanger (2006) and Cooper and Willis (2009) use indirect inference to estimate parameters of a general adjustment cost function of capital and labor which incorporates both convex and non-convex costs of adjustment as well as irreversible investment. They find that a model which mixes both convex and non-convex adjustment costs fits the capital data best, while a non-convex adjustment cost model fits the employment data best. Bond and Van Reenen (2007) survey recent microeconometric research on investment and employment which use firm or plant level panel data. However, the estimates of the adjustment-cost parameters in most of these studies are conditional on the hypothesis of Cobb-Douglas production technology. Another main concern is that unobserved productivity can affect output and input growth. Not controlling for unobserved productivity shocks biases the estimates of adjustment costs as productivity is potentially correlated with input choices. In most studies, instruments are applied to deal with the endogeneity problem. For instance, Shapiro (1986) and Cooper and Haltiwanger (2006) use lagged endogenous variables and Hall (2004) applies military spending and the timing of oil price shocks as instruments in their research.

In this paper, we specify a dynamic cost minimization model allowing for adjustment costs of capital and labor. Under perfect competition, the output elasticity of a variable factor is equal to its revenue share. In the presence of (any form of) imperfect competition, the wedge between output elasticity of a variable input free of adjustment costs and its revenue share captures markups. However, the wedge between output elasticity and its revenue share for a quasi-fixed input is larger than that for a variable input, as the shadow price of a quasi-fixed input to a firm exceeds its market price (i.e., wage and the rental price of capital). We develop a dynamic model capturing these properties and a simple econometric framework to infer the underlying adjustment-cost parameters.

The contribution of this paper is three-folded. First, it does not impose any restrictions on returns to scale and allows for flexible underlying production technologies. Second, it allows for various price setting models. In other words, our methodology is flexible with respect to different underlying market structures. Third, unlike previous studies relying on the use of instrumental variables or GMM, we control for unobserved productivity by using proxy approach introduced by Olley and Pakes (1996) and Levinsohn and Petrin (2003).

We use firm-level data for the manufacturing sector in Belgium to estimate a model in which capital and labor are treated as quasi-fixed inputs, and materials as a variable input. Our results suggest that, for labor, the adjustment costs are substantial and asymmetric. More specifically, firing costs exceed hiring costs in Belgium, which is consistent with some evidence found in other studies for Europe (Goux, Maurin, and Marianne, 2001; Kramarz and Michaud, 2010; Dhyne, Fuss, and Mathieu, 2010). Whereas the methodology does not provide reliable estimates of capital adjustment costs because of the absence of comprehensive micro data on the rental price of capital.

The reminder of this paper is organized as follows. Section 2 introduces a dynamic cost minimization model that incorporates costs of adjustment and provides a simple estimation framework to estimate adjustment costs of capital and labor. Section 3 briefly discusses specifications of adjustment costs. Section 4 presents the detailed estimation procedure. Section 5 describes the data used and shows some stylized facts. The main results are reported and discussed in Section 6. The final section concludes.

2 Theory

A firm chooses the optimal levels of three inputs, capital K_t, labor L_t and material M_t to minimize the present value of the cost of producing a given flow of output Q_t, subject to a production function constraint $Q_t = Q(K_t, L_t, M_t)$. We omit the firm subscript i

here. In this paper, we treat material as a variable factor, in the sense that the level of material can be varied immediately without paying any adjustment costs. We assume that capital and labor are quasi-fixed factors, in the sense that variations in capital or employment impose adjustment costs on to the firm. The capital stock in period t for firm i is determined as $K_{it} = (1-\delta)K_{it-1} + I_{it-1}$, where I_{it-1} is the investment in period $t-1$ and δ is the depreciation rate. The number of employees in period t is defined as $L_{it} = L_{it-1} + H_{it-1}$, where H_{it-1} is the number of hired or laid-off workers in period $t-1$. Note that, we implicitly assume a zero quit rate for labor here.

The changes in capital K_t and labor L_t result in costs of adjustment. Examples of costs of investment are planning and installation costs. Costs of disinvestment include the cost of redundancy, other costs of closure and the transaction costs of the sales of tangible assets. Hiring costs include recruiting and training costs for new employees. Firing costs are the cost of advanced notice requirement, severance payment and penalties due when terminating a redundant worker. We denote the cost of capital adjustment by $C_{K,t}(K_{t+1}, K_t)$, the cost of labor adjustment by $C_{L,t}(L_{t+1}, L_t)$. It indicates that the quasi-fixed factors are available at variable prices, depending on the forms of adjustment costs. In contrast, the variable input is available at a constant price.

The present value of cost at time $t = 0$ is

$$Min_{\{M_t,K_t,L_t\}} C(0) = \sum_{t=0}^{\infty} \beta^t [P_{M,t}M_t + R_tK_t + W_tL_t + C_{K,t}(K_{t+1}, K_t) + C_{L,t}(L_{t+1}, L_t)]$$
$$s.t.\ Q = \sum_{t=0}^{\infty} \beta^t Q(M_t, K_t, L_t) \tag{1}$$

where $\beta \in (0, 1)$ is the discount factor, $P_{M,t}$ is the real price of material inputs, R_t is the rental price of capital and W_t is the real wage.

Consider the associated Lagrangian function

$$\mathcal{L} = \sum_{t=0}^{\infty} \beta^t \{P_{M,t}M_t + R_tK_t + W_tL_t + C_{K,t}(K_{t+1}, K_t) + C_{L,t}(L_{t+1}, L_t) + \lambda_t[Q_t - Q(M_t, K_t, L_t)]\}$$

The first-order condition for the variable factor, i.e., material, is

$$\frac{\partial \mathcal{L}}{\partial M_t} = \beta^t P_{M,t} - \beta^t \lambda_t \frac{\partial Q_t}{\partial M_t} = 0 \tag{2}$$

where Lagrange multiplier λ_t measures the marginal cost of production $\partial C_t / \partial Q_t$. Rearranging terms and multiplying both sides by $\frac{M_t}{Q_t}$, we have

$$\frac{P_{M,t} M_t}{\lambda_t Q_t} = \frac{\partial Q_t}{\partial M_t} \frac{M_t}{Q_t} \tag{3}$$

indicating that the output elasticity of material equals to its cost share $\frac{P_{M,t} M_t}{\lambda_t Q_t}$, which holds under any form of competition and underlying consumer demand[2]. Equation (3) conditions on the use of dynamic inputs of production, such as capital and labor. As in De Loecker and Warzynski (2012), we define a markup as the price-marginal cost ratio $\mu_t \equiv \frac{P_t}{\lambda_t}$ and obtain the following expression of the markup:

$$\mu_t = \frac{P_t}{\lambda_t} = \frac{\frac{\partial Q_t}{\partial M_t} \frac{M_t}{Q_t}}{\frac{P_{M,t} M_t}{P_t Q_t}} \tag{4}$$

where $\frac{\partial Q_t}{\partial M_t} \frac{M_t}{Q_t}$ is the output elasticity of material, $\frac{P_{M,t} M_t}{P_t Q_t}$ is its expenditure share in total revenue. Note that, under perfect competition, the cost share in total revenue is a measure of the elasticity of the production function with respect to material input, i.e., $\mu_t = 1$. Equation (4) shows that in order to obtain a measure of firm level markups using production data, we only require estimates of the output elasticity of material and its revenue share. The revenue shares are directly observed in most micro data. To obtain output elasticity of input X_t, we estimate the production function and rely on proxy methods developed by Olley and Pakes (1996) (OP hereafter), Levinsohn and Petrin (2003) (LP hereafter) and Ackerberg, Caves, and Frazer (2006) (ACF hereafter).

We now turn to the quasi-fixed factors, namely capital and labor. The first-order

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[2] It is important to note that we do impose an assumption on price setting that prices are set period by period. In other words, it is costless to adjust prices.

condition for capital is

$$\frac{\partial \mathcal{L}}{\partial K_t} = \beta^t [R_t + \frac{\partial E_t[C_{K,t}(K_{t+1}, K_t)]}{\partial K_t}] + \beta^{t-1} \frac{\partial C_{K,t-1}(K_t, K_{t-1})}{\partial K_t} - \beta^t \lambda_t \frac{\partial Q_t}{\partial K_t} = 0 \quad (5)$$

$$\lambda_t \frac{\partial Q_t}{\partial K_t} = R_t + \frac{\partial E_t[C_{K,t}(K_{t+1}, K_t)]}{\partial K_t} + \frac{1}{\beta} \frac{\partial C_{K,t-1}(K_t, K_{t-1})}{\partial K_t} \quad (6)$$

Equation (6) indicates that the marginal cost of capital consists of a rental price of capital R_t, a discounted adjustment cost in period $t-1$, $\frac{1}{\beta}\frac{\partial C_{K,t-1}(K_t,K_{t-1})}{\partial K_t}$, and an expected saving in adjustment costs in period t (by installing the capital in period $t-1$ rather than in this period), $\frac{\partial E_t[C_{K,t}(K_{t+1},K_t)]}{\partial K_t}$.

The markup is then

$$\mu_t = \frac{P_t}{\lambda_t} = \frac{\frac{\partial Q_t}{\partial K_t}\frac{K_t}{Q_t}}{\frac{R_t K_t}{P_t Q_t} + \frac{K_t}{P_t Q_t}\frac{\partial E_t[C_{K,t}(K_{t+1},K_t)]}{\partial K_t} + \frac{1}{\beta}\frac{K_t}{P_t Q_t}\frac{\partial C_{K,t-1}(K_t,K_{t-1})}{\partial K_t}} \quad (7)$$

As the marginal adjustment costs of capital are unobservable, we are not able to obtain μ_t from equation (7) based on capital input. We define $\mu_t^K \equiv \frac{\frac{\partial Q_t}{\partial K_t}\frac{K_t}{Q_t}}{\frac{R_t K_t}{P_t Q_t}}$ as a pseudo markup based on capital input, which is the ratio of the output elasticity of capital and its revenue share. And μ_t^K can be obtained from production data. Note that μ_t^K is larger than μ_t, because the shadow price of capital to a firm exceeds the rental price of capital due to adjustment costs. Rearranging terms and substituting μ_t^K into equation (7), we have

$$\frac{\mu_t^K - \mu_t}{\mu_t} R_t = \frac{\partial E_t[C_{K,t}(K_{t+1}, K_t)]}{\partial K_t} + \frac{1}{\beta}\frac{\partial C_{K,t-1}(K_t, K_{t-1})}{\partial K_t} \quad (8)$$

Similarly, the first-order condition for labor is

$$\mu_t = \frac{P_t}{\lambda_t} = \frac{\frac{\partial Q_t}{\partial L_t}\frac{L_t}{Q_t}}{\frac{W_t L_t}{P_t Q_t} + \frac{L_t}{P_t Q_t}\frac{\partial E_t[C_{L,t}(L_{t+1},L_t)]}{\partial L_t} + \frac{1}{\beta}\frac{L_t}{P_t Q_t}\frac{\partial C_{L,t-1}(L_t,L_{t-1})}{\partial L_t}} \quad (9)$$

$$\frac{\mu_t^L - \mu_t}{\mu_t} W_t = \frac{\partial E_t[C_{L,t}(L_{t+1}, L_t)]}{\partial L_t} + \frac{1}{\beta}\frac{\partial C_{L,t-1}(L_t, L_{t-1})}{\partial L_t} \tag{10}$$

where μ_t^L is the pseudo markup based on labor input, which is the ratio of the output elasticity of labor and its revenue share. Equation (8) and (10) show that the deviation of pseudo markups, namely μ_t^K and μ_t^L, from the real markups μ_t can be applied to refer adjustment-cost parameters of capital and labor given the specification of adjustment cost functions.

Finally, we follow Hall (2004) and substitute rational expectation by the ex post realization and the expectations error, $\frac{\partial E_t[C_{K,t}(K_{t+1},K_t)]}{\partial K_t} = \frac{\partial C_{K,t}(K_{t+1},K_t)}{\partial K_t} + \upsilon_t$, $\frac{\partial E_t[C_{L,t}(L_{t+1},L_t)]}{\partial L_t} = \frac{\partial C_{L,t}(L_{t+1},L_t)}{\partial L_t} + \eta_t$.

$$\begin{aligned}\frac{\mu_t^K - \mu_t}{\mu_t} R_t &= \frac{\partial C_{K,t}(K_{t+1}, K_t)}{\partial K_t} + \frac{1}{\beta}\frac{\partial C_{K,t-1}(K_t, K_{t-1})}{\partial K_t} + \upsilon_t \\ \frac{\mu_t^L - \mu_t}{\mu_t} W_t &= \frac{\partial C_{L,t}(L_{t+1}, L_t)}{\partial L_t} + \frac{1}{\beta}\frac{\partial C_{L,t-1}(L_t, L_{t-1})}{\partial L_t} + \eta_t\end{aligned} \tag{11}$$

where the disturbance terms υ_t and η_t capture the expectation errors made by firm i when forecasting its period $t+1$ investment or employment, which will be orthogonal to information available in period t under the assumption of rational expectation. υ_t and η_t can contain unobserved firm-specific component, reflecting firm heterogeneity in forecasting. We incorporate firm fixed effects to capture firm specific expectation errors. The discount factor β is set at 0.95, but we check the robustness of our results using alternative values. Given the specification of adjustment cost functions, the adjustment-cost parameters can be estimated from the above two estimation equations. In the next section, we discuss alternative specifications of adjustment costs.

3 Adjustment Costs Function

A variety of functional forms of adjustment costs have been proposed in the literature (see Hamermesh and Pfann, 1996, for a survey). In this section, we discuss different structures for this function.

The traditional investment model assumes that costs of adjustment are convex, indicating that K_t and L_t are subject to increasing costs of adjustment. Convex adjustment costs imply that firms continuously and smoothly adjust their capital stock and employment over time. This form is commonly used in empirical and theoretical work, as it allows the derivation of decision rules for adjusting inputs. Among convex adjustment costs, quadratic adjustment cost function is widely applied in the literature (Gould, 1968; Pindyck and Rotemberg, 1983; Hall, 2004).

We specify quadratic adjustment costs as,

$$C_{K,t}(K_{t+1}, K_t) = \begin{cases} \frac{\gamma^+}{2} K_t (\frac{K_{t+1}-K_t}{K_t})^2 \ if \ K_{t+1} > Kt \\ \frac{\gamma^-}{2} K_t (\frac{K_{t+1}-K_t}{K_t})^2 \ if \ K_{t+1} < Kt \end{cases} \tag{12}$$

where γ^+ and γ^- are parameters. Equation (12) suggests that it is costly to both invest and disinvest. Here we allow the quadratic specification to be asymmetric, i.e., investment costs can be different from disinvestment costs.

The first order condition for the cost minimization problem relates the investment rate to the deviation of pseudo markups estimated using capital input from the real markup. Thus the estimation equation under a quadratic adjustment cost is:

$$\begin{aligned} \frac{\mu_t^K - \mu_t}{\mu_t} R_t = & \gamma^+ [\frac{1}{\beta} g_{kt-1} - g_{kt} - \frac{1}{2} g_{kt}^2] + \\ & (\gamma^- - \gamma^+)[\frac{1}{\beta} g_{kt-1} I_{kt-1}(g_{kt-1}) - (g_{kt} + \frac{1}{2} g_{kt}^2) I_{kt}(g_{kt})] + \upsilon_t \end{aligned} \tag{13}$$

where $g_{kt} = \frac{K_{it+1}-K_{it}}{K_{it}}$, I_{kt} is an indicator function, with $I_{kt} = 1$ if $g_{kt} < 0$, and 0 otherwise; and $I_{kt-1} = 1$ if $g_{kt-1} < 0$, and 0 otherwise. The coefficient $\gamma^- - \gamma^+$ captures whether the cost of investment is significantly different from the cost of disinvestment.

A recent literature has developed an analysis of non-convex costs and suggested that non-convex costs provide a better description of the structure of adjustment costs (Hamermesh, 1989; Cooper and Willis, 2009). The empirical investigation of factor adjustment addresses the importance of "lumpy" adjustment. The lumpy cost parameter does not enter the first order condition directly and it is therefore not possible to identify the effects of lumpy costs. In order to identify fixed adjustment costs, we need to consider discrete choice model, which is beyond the scope of this paper.

4 Estimation Method

To estimate output elasticity, we consider the production function with Hicks-neutral productivity term $Q = F(K_{it}, L_{it}, M_{it})exp(\omega_{it})$. Thus output elasticity is given by $\frac{\partial lnF(K_{it},L_{it},M_{it})}{\partial lnX_{it}}$, $X_{it} = K_{it}, L_{it}, M_{it}$. We rely on proxy methods suggested by OP, LP and ACF to obtain consistent estimates of the technology parameters. These methods use observed input decisions to "control" for unobserved productivity shocks. Among these methods, ACF is preferred in this paper, since it allows for adjustment costs in labor.

The output elasticity is estimated using a gross-output trans-log production function:

$$y_{it} = \beta_m m_{it} + \beta_l l_{it} + \beta_k k_{it} + \beta_{mm} m_{it}^2 + \beta_{ll} l_{it}^2 + \beta_{kk} k_{it}^2 + \beta_{ml} m_{it} l_{it} + ... + \beta_{lk} l_{it} k_{it} + \omega_{it} + \epsilon_{it} \quad (14)$$

where lower cases denote the log of a variable, for example, $m_{it} = lnM_{it}$. ω_{it} is productivity shocks that are observed by firms when making input decisions. However ϵ_{it} is the shocks to production that are not observable by firms before making their input decisions. The use of trans-log production function allows for the variation in output elasticity across firms and time. While the standard Cobb-Douglas production function assumes constant output elasticities. Thus we attribute variation in markups to variation in the revenue shares.

In Olley and Pakes (1996), factor prices are assumed to be common across firms. However, input prices may differ across firms. Katayama, Lu, and Tybout (2003) point out how the estimates of production function can be biased in the presence of imperfect competition in the product market and in the input market. In this paper, we estimate the production function for each branch separately. We assume that firms within the same branch face the same input prices, which is less problematic than extending this assumption to the entire manufacturing industry.

Capital is assumed to be a dynamic input in Olley and Pakes (1996) and the capital stock in period t of a firm is determined at period $t-1$. Following Ackerberg, Caves, and Frazer (2006), we implicitly assume that labor is "less variable" than material. More precisely, we suppose that l_{it} is chosen by firms at time $t-b$ $(0 < b < 1)$, after k_{it} being chosen at $t-1$ but prior to m_{it} being chosen at t. We follow Levinsohn and Petrin (2003) and assume that material demand is monotonic in ω_{it}. We thus reply on material demand equation $m_{it} = f_t(\omega_{it}, l_{it}, k_{it})$ to proxy for productivity by inverting $f_t(\cdot)$.

Substituting the inverse function into the production function results in a first stage equation of the form

$$\begin{aligned} y_{it} =& \beta_m m_{it} + \beta_l l_{it} + \beta_k k_{it} + \beta_{mm} m_{it}^2 + \beta_{ll} l_{it}^2 + \beta_{kk} k_{it}^2 + \beta_{ml} m_{it} l_{it} + ... + \beta_{lk} l_{it} k_{it} + \\ & f_t^{-1}(m_{it}, l_{it}, k_{it}) + \epsilon_{it} = \Phi_{it}(m_{it}, l_{it}, k_{it}) + \epsilon_{it} \end{aligned} \tag{15}$$

Note that β is not identified in the first stage. We obtain an estimate $\hat{\Phi}_{it}$, of the composite term,

$$\begin{aligned} \Phi_{it}(m_{it}, l_{it}, k_{it}) =& \beta_m m_{it} + \beta_l l_{it} + \beta_k k_{it} + \beta_{mm} m_{it}^2 + \beta_{ll} l_{it}^2 + \beta_{kk} k_{it}^2 + \beta_{ml} m_{it} l_{it} + ... + \\ & \beta_{lk} l_{it} k_{it} + f_t^{-1}(m_{it}, l_{it}, k_{it}) \end{aligned} \tag{16}$$

which represents output net of the unobservable shocks ϵ_{it}. We follow the standard assumption that productivity follows a first order Markov process and is given by

$$\begin{aligned} \omega_{it} &= g_t(\omega_{it-1}) + \xi_{it} \\ \omega_{it} &= E[\omega_{it} | \omega_{it-1}] + \xi_{it} \end{aligned}$$

where ξ_{it} is mean independent of all information known at $t-1$. Given the timing assumption of OP/LP, k_{it} is decided at $t-1$ because of planning and installation lags (time to build). Thus k_{it} is uncorrelated with ξ_{it}. Since l_{it} is chosen at time $t-b$, l_{it} will be correlated with ξ_{it}. However, lagged labor input, l_{it-1}, is chosen at time $t-b-1$. And it is uncorrelated with ξ_{it}. In addition, lagged material input m_{it-1} is chosen at time $t-1$ and it is uncorrelated with ξ_{it}. Finally, we have the following moments which are used to identify β.

$$E\left(\xi_{it}\left|\begin{array}{c} k_{it} \\ l_{it-1} \\ m_{it-1} \\ k_{it}^2 \\ l_{it-1}^2 \\ m_{it-1}^2 \\ k_{it}l_{it-1} \\ k_{it}m_{it-1} \\ m_{it-1}l_{it-1} \end{array}\right.\right) = 0 \tag{17}$$

Productivity can be computed using $\omega_{it} = \hat{\Phi}_{it} - \beta_m m_{it} - \beta_l l_{it} - \beta_k k_{it} - \beta_{mm} m_{it}^2 - \beta_{ll} l_{it}^2 - \beta_{kk} k_{it}^2 - \beta_{ml} m_{it} l_{it} - ... - \beta_{lk} l_{it} k_{it}$ for any value of parameters β. By non-parametrically regressing $\omega_{it}(\beta)$ on its lag $\omega_{it-1}(\beta)$, we obtain the residual from the regression ξ_{it}. The estimates of the production function β can be obtained from the moment conditions. The estimated output elasticity of material under the trans-log production function is given by: $\frac{\partial Q_{it}}{\partial M_{it}} \frac{M_{it}}{Q_{it}} = \hat{\beta}_m + 2\hat{\beta}_{mm} m_{it} + \hat{\beta}_{ml} l_{it} + \hat{\beta}_{mk} k_{it}$. And it is $\hat{\beta}_m$ under a Cobb-Douglas production function.

In addition, revenue shares are required to obtain firm level markups according to equation (4). However, we cannot observe correct revenue shares since output directly observed from the production data is $\tilde{Q}_{it} = Q_{it} exp(\epsilon_{it})$. Revenue shares are adjusted using the estimates of ϵ_{it} from the first stage procedure as follows

$$\frac{P_{X,it}X_{it}}{P_{it}\frac{\tilde{Q}_{it}}{exp(\hat{\epsilon}_{it})}} \tag{18}$$

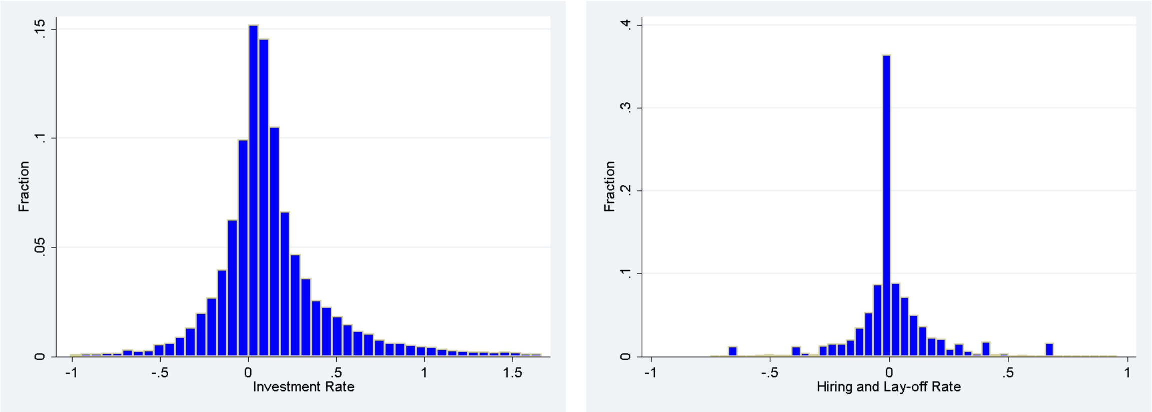
We obtain (pseudo) markups by applying the FOCs on input demand for variable and quasi-fixed factors in production in the following way:

$$\mu_{it} = \frac{\frac{\partial Q_{it}}{\partial X_{it}}\frac{X_{it}}{Q_{it}}}{\frac{P_{X,it}X_{it}}{P_{it}\frac{\tilde{Q}_{it}}{exp(\hat{\epsilon}_{it})}}} \tag{19}$$

5 Data and Some Stylized Facts

The data used in this paper are drawn from the Belfirst dataset, commercialized by Bureau Van Dijk. The database includes the full income statements of every Belgian firm that has to report to the tax authorities. We obtain an unbalanced panel for the period 1999-2007 of manufacturing firms. The variables used for the analysis are turnover, number of employees (in full-time equivalents), wage bill of full-time equivalent employees, material costs (raw materials, consumables and services) and tangible fixed assets. After cleaning up the data to exclude outliers and firms with incomplete information, we end up with a sample of 10,099 firms or 48,082 observations over the sample period. We refer to Appendix A for more details on the Belfirst dataset.

It is useful to describe a few features of the data that are suggestive of the relevance of the framework. The employment growth rate (hiring and lay-off rate) in Davis and Haltiwanger (1992) is $G_{Lit} = \frac{L_{it}-L_{it-1}}{0.5(L_{it}+L_{it-1})}$. Similarly, we construct investment rate as $G_{Kit} = \frac{K_{it}-(1-\delta)K_{it-1}}{0.5(K_{it}+K_{it-1})}$, where δ is the depreciation rate. The first panel of figure 1 depicts the histogram of firm-level investment rate. It is transparent that the distribution of firm-level investment rate has a flat tails and is highly skewed to the right (highly asymmetric). The second panel shows the histogram of firm-level hiring and lay-off rate. The distribution has a considerable mass around 0, which reveals a considerable stickiness in employment. More specifically, the data shows that hiring and lay-off rate



(a) Investment Rate Distribution (b) Hiring and Lay-off rate distribution

Figure 1: Capital/Employment Growth Rate Distributions

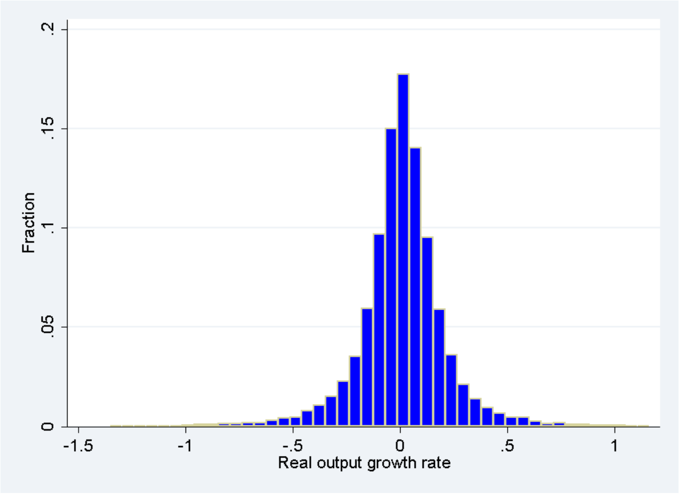


Figure 2: Real output Growth Rate Distribution

is zero for around 30% of firms[3]. It also shows some evidence of a higher frequency of small increases in employment relative to small decreases. The two panels in Figure 1 suggest that employment has a lower variability than investment in Belgium. By contrast, the rate of change in real output is characterized by a standard bell-shaped distribution. The distribution of real output growth rate is shown in Figure 2.

Figure 3 shows the average investment rate and average hiring and lay-off rate over

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[3] This is consistent with the fact that the employees of Belgium as a result of the trade union are hard to fire, as the labor laws require one of three options: a standard three months advanced notice, severance pay or a combination of the two.

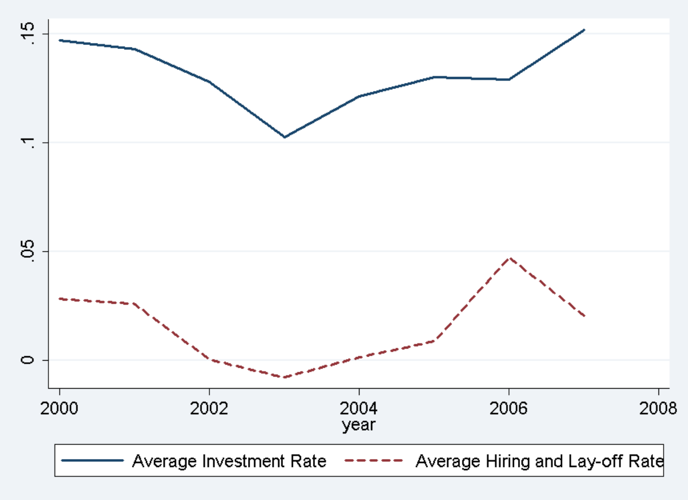

Figure 3: Average Rate of Change: 2001-2008

time. The average investment rate for manufacturing firms in Belgium, ranging from 10.24% to 15.18%, is much higher than the average hiring and lay-off rate, ranging from -0.79% to 4.72%.

6 Results

In this section, we use our empirical framework to estimate adjustment-cost parameters of capital and labor for Belgian manufacturing firms over the period 1999-2007. The output elasticities are obtained by estimating production function by using OLS and ACF approach relying on material inputs to proxy for productivity. The production function parameters are estimated at the broad NACE 31 branch level. This includes 14 manufacturing branches, from which we exclude branches DC (leather and footwear) and DF (coke, refined petroleum products and nuclear fuel) owing to a lack of observations. Table 6 in Appendix B reports the average output elasticities and corresponding standard deviations based on the estimates of production function. OLS and ACF approach give similar estimates of output elasticities.

After estimating the output elasticities with respect to material, capital and labor, we can compute the implied real and pseudo markups from the FOCs as described in

Section 2. We then construct the deviation of pseudo markups from the real markup to recover adjustment-cost parameters.

6.1 Cost of Adjusting Capital

We apply quadratic adjustment cost model to our empirical framework. Table 1 reports the estimates of the capital adjustment cost parameters γ^+, γ^- for each industry. It shows that only one industry has significantly positive adjustment cost for investment, i.e., Transport Equipment industry. Four industries, such as Food, Beverages and Tobacco, Manufacturing of Rubber and Plastic Products, Machinery and Equipment n.e.c. and Electrical and Optical Equipment, have significantly positive adjustment costs for disinvestment. For 4 out of 12 industries, capital adjustment costs are asymmetric and disinvestment costs exceed investment costs. A few industries have negative estimates. However, the true values of the parameter cannot be negative. The negative estimates of capital adjustment cost parameters indicate that the shadow cost of capital to a firm is below the rental price of capital. One possible reason of negative estimates is that we do not have the comprehensive micro data on the rental price of capital an individual firm faces. Thus we use country level instead of firm level measure of the rental price of capital. However, the country level measure of the rental price of capital may over-measure the real rental price of capital a firm faces for some industries. Thus we obtain negative estimates of capital adjustment costs for these industries. In addition, the negative estimates may also arise from specification errors, for example, the specification of convex adjustment costs.

In the literature, a number of studies find considerable adjustment cost of capital, for example, Shapiro (1986), Lichtenberg (1988) and Cooper and Haltiwanger (2006). However, applying Euler equation approach, Hall (2004) also finds negative estimates of the adjustment-cost parameter for some industries, though the precision is moderate.

Table 1: Estimates of Adjustment-cost Parameters for Capital Inputs

		γ^+	$\gamma^- - \gamma^+$	Obs.
DA:	Food, beverages and tobacco	0.0019	0.076^{***}	3,336
		(0.0032)	(0.021)	
DB:	Textiles and textile products	0.0025	-0.043^{*}	1,341
		(0.0053)	(0.026)	
DD:	Wood and wood products	0.0041	-0.0050	802
		(0.0029)	(0.039)	
DE:	Pulp, paper and paper products; publishing and printing	-0.0034^{**}	0.012	2,390
		(0.0016)	(0.023)	
DG:	Chemical, chemical products and man-made fibres	-0.00041	-0.020	1,382
		(0.0047)	(0.027)	
DH:	Rubber and plastic products	-0.0012	0.085^{**}	1,030
		(0.0012)	(0.036)	
DI:	Non-metallic mineral products	-0.0063^{***}	-0.12^{***}	1,652
		(0.0017)	(0.014)	
DJ:	Basic metals and fabricated metal products	-0.0021	-0.028	4,364
		(0.0018)	(0.019)	
DK:	Machinery and equipment n.e.c.	0.0017	0.096^{***}	1,803
		(0.0019)	(0.026)	
DL:	Electrical and optical equipment	-0.0040	0.16^{***}	1,404
		(0.0035)	(0.039)	
DM:	Transport equipment	0.035^{*}	-0.031	117
		(0.018)	(0.088)	
DN:	Manufacturing n.e.c.	0.00077	-0.0059	1,249
		(0.0021)	(0.032)	

Note: Estimates and standard errors of parameters γ^+, γ^- from equation (13). Robust standard errors adjusted for clustering at firm level are in parentheses. *** significant at the 1% level; ** significant at the 5% level; * significant at the 10% level. Firm fixed effect model is applied.

6.2 Cost of Adjusting Labor

Table 2 shows the estimates of the labor adjustment cost parameters γ^+, γ^- for each industry. We find that for 10 out of 12 industries, the labor adjustment-cost parameters (either γ^+ or γ^-) are significantly positive. For 6 out of 12 industries, firms have significantly higher firing costs than hiring costs. The estimate of firing cost parameter is more than twice as high as that of hiring cost parameter. The evidence support asymmetric labor adjustment costs, in which firing costs exceed hiring costs. This reflects stringent legislation in the European labor markets, as found in other studies for Italy (Jaramillo, Schiantarelli, and Sembenelli, 1993), France (Goux, Maurin, and

Marianne, 2001; Kramarz and Michaud, 2010) and Belgium (Dhyne, Fuss, and Mathieu, 2010). A different picture is shown in the United States in which labor market is more flexible. Firing costs are much smaller than hiring costs (Hamermesh, 1993; Caballero, Engel, and Haltiwanger, 1997).

Table 2: Estimates of Adjustment Cost Parameters for Labor Inputs

		γ^+	$\gamma^- - \gamma^+$	Obs.
DA:	Food, beverages and tobacco	4.29^{***} (0.45)	4.48^{***} (1.29)	3,336
DB:	Textiles and textile products	1.35^{*} (0.78)	4.28^{*} (2.26)	1,341
DD:	Wood and wood products	6.41^{***} (0.89)	-2.58 (2.40)	802
DE:	Pulp, paper and paper products; publishing and printing	5.14^{***} (0.79)	11.58^{***} (2.01)	2,390
DG:	Chemical, chemical products and man-made fibres	0.020 (0.92)	6.73^{***} (4.06)	1,382
DH:	Rubber and plastic products	0.76 (0.89)	2.08 (2.70)	1,030
DI:	Non-metallic mineral products	3.93^{***} (0.87)	2.76 (2.82)	1,652
DJ:	Basic metals and fabricated metal products	3.51^{***} (0.60)	4.80^{***} (1.57)	4,364
DK:	Machinery and equipment n.e.c.	4.38^{***} (1.23)	2.15 (2.93)	1,803
DL:	Electrical and optical equipment	3.64^{***} (0.84)	7.34^{***} (2.48)	1,404
DM:	Transport equipment	9.94^{***} (2.34)	11.7 (13.67)	117
DN:	Manufacturing n.e.c.	0.099 (0.79)	3.83 (3.03)	1,249

Note: Estimates and standard errors of parameters γ^+, γ^- from equation (13). Robust standard errors adjusted for clustering at firm level are in parentheses. *** significant at the 1% level; ** significant at the 5% level; * significant at the 10% level. Firm fixed effect model is applied.

The results in Table 1 and Table 2 indicate that our methodology provides reasonable estimates of labor adjustment cost parameters but it does not provide reliable estimates for capital. One important difference between the firm level study of adjustment cost for labor and capital is that firm level data often has some information on wages. Though these are quite crude measures, for instance, the average wage, it is a major advantage over capital where the variation in the rental price of capital across firms is small (or even zero). This methodology requires accurate measures of market prices of capital and labor.

Most studies provide evidence of substantial labor adjustment costs. For instance, Shapiro (1986) finds moderate adjustment cost for non-production workers. Jaramillo, Schiantarelli, and Sembenelli (1993) also find asymmetric adjustment cost of labor. However, using the same adjustment cost function, Hall (2004) finds that labor adjustment-cost parameter is close to zero.

The estimates reported in Table 2 are used to compute average labor adjustment costs and the ratio of average labor adjustment cost to annual wage per worker for each sector and the results are shown in Table 3. There is considerable variation in the magnitude of the estimated ratio of labor adjustment cost to annual wage per worker. Average firing cost is more than twice as high as average hiring cost. The estimates of labor adjustment costs are well above the level suggested by Hall (2004).

Applying our methodology to firm level production data allows us to investigate heterogeneity in employment behavior between different types of firms. Firm's employment behavior may differ across firm sizes. On one hand, large firms with the number of employees larger than 50 are more likely to face trade union resistance to reduction in employment. While small firms are often exempted from employment protection. Thus large firms may have higher firing costs because of trade union. On the other hand, labor indivisibility, which is one form of increasing returns in the adjustment technology, is potentially important for small firms. For instance, it requires at least one teacher to train one worker, but no more teachers are required for two or three workers. Small firms are more confronted to labor indivisibility issues when adjusting employment and increase or decrease their number of employees less frequently than large firms. Thus, the firm size effect on labor adjustment cost depends on the relative magnitude of trade union and labor indivisibility effect. To investigate the firm size effect on labor adjustment costs, we introduce a firm size dummy variable for the threshold of 50 (or 100) employees in the regression. Some other studies suggest that

Table 3: Average Labor Adjustment Cost

		average hiring cost (Euro)	average firing cost (Euro)	ratio of average hiring cost to annual wage per worker (%)	ratio of average firing cost to annual wage per worker (%)
DA:	Food, beverages and tobacco	536	1097	1.54	3.16
DB:	Textiles and textile products	169	704	0.51	2.13
DD:	Wood and wood products	802	480	2.40	1.44
DE:	Pulp, paper and paper products; publishing and printing	642	2089	1.50	4.89
DG:	Chemical, chemical products and man-made fibres	2.55	844	0.0050	1.65
DH:	Rubber and plastic products	95	355	0.23	0.85
DI:	Non-metallic mineral products	491	836	1.23	2.09
DJ:	Basic metals and fabricated metal products	439	1039	1.13	2.67
DK:	Machinery and equipment n.e.c.	547	816	1.22	1.82
DL:	Electrical and optical equipment	455	1373	1.02	3.08
DM:	Transport equipment	1243	2705	3.02	6.58
DN:	Manufacturing n.e.c.	12.40	491	0.035	1.37

Note: The number of employees is 100 and the employment change rate is 5%.

firm age may also affect labor adjustment costs, we thus assume that

$$\begin{cases} \gamma^{+} = \gamma_0^{+} + \gamma_1^{+} \times large + \gamma_2^{+} \times incumbent + \tau_j \\ \gamma^{-} = \gamma_0^{-} + \gamma_1^{-} \times large + \gamma_2^{-} \times incumbent + \tau_j \end{cases} \tag{20}$$

where *large* is a dummy variable taking the value 1 for large firms, *incumbent* is a dummy variable which equals to 1 if a firm's age is larger than 5, and τ_j is an industry fixed effect.

Table 4 reports the hiring and firing costs for small and large manufacturing firms in Belgium. Large firms have lower hiring costs but higher firing costs[4], suggesting that the labor indivisibility effect dominates the trade union effect during the hiring process, however, trade union effect dominates the labor indivisibility effect during

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[4] Different findings are shown in other studies, for example, Blatter, Semuel, and Samuel (2012) use Swiss firm level data and find that hiring costs are increasing strongly in firm size based on a direct inference of hiring cost.

Table 4: Labor Adjustment Costs for Small and Large Firms

	(1)	(2)
γ_0^+	4.16^{***}	4.07^{***}
	(1.21)	(1.23)
$\gamma_1^+ \times large$	-2.86^{***}	-3.68^{***}
	(0.69)	(0.93)
$\gamma_2^+ \times incumbent$	-0.15	-0.24
	(0.67)	(0.67)
γ_0^-	1.49	3.88
	(3.32)	(4.06)
$\gamma_1^- \times large$	3.81^{*}	6.96^{**}
	(2.15)	(2.99)
$\gamma_2^- \times incumbent$	-2.25	-2.19
	(2.45)	(2.45)
$\gamma_3^+ \times$ industry dummy	Yes	Yes
$\gamma_3^- \times$ industry dummy	Yes	Yes
Observations	20,870	20,870
Number of firms	5,208	5,208
R-squared(overall)	0.015	0.015

Note: In column (1), large firm dummy equals to 1 if a firm has at least 50 employees. In column (2), large firm dummy equals to 1 if a firm has at least 100 employees. Incumbents are defined as firms of age more than 5 years. Industry dummies are at NACE 3-digit level. Robust standard errors adjusted for clustering at firm level are in parentheses. *** significant at the 1% level; ** significant at the 5% level; * significant at the 10% level. Firm fixed effect model is applied.

the firing process. Hiring costs are expenditure on advertising, screening and training people, which are likely to exhibit increasing returns. So large firms tend to have lower marginal hiring cost. The results for firing costs are also consistent with the fact that one of a trade union's main aims is to protect employment, which implies that trade union plays an important role during the process of firing in large firms. However, after controlling for firm size, firm age does not have significantly impact on firing costs and hiring costs.

6.3 Remarks

6.3.1 Unobserved prices

We use deflated sales as a proxy of physical quantity when estimating output elasticities. Thus our estimates of output elasticities are subject to omitted price variable bias. Klette and Griliches (1996) show that the omitted price variable leads to a downward bias in the estimates obtained from production function regression under a variety of assumptions about the technology patterns, demand and factor price shocks. Among inputs, predetermined capital and the number of employees are less responsive to temporary demand shocks, compared to variable inputs in the production function. Thus, the estimates of technology parameters are more problematic for material input. But if the bias caused by the negative correlation between material input and prices is uncorrelated with the growth rate of capital and labor, the estimates of adjustment cost parameters are less likely to be biased.

6.3.2 Time aggregation

We estimate with annual data even though decisions about factor inputs are likely to be made more frequently, especially for labor[5]. Estimation using annual data results in a bias from time aggregation. Hall (2004) shows that time aggregation is a substantial source of the upward bias. Employment in studies based on quarterly data has more rapid adjustment than that using annual data. Therefore, the estimates of adjustment cost parameters for labor using annual data tend to have upward bias.

7 Conclusion

This paper proposes a new methodology to estimate adjustment costs for capital and labor based on the empirical framework developed by De Loecker (2011) and De Loecker and Warzynski (2012). Our approach has a number of advantages. Firstly, it does not

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[5] Lags in employment are fairly short (Hamermesh, 1993).

impose any restrictions on returns to scale and allows for flexible underlying production technologies. Secondly, it allows for various price setting models and thus different market structures. Finally, we control for unobserved productivity by using proxy approach introduced by Olley and Pakes (1996) and Levinsohn and Petrin (2003).

We use Belgian manufacturing data to estimate adjustment cost parameters of capital and labor. The results provide evidence on substantial and asymmetric adjustment costs in labor in Belgium. More specifically, firing costs exceed hiring costs, suggesting a labor market rigidity in Belgium. However, because we do not have comprehensive information on the rental price of capital faced by individual firms from standard production data, this methodology does not provide reliable estimates of adjustment costs parameters for capital. The results show weak evidence of insignificant investment cost but significant disinvestment cost for some industries in manufacturing sector.

Firms own many varieties of heterogeneous capital goods with different adjustment costs. And the labor adjustment costs may also vary with the amount of skills embodied in workers. For instance, Shapiro (1986) finds zero adjustment cost for production workers but moderate adjustment cost for non-production workers. In future work, it is of interest to estimate the adjustment costs of heterogeneous capital, hiring and firing costs for production and non-production workers. It also calls for the application of richer forms of adjustment costs to structural investment or employment equation.

8 Appendix

Appendix A: Data Description

The data used in this paper are drawn from the Belfirst dataset, commercialized by Bureau Van Dijk. The database includes the full income statements of every Belgian firm that has to report to the tax authorities. However, only a fraction of firms have to report sales[6], which we use in our empirical strategy. We obtain an unbalanced panel for the period 1999-2007 of manufacturing firms. We restrict the sample to observations where labor productivity (value-added per worker), investment-capital ratio, capital intensity (the capital-labor ratio), output growth rate, employment growth rate and expenditure shares of material, labor and capital in revenue lie within the inter-percentile rage of P1-P99. We end up with a sample of 10,099 firms or 48,082 observations over the sample period.

The variable used in this analysis are: sales (PQ): turnover in thousands of Euro, employment (L): number of full-time equivalent employees in a given year, capital (K): book value of tangible fixed assets in thousands of Euro, material (M): raw materials, consumables and services, total cost of employees (WL): staff costs of full-time equivalent employees in thousands of Euro, rental price of capital (R) is the cost of holding one unit of plant and equipment for one year. We follow Hall and Jorgenson (1967) and use an industry-specific measure of the rental price of capital $R = P_I(r - \pi + \delta)$, where P_I is the index of investment goods prices, r is the nominal interest rate, π is the inflation rate and δ is the industry-specific depreciation rate, computed as the total amount of depreciation in year t divided by net tangible fixed assets in year t-1. Turnover and material cost are deflated using price deflators at the 2-digit NACE level from the EU KLEMS. Tangible fixed assets are deflated using a countrywide investment deflator taken from the EU AMECO database.

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[6] Only large firms in Belgium have to submit a full version of the annual report. Smaller firms only have to submit a shorter version which does not include material costs. Firms are defined to be large if they have on average more than 50 employees, realize a turnover of more than 7.3 million euro or report a total value of assets of more than 3.65 million euro.

Table 5 provides some summary statistics of the full sample and restricted sample. Manufacturing firms in Belgium employ, on average, 37.95 employees. They have average labor productivity of 69,100 euro and average capital per worker of 67,430 euro. The restricted sample is limited in size and accounts for around 42% of the firms. As these are large firms, they make up 75% of total employment and 68% of capital stock. Labor productivity and investment rate in the restricted sample do not differ from the full sample.

Table 5: Summary Statistics

	Mean	Standard deviation
Full sample		
Observations	130,319	
Employment	37.95	266.83
Labor cost per worker (thousand euro)	37.93	174.15
Labor productivity (thousand euro)	69.10	210.62
Capital intensity (thousand euro)	67.43	335.56
Investment rate	0.12	0.44
Hiring and lay-off rate	0.023	0.27
Restricted sample		
Observations	48,082	
Employment	77.02	287.32
Labor cost per worker (thousand euro)	39.13	16.12
Labor productivity (thousand euro)	67.35	39.75
Capital intensity (thousand euro)	50.29	64.99
Investment rate	0.13	0.32
Hiring and lay-off rate	0.015	0.18

Appendix B: Production Function Estimation

The production function coefficients are estimated at the broad NACE 31 branch level (which is higher than the 2-digit NACE sector level). This includes 14 manufacturing branches (DA to DN), from which we exclude branches DC (leather and footwear) and DF (coke, refined petroleum products and nuclear fuel) due to a lack of observations. Table 6 presents the results of the production function estimations by industry. The average output elasticities of material, labor and capital using OLS and ACF are reported, respectively.

Table 6: Production Function Estimation

		Material		Labor		Capital		Nr. Obs.
		OLS	ACF	OLS	ACF	OLS	ACF	
DA:	Food, beverages and Tobacco	0.73	0.73	0.23	0.22	0.062	0.063	5,896
		(0.11)	(0.11)	(0.10)	(0.10)	(0.033)	(0.033)	
DB:	Textiles and textile products	0.75	0.75	0.20	0.19	0.067	0.065	2,231
		(0.12)	(0.11)	(0.088)	(0.085)	(0.040)	(0.038)	
DD:	Wood and wood products	0.75	0.74	0.21	0.21	0.043	0.049	1,405
		(0.11)	(0.12)	(0.092)	(0.096)	(0.032)	(0.034)	
DE:	Pulp, Paper and paper products;	0.68	0.69	0.27	0.27	0.047	0.048	4,187
	publishing and printing	(0.12)	(0.12)	(0.11)	(0.12)	(0.028)	(0.029)	
DG:	Chemical, chemical products and	0.76	0.76	0.20	0.20	0.054	0.054	2,071
	man-made fibres	(0.088)	(0.083)	(0.064)	(0.062)	(0.034)	(0.030)	
DH:	Rubber and plastic products	0.76	0.76	0.21	0.21	0.040	0.040	1,542
		(0.081)	(0.067)	(0.076)	(0.069)	(0.022)	(0.020)	
DI:	Non-metallic mineral products	0.75	0.75	0.22	0.21	0.045	0.044	2,646
		(0.11)	(0.095)	(0.094)	(0.088)	(0.016)	(0.013)	
DJ:	Basic metals and fabricated metal products	0.69	0.70	0.26	0.26	0.047	0.049	7,322
		(0.12)	(0.10)	(0.10)	(0.096)	(0.021)	(0.023)	
DK:	Machinery and equipment n.e.c.	0.73	0.74	0.25	0.24	0.028	0.027	2,908
		(0.10)	(0.096)	(0.10)	(0.095)	(0.016)	(0.015)	
DL:	Electrical and optical equipment	0.71	0.70	0.26	0.27	0.044	0.045	2,454
		(0.12)	(0.13)	(0.12)	(0.13)	(0.028)	(0.029)	
DM:	Transport equipment	0.71	0.74	0.27	0.26	0.024	0.017	255
		(0.12)	(0.17)	(0.12)	(0.19)	(0.026)	(0.013)	
DN:	Manufacturing n.e.c.	0.73	0.74	0.22	0.21	0.056	0.055	2,206
		(0.085)	(0.078)	(0.070)	(0.064)	(0.028)	(0.025)	

Note: Average output elasticities are reported in the table. And standard deviation is in parentheses.

Appendix C: Firm Level Markups

We compute firm-specific markups based on the ratio of input's output elasticity and its revenue share. Table 7 shows the average (pseudo) markups using different input factors. The standard deviation indicates a substantial variation in markups across firms in manufacturing sectors. We obtain (pseudo) markups in the range of 1.049 -1.44. As expected, the average markup by using variable input material is significantly lower than the average pseudo markups estimated using capital input. However, the average pseudo markups estimated using labor input are comparable to the average markups from material.

Table 7: Estimated Markups

	Markups/pseudo markups	
	OLS	ACF
Material	1.075	1.077
	(0.11)	(0.053)
Labor	1.066	1.049
	(0.27)	(0.29)
Capital	1.44	1.44
	(0.92)	(0.83)

Note: The average markups are shown in the table. The Standard deviation around the markup is in parentheses.

References

Abel, A. (1980): *On the State of Macroeconomics*chap. Empirical Investment Equations: An Integrative Framework, pp. 39–93. Carnegie-Rochester Conference Series.

Ackerberg, D. A., K. Caves, and G. Frazer (2006): “Structural Identification of Production Functions,” *Working Paper.*

Berndt, E., C. Morrison, and G. Watkins (1981): *Modelling and Measuring Natural Resources Substitution*chap. Dynamic Models of Energy Demand: an Assessment and Comparison, pp. 259–281. MIT Press, Cambridge.

Blatter, M., M. Semuel, and S. Samuel (2012): “The Cost of Hiring Skilled Workers,” *European Economic Review*, 56(1), 20–35.

Bond, S., and J. Van Reenen (2007): *Handbook of Econometrics, 6A*chap. Microeconometric Models of Investment and Employment, pp. 4417–4498. North Holland, London, UK.

Caballero, R. (1999): *Handbook of Macroeconomics, vol. 1B*chap. Aggregate Investment. North Holland, Amsterdam.

Caballero, R. J., E. M. R. A. Engel, and J. Haltiwanger (1997): “Aggregate Employment Dynamics: Building from Microeconomic Evidence,” *American Economic Review*, 87(1), 115–137.

Caballero, R. J., E. M. R. A. Engel, and J. C. Haltiwanger (1995): “Plant-Level Adjustment and Aggregate Investment Dynamics,” *Brookings Papers on Economic Activity*, 26(2), 1–54.

Chirinko, R. (1993): “Business Fixed Investment Spending: Modeling Strategies, Empirical Results and Policy Implications,” *Journal of Economic Literature*, 31(4), 1875–1911.

Cooper, R., J. Haltiwanger, and L. Power (1999): "Machine Replacement and the Business Cycle: Lumps and Bumps," *American Economic Review*, 89(4), 921–946.

Cooper, R. W., and H. Haltiwanger (2006): "On the Nature of Capital Adjustment Costs," *Review of Economic Studies*, 73(3), 611–633.

Cooper, R. W., and J. Willis (2009): "The Cost of Labor Adjustment: Inferences from the Gap," *Review of Economic Dynamics*, 12(4), 632–647.

Davis, S. J., and J. Haltiwanger (1992): "Gross Job Creation, Gross Job Destruction, and Employment Reallocation," *Quarterly Journal of Economics*, 107(3), 819–863.

De Loecker, J. (2011): "Recovering Markups from Production Data," *International Journal of Industrial Organization*, 29(3), 350–355.

De Loecker, J., and F. Warzynski (2012): "Markups and Firm-Level Export Status," *American Economic Review*, 102(6), 2437–2471.

Dhyne, E., C. Fuss, and C. Mathieu (2010): "Labor demand adjustment: Does foreign ownership matter?," National Bank of Belgium Working Paper No 207.

Gould, J. P. (1968): "Adjustment Costs in the Theory of Investment of the Firm," *Review of Economic Studies*, 35(1), 47–55.

Goux, D., E. Maurin, and P. Marianne (2001): "Fixed-term Contracts and the Dynamics of Labour Demand," *European Economic Review*, 45(3), 533–552.

Hall, R. E. (2004): "Measuring Factor Adjustment Costs," *Quarterly Journal of Economics*, 119(3), 899–927.

Hamermesh, D. S. (1989): "Labor Demand and the Structure of Adjustment Costs," *American Economic Review*, 79(4), 674–689.

——— (1993): *Labor Demand.* Princeton: Princeton University Press.

Hamermesh, D. S., and G. A. Pfann (1996): “Adjustment costs in factor demand,” *Journal of Economic Literature*, 34(3), 1264–1292.

Jaramillo, F., F. Schiantarelli, and A. Sembenelli (1993): “Are Adjustment Costs for Labor Asymmetric? An Econometric Test on Panel Data for Italy,” *Review of Economics and Statistics*, 75(4), 640–648.

Katayama, H., S. Lu, and J. Tybout (2003): “Why Plant-Level Productivity Studies are Often Misleading, and an Alternative Approach to Interference,” NBER Working Paper No. 9617.

Klette, T. J., and Z. Griliches (1996): “The Inconsistency of Common Scale Estimators When Output Prices are Unobserved and Endogenous,” *Journal of Applied Econometrics*, 11(4), 343–361.

Kramarz, F., and M.-L. Michaud (2010): “The shape of hiring and separation costs in France,” *Labour Economics*, 17(1), 27–37.

Levinsohn, J., and A. Petrin (2003): “Estimating Production Functions Using Inputs to Control for Unobservables,” *Review of Economic Studies*, 70(2), 317–341.

Lichtenberg, F. R. (1988): “Estimation of the Internal Adjustment Costs Model Using Longitudinal Establishment Data,” *Review of Economics and Statistics*, 70(3), 421–430.

Lucas, R. E. (1967): “Adjustment Costs and the Theory of Supply,” *Journal of Political Economy*, 75(4), 321–334.

Olley, S. G., and A. Pakes (1996): “The Dynamics of Productivity in the Telecommunication Equipment Industry,” *Econometrica*, 64(6), 1263–1297.

Pindyck, R. S., and J. J. Rotemberg (1983): “Dynamic Factor Demands and the Effects of Energy Price Shocks,” *American Economic Review*, 73(5), 1066–1079.

Shapiro, M. D. (1986): "The Dynamic Demand for Capital and Labor," *Quarterly Journal of Economics*, 101(3), 513–542.

Treadway, A. (1969): "On Rational Entrepreneurial Behaviour and the Demand for Investment," *Review of Economic Studies*, 36(2), 227–239.

——— (1970): "Adjustment costs and variable inputs in the theory of the competitive firm," *Journal of Economic Theory*, 2(4), 329–347.

Uzawa, H. (1969): "Time Preference and the Penrose Effect in a Two-Class Model of Economic Growth," *Journal of Political Economy*, 77(4), 628–652.