EMPLOYMENT RESPONSE TO REAL EXCHANGE RATE MOVEMENTS: EVIDENCE FROM HUNGARIAN EXPORTING FIRMS*

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This paper estimates the labor demand response of Hungarian exporting firms to real exchange rate movements. The use of firm level export–import data enables the separation of two channels through which the exchange rate affects labor demand. First, a real depreciation raises the forint-equivalent price of foreign competitors, thereby boosting demand for the firm's export and, hence, the firm's demand for labor. Second, by raising the cost of imported inputs, a depreciation has an adverse effect on employment through the cost channel. A higher marginal cost induces a decrease in production and thus shrinks labor demand. Since firms with higher export share tend to import more, this latter negative effect might offset the former positive one. The cost effect may be dampened if labor and imported inputs are substitutes.

The paper shows that the relative importance of the demand and cost effects is industry specific. The short-run exchange rate and employment elasticity stemming from the demand effect is around 0.04. This channel is most pronounced in the case of the Food and tobacco industry. Machinery, on the other hand, exhibits a cost effect of roughly –0.04. Surprisingly, there is no evidence that export share affects exchange rate exposure.

KEYWORDS: Labor demand; Exchange rate; Panel data.

The present paper addresses the question of how workers of Hungarian exporting firms are affected by movements in the Hungarian real exchange rate. In particular, it examines the changes in labor demand attributable to exchange rate movements. To the extent a weaker forint implies an expansion in Hungarian exports, firms may be willing to expand their labor force. Besides the magnitude and speed of this demand-driven adjustment, we are interested in the cost side of the exchange rate. It is a common observation that Hungarian exporting companies use a substantial amount of imported inputs. This means that a depreciation of the forint raises the marginal cost of production, thereby affecting the demand for labor non-trivially. This paper attempts to separate the demand- and cost-side effects.

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Using a panel of large Hungarian exporting firms from 1992–1996, the paper quantifies the effect of real exchange rate movements on labor demand. Although this effect is well documented for U.S. industries, we are unaware of any such empirical study concerning transition countries. As these economies have opened up to international trade, it is important to quantify how much their labor force is exposed to external market conditions. The immediate observation that most Central and Eastern European countries have limited the fluctuation of their exchange rate in one fashion or another does not render the question irrelevant. Even if the nominal exchange rate is stabilized, the real exchange rate faced by firms can vary remarkably depending on foreign and home market conditions. As for the case of the HUF, we document firm-specific real exchange rates based on product- and firm-level data on Hungarian exports and imports and show that there is much more fluctuation in these rates than in the nominal HUF rate. Also, the recent tendency of more flexible exchange rate regimes further justifies the analysis of exchange rate movements.

The rest of the paper is organized as follows. Section 1 gives a brief survey on the existing literature on U.S. estimations. Section 2 derives the estimable equations from a standard dynamic model of labor demand. Estimation methodology and results are reported in section 3. Finally, section 4 concludes. There is an appendix describing the data used and some of the technical derivations of the estimation technique.

1. PREVIOUS RESULTS

In this section we present some of the empirical literature that have addressed a wide range of questions concerning labor market adjustment to exchange rate shocks. Besides net changes in employment (either in number of employed or in hours worked) and wages, gross job flows are also analyzed.

Employment and wage response

In one of the earliest papers, *Branson* and *Love* (1988) examine the effects of the real appreciation of the U.S. dollar in the early eighties. Using industry-level data from 1970 to 1986, they estimate how a labor-cost based real exchange rate can explain changes in U.S. manufacturing employment. They find a sizeable exchange rate effect, an average elasticity of 0.11 for non-durable goods and 0.29 for durable goods.[2] That is, a 10 percent real appreciation of the dollar results in a 1.1 percent, respectively 2.9 percent decline in industry employment. They also document that employment reacts very slowly, so the long-run coefficients may well be three to ten times higher than the short-run elasticities.

Burgess and *Knetter* (1998) estimate the *reduced form* of a simple dynamic labor demand model for G-7 countries. They examine the elasticity of employment with respect to exchange rates, as well as the speed of adjustment. They find that both of these relationships heavily differ among industries and countries. Their estimation for employment-exchange rate elasticity are rather mixed, ranging from −1.5 to +1.2.[3] They conclude that in roughly 30 percent of the country–industry pairs there is a significant em

[2] *Branson–Love* (1988) p. 249, significant coefficients only.
[3] *Burgness–Knetter* (1998), Table 3, significant coefficients only.

ployment response to exchange rates: an appreciation of the home currency results in loss of jobs. Germany and Japan seem somewhat less responsive to exchange rate fluctuations than the other G-7 countries. The stylized fact that the labor markets of Anglo-Saxon countries (United Kingdom, United States, Canada) adjust faster is also confirmed.

Dekle (1998) applies a partial equilibrium model of monopolistic competition on Japanese manufacturing firms. He calculates industry specific real exchange rates as demand shifters, by using industry specific GDP deflators and trade shares. Dekle founds that there is a sizeable impact of real exchange rate changes to employment. He rejects, however, that this impact is linked with the industries' exposure to foreign markets (either export or import shares). The estimated employment/exchange rate elasticity ranges from 0.71 to 1.26, but the speed of adjustment is rather slow.[4]

In contrast to the result of *Burgess* and *Knetter* (1998), *Campa* and *Goldberg* (1998) find very weak relationship between employment and exchange rates in U.S. manufacturing industries. They investigate both the *demand* and the *supply* of labor, measuring job, working hours and wage responses to fluctuations of the U.S. dollar between 1972 and 1995. Using industry-level data, they find that wages respond significantly to exchange rate changes (with an average elasticity of 0.04), whereas the number of jobs and working hours is virtually unaffected (with an elasticity of 0.01).[5] In explaining the differences in labor market adjustment among sectors, the competitive structure (measured by the price over costs markup) and the external orientation of the industry (a higher export share yields larger labor demand increase in response to a real depreciation, while a higher import share results in lower, or even in negative demand change) and the skill-level of the labor force have proven to be the most important factors.

Lebow (1993) criticizes those studying the behavior of tradable goods sectors alone. He argues that the cross sectoral adjustment of labor supply (although mobility is imperfect in his model) affects the wage level of the nontradable goods sector, as well. The overall effect of exchange rate on relative and aggregate real wage is thus ambiguous, its sign depends on the degree of labor mobility and the share of the tradable sector in production and employment. He also finds that wages are more responsive to export and import *price*s than the real exchange rate.

Job flows

The use of industry-level employment *stock* data can yield misleading predictions. In the last few years it has become fashionable to address the question with the use of firm-level *flow* data. Instead of number of jobs or total working hours, research is directed towards job creation and job destruction of firms and entry–exit decision of workers. The simultaneous creation and destruction of jobs (resulting from heterogeneity across firms) may cover a substantial part of labor market adjustment, even if net employment is unchanged. These gross job flows may be correlated with the firm's external exposure.

At the individual worker's level, employment stability has got little to do with net employment flows. Newly created jobs may require very different skills from those that a freshly laid-off worker has. Even in absence of these structural differences, higher gross

[4] *Dekle* (1998), p. 797.
[5] *Campa–Goldberg* (1998), p. 24.

job flows give rise to higher search unemployment. This is why the analysis of gross flows is essential in understanding the labor market consequences of real exchange rate movements.

Analyzing U.S. job flows, *Gourinchas* (1998) finds that although net industry employment responds very little to dollar exchange rate movements, there is a substantial response of job destruction and creation rate within the industries. A weaker dollar implies both less job creation and less job destruction, and, conversely, a strong dollar means more job adjustment. *Goldberg, Tracy* and *Aaronson* (1999) incorporate another important margin of labor market adjustment, the worker's switching of industry. They document that roughly half of the job-changers change their two-digit industry as well.[6] The authors use matched samples from the Current Population Survey, which contains individual-level data on employment, too. They estimate a probit model to explain the job or industry switching of the worker by industry specific export and import real exchange rates, and also examine the asymmetry of these effects. They find that manufacturing workers' likelihood to switch industry is largely effected by the import real exchange rate, that is, an appreciation reduces the likelihood of switching. The relationship is most pronounced in the non-durable goods sector and in sectors with high import shares. For non-manufacturing workers, both export and import exchange rates influence the probability of industry switching, while the probability of job changing remains unaffected. This means that sectoral composition of the labor market is responsive to exchange rate movements.

Similarly to *Gourinchas* (1998), *Klein, Schuh* and *Triest* (2000) turn to gross job flows in U.S. manufacturing industries during 1973 and 1993. They calculate job creation and destruction rates from firm-level employment data, showing substantial heterogeneity across industries in this respect. They find that the differences are connected with the sector's external exposure. Interestingly, this connection is asymmetric: whereas job destruction increases with an appreciation of the dollar (a 1 percent appreciation causing a 0.47 percentage point higher destruction rate), job creation seems to be unaffected.[7] This may be due to asymmetric adjustment costs: creating new jobs is likely to be more costly than laying off workers. The authors also find evidence that the responsiveness of job destruction is higher in industries more open to international competition.

Goldberg and *Tracy* (2001) improve upon *Goldberg et al.* (1999) by incorporating a wage equation in their estimation. This enables them to address the puzzling result that wages are much more responsive to exchange rates than employment is (see *Campa-Goldberg*, 1998, for instance). They show that these large wage changes are mostly associated with job transitions (though they are not captured by industry-level data), that is, workers remaining on the same job face little wage change.

2. ANALYTICAL FRAMEWORK

This section introduces the analytical framework used to derive the estimable equations.

[6] *Goldberg et al.* (1999), p. 206, Table 1.
[7] *Klein et al.* (2000).

Product Demand

Consider a Hungarian exporting firm, competing in two markets, the domestic (henceforth indexed by *H*) and the foreign (hence *F*). Demand for the firm's products Q^D depends on its price relative to its competitors,

$$Q^D = f\left(P^F \middle/ P^F_{comp}, P^H \middle/ P^H_{comp}\right), \qquad /1/$$

and both relative prices have negative effect on the demand.[8] If the demand elasticities are constant in both markets, then markups are constant, too. This implies that the prices charged depend only (positively) on the marginal cost of production, hence one can write total production as a function of competitor's prices and marginal cost shifters.

$$Q = g(\underset{+}{P^F_{comp}}, \underset{+}{P^H_{comp}}, \underset{-}{W}, \underset{-}{R}, \underset{-}{P_M}), \qquad /2/$$

where W is the wage rate, R is the rental cost of capital, and P_M is the price of imported inputs. All prices are expressed in domestic currency (henceforth referred to as HUF). Adopting a log-linear functional form,

$$q = \alpha_0 + \alpha_1 p^F_{comp} + \alpha_2 p^H_{comp} + \alpha_3 w + \alpha_4 r + \alpha_5 p_M \qquad /3/$$

where lowercase letters denote logarithmized variables. We expect α_1 and α_2 to be positive while α_3, α_4, and α_5 to be negative.

Labor demand

With any static production function, labor demand of the firm is a function of the production level, the wage rate, and the price of other inputs that either complement or substitute labor in production. Two such factors will be examined: capital and imported materials.

$$L = h(\underset{+}{Q}, \underset{-}{W}, \underset{?}{R}, \underset{?}{P_M}), \qquad /4/$$

where L is the amount of labor demanded (measured in the number of workers) and Q is the level of production. We will assume a log-linear form,

$$l = \beta_0 + \beta_1 q + \beta_2 w + \beta_3 r + \beta_4 p_M \quad . \qquad /5/$$

Here β_1 is expected to be positive, β_2 to be negative, while the signs of β_3 and β_4 are indeterminate. They depend on whether capital and imported inputs substitute or comple

[8] Insofar as Hungary can be considered a small open economy, the foreign disposable income does not affect demand for Hungarian products. Specifications with foreign and Hungarian spending have been tested but none of them entered significantly.

ment labor. If the factors are gross substitutes then the coefficient is positive, otherwise, if they are gross complements, it is negative. Substituting in for q from /3/ to avoid endogeneity bias in the estimation yields,

$$l = (\beta_0 + \alpha_0\beta_1) + \alpha_1\beta_1 p_{comp}^F + \alpha_2\beta_1 p_{comp}^H + \\ + (\beta_2 + \alpha_3\beta_1)w + (\beta_3 + \alpha_4\beta_1)r + (\beta_4 + \alpha_5\beta_1)p_M , \qquad /6/$$

or, after redefining the parameters,

$$l = \gamma_0 + \gamma_1 p_{comp}^F + \gamma_2 p_{comp}^H + \gamma_3 w + \gamma_4 r + \gamma_5 p_M \ . \qquad /7/$$

This is the static version of the labor demand equation that we wish to estimate. We will also refer to the previous equation as $l = \boldsymbol{\gamma}^T \mathbf{x}$ with $\boldsymbol{\gamma}$ being the vector of coefficients and **x** being the vector of demand and cost shifters.

There are three channels through which exchange rate affects labor demand. First, a real depreciation raises the forint-equivalent price of foreign competitors (p^F_{comp}), thereby boosting demand for the firm's export.[9] This is what we call the *demand channel*. The exchange rate elasticity of labor demand, γ_1 is expected to be positive and increasing in the company's export exposure. Second, by raising the cost of imported inputs (p_M), a depreciation has an adverse effect on employment through the *cost channel*. A higher marginal cost induces a decrease in production and thus shrinks labor demand. Third, depending on the production function, an increase in imported material prices may cause substitution towards labor to the extent that these two factors are substitutable in production. This *substitution channel* dampens the effect of the cost channel. Their gross impact is summarized in coefficient γ_5. The overall employment-exchange rate elasticity will be $\gamma_1+\gamma_5$.[10]

Let us now turn to a dynamic version of the previous model.

Sluggish Adjustment

The static model of labor demand presented in the previous subsection is only valid in absence of adjustment costs. However, there are significant costs of *hiring* and *firing* workers. This means that the present employment decision is influenced by past employment and also by the expectation to future market conditions. Let us briefly examine the dynamic considerations arising from adjustment costs. We will only consider net changes in the labor force, leaving working hours unchanged.

In general, the firm would solve the following dynamic optimization problem:

$$\max_{\{l_t\}} \mathrm{E}_0 \sum_{t=0}^{\infty} \left[\delta^t \pi(l_t, \mathbf{x}_t) - C(\Delta l_t)\right] , \qquad /8/$$

[9] 'Real' deprecation means that domestic prices are unchanged.

[10] It has been assumed that the wage rate and the rental cost of capital are unaffected by the real exchange rate. Although wages can play a significant role in labor market adjustment to external shocks (see *Campa–Goldberg*; 1998), we anticipate that this occurs over a longer horizon due to some rigidity in the nominal wages. As for the cost of capital, a liberalized capital market ensures that it is relatively fixed.

where $\delta = 1/(1+r)$ is the firm's discount factor, π_t is profit, l_t is (log of) employment, $\mathbf{x}_t$ is a vector of exogenous variables (demand and cost shifters, among others, most importantly, foreign product prices and prices of other factors) in period t, $C(\cdot)$ is the adjustment cost depending on the one period net percentage change in employment, $\Delta l_t = l_t - l_{t-1}$.

The simplest specification of adjustment costs is the most widely used *quadratic form*:

$$C(\Delta l) = c\Delta l^2 ,$$

where c is a parameter representing the size of adjustment costs. Together with a quadratic profit function, this assumption ensures that labor demand evolves according to the following dynamics:[11]

$$l_t = \mu l_{t-1} + (1-\mu)(1-\delta\mu)\sum_{s=0}^{\infty}(\delta\mu)^s \, \mathrm{E}_t \, l^*(\mathbf{x}_{t+s}) , \qquad /9/$$

where l^* is the *optimal* level of labor demand that would prevail itself in absence of adjustment costs, and μ is a positive parameter depending positively on the magnitude of adjustment costs. Observe that optimal employment is a weighted average of previous period employment and present and all future optimal employments.

Now the question remains how expectation on future market conditions, $\mathbf{x}_{t+s}$'s can be specified. In the estimations we will assume that the exogenous variables follow a first-order vector-autoregression, that is,

$$E_t \mathbf{x}_{t+s} = \mathbf{A}^s \mathbf{x}_t ,$$

where $\mathbf{A}$ is the matrix of the VAR coefficients. Recall that $l^* = \boldsymbol{\gamma}^T \mathbf{x}$, implying that $E_t l^*_{t+s} = \boldsymbol{\gamma}^T \mathbf{A}^s \mathbf{x}_t$. If the Leontief inverse of $\delta\mu\mathbf{A}$ exists then /9/ simplifies to

$$l_t = \mu l_{t-1} + \underbrace{(1-\mu)(1-\delta\mu)\gamma(\mathbf{I}-\delta\mu\mathbf{A})^{-1}}_{\boldsymbol{\theta}} x_t . \qquad /10/$$

Here $\boldsymbol{\theta}$ denotes the vector of directly estimable short-run (or contemporaneous) parameters. However, we might also be interested in the long-run parameters, γ. If we know $\mathbf{A}$ and δ then we can calculate

$$\gamma = \frac{\boldsymbol{\theta}(\mathbf{I}-\delta\mu\mathbf{A})}{(1-\mu)(1-\delta\mu)} .$$

We will apply the previous dynamic framework to estimate the production equation, /3/, too. Since adjusting the production level can indeed be a costly decision (We have al

[11] See *Nickell* (1986), p. 502–504 for the details of the algebra.

ready discussed the role of hiring and firing costs, but adjustment costs also occur in investment and disinvestment), it is right to estimate /3/ in a dynamic setting. In this case, present production will also depend on last-period production, so lagged production will enter the labor demand equation, too.

$$l_t = \theta_0 + \mu l_{t-1} + \eta q_{t-1} + \theta_1 p^F_{comp,\,t} + \theta_2 p^H_{comp,\,t} + \theta_3 w_t + \theta_4 r_t + \theta_5 p_{M,t}\,, \qquad /11/$$

$$q_t = \alpha_0 + \lambda q_{t-1} + \alpha_1 p^F_{comp,\,t} + \alpha_2 p^H_{comp,\,t} + \alpha_3 w_t + \alpha_4 r_t + \alpha_5 p_{M,t}\;. \qquad /12/$$

These are the equations to be estimated. We are interested in θ_1, the demand-side exchange rate elasticity of employment, θ_5, the cost-side elasticity, and their production-equation counterpart, α_1 and α_5.

These are only the short-run elasticities. To see the magnitude of the long-run elasticities, we must take the speed of labor demand adjustment and the expectation for future market conditions into account. The sample is too short to forecast exogenous variables so we are not calculating long-run elasticities based on the VAR approach outlined former. A crude measure can be obtained if we assume that all the exogenous variables follow a random walk (i.e., $\mathbf{A}=\mathbf{I}$). The respective demand- and cost-side exchange rate elasticities of employment are $\theta_1/(1-\mu)$ and $\theta_5/(1-\mu)$.

3. EMPIRICAL ANALYSIS

In the following section I first describe the data and the econometric methodology used, then discuss the main empirical findings.

Data

The dataset consists of a panel of Hungarian exporting companies from 1992 to 1996. Data were matched from three different sources, the Customs Statistics, the firms' balance sheet and earnings statement data, and Eurostat's Extra-EU Trade Statistics. 'Foreign market' of the firms is identified with the European Union because this is the largest market segment that we have data on. This approximation is valid up to the extent that Hungarian export is oriented towards the EU. The median firm in the sample collects 65 percent of its export revenues from the EU, and this number is above 99 percent for the top decile, so we regard the use of EU data as a good approximation.

The Customs Statistics dataset contains the annual export and import traffic of Hungarian firms, both in value (HUFs and U.S. dollars) and in tons, so we are able to calculate unit value measures. The traffic is divided into product categories broken down to HS6 (the Harmonized System) level. The use of the Harmonized System makes prices and quantities comparable to European external trade statistics. Annual EU exports and imports are given in ecus and tons for each HS6 category. This enables us to calculate import and export unit values as a proxy for the average foreign price for each product. These prices are then converted to HUF and are averaged for each firm as described in Appendix 1. The companies were then matched with their balance sheets and profit and loss accounts, to obtain data on employment, sales and costs. Appendix 2 describes how the variables were constructed.

Those large companies were selected, whose performance depend largely on export markets. A firm was chosen if it exported at least 100 million HUFs and possessed at least 100 million HUFs book equity in 1994. The dynamic nature of the model restricts us to use only those companies who have data from consecutive years. Out of the resulting 356 firms we selected those in one of the four most export-oriented industries: Food and tobacco (SIC 15 and 16), Chemical industry (SIC 23 through 26), Metallurgy (SIC 27 and 28) and Machinery (SIC 29 through 35). This limited the number of firms in the unbalanced panel to 266 with an average span of 2.7 years, which means 707 observations.

Altogether, the companies in the sample represent a substantial fraction of Hungarian exports (see Table 1). Their share is between one fourth and one third, although in 1992 there are remarkably few firms in the sample (31 firms with an export share of 8.4 percent).[12] Although the selection by size can introduce selection bias, the large degree of representativity may justify this choice.

Table 1

Sample allocation

Industry	Number of firms						Average span (years)
	1992	1993	1994	1995	1996	Total	
Food and tobacco	8	28	43	44	51	67	2.6
Chemical	8	38	46	37	55	63	2.9
Metallurgy	5	23	28	29	29	50	2.6
Machinery	10	43	57	48	77	90	2.3
Total	*31*	*132*	*174*	*158*	*212*	*266*	*2.7*
Share in total Hungarian exports* (percent)	8.4	24.3	26.2	28.2	35.2	27.4	

* *Source*: Statistical Yearbook of External Trade (1997–1998). Külkereskedelmi Statisztikai Évkönyvek 1997, 1998. KSH. Budapest.

Since we have an unbalanced panel, we need to check whether falling out of the panel is endogenous, in which case we would encounter serious selection bias in the estimation. Fortunately, the variables of interest do not explain fall-out from the panel (we have estimated a probit equation to examine this problem), meaning that survival is indeed random.

Table 2 summarizes the external exposure of firms within each industry. We report the share of exports in total revenues as a measure of exposure to demand shocks, the share of import costs in total costs to capture the cost-effect of the exchange rate, and the share of foreign owned firms in the sample. This latter ratio may be relevant to the extent that foreign owned firms respond differently to external conditions than domestic firms. Sources of this difference may include greater market power in external markets and

[12] This is most probably because of the accounting and bankruptcy reforms of 1992; a lot of firms have gone out of business or changed their status and thus their tax registration number. Hence they cannot be linked into a panel and drop out of the sample.

transfer pricing between the multinational company and its Hungarian subsidy. After experimenting with several specifications (not reported in this paper), we were unable to identify significant differences between foreign and domestically owned firms.

Table 2

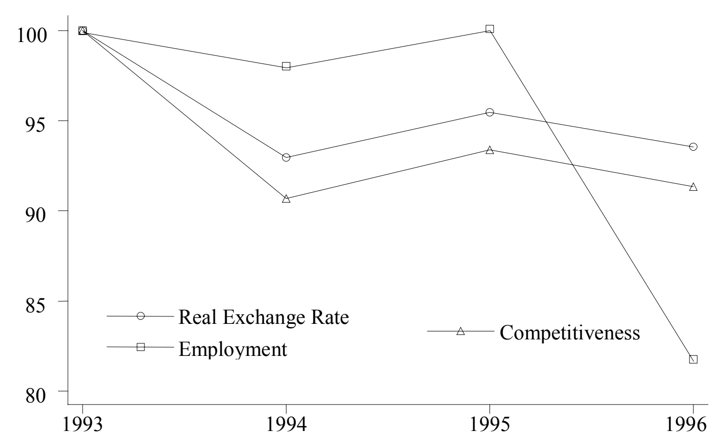
External exposure
(percent)

Industry	Export share in revenues	Import share in costs	Sample share of foreign owned firms
Food and tobacco	26.1	13.7	58.1
Chemical	47.6	29.5	59.8
Metallurgy	45.0	34.3	39.5
Machinery	65.8	40.3	58.3
Total	*47.2*	*29.8*	*55.6*

It is a surprising observation how much export and import exposure correlate. The industry with the lowest export share, Food industry (26.1%) has also the lowest share of imports (13.7%), and, conversely, that with the highest export share (Machinery, 65.8%) has the highest import share, too (40.3%). This amplifies the importance of looking at the cost-channel of exchange rate: it may well be the case that a weakening HUF has a negative impact on employment because the price increase of imports outweighs the expansion of demand.

To get a sense of how the exchange rate and employment co-move, let us have a look at Figures 1 through 4. They display cumulated change in the real exchange rate, the firm's external competitiveness, and employment averaged across each of the industries (1993=100).[13]

Figure 1. Mean employment and the real exchange rate: Food and tobacco industry
(1993=100)



[13] Year 1992 has been omitted because there are too few observations to calculate meaningful averages.

Figure 2. Mean employment and the real exchange rate: Chemical industry
(1993=100)

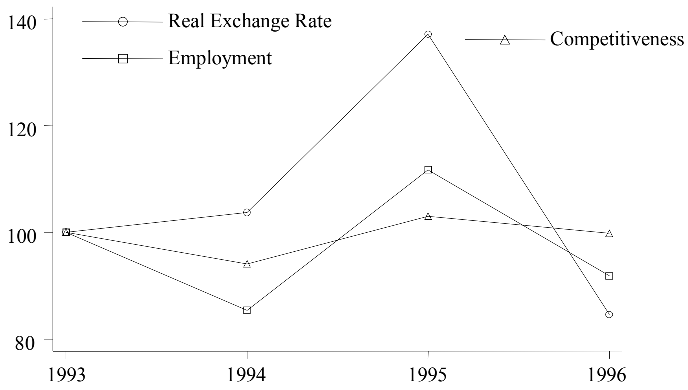


Figure 3. Mean employment and the real exchange rate: Metallurgy
(1993=100)

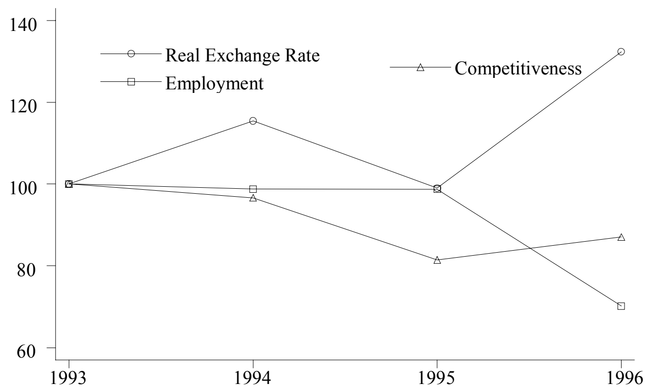
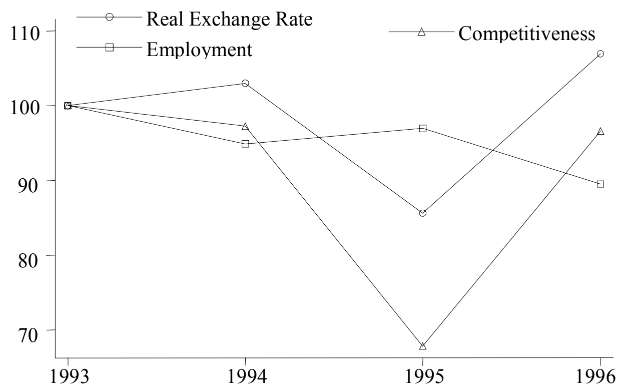


Figure 4. Mean employment and the real exchange rate: Machinery
(1993=100)



The real exchange rate is average foreign price relative to domestic price (in common currency), while competitiveness is measured as the foreign competitors' price relative to the firm's export price (see Appendix 1 for more details on variable definitions). We can see that the real exchange rate moves along a wide range during the years with the patterns differing remarkably across industries. For example, Machinery has experienced almost the opposite real exchange rate movements than the Chemical industry did. There is also a large within-industry variation in the real exchange rate not reported in the figures. These findings call for the use of industry-specific, or even firm-specific exchange rate instead of an aggregate macroeconomic measure.

Also observe that in the case of Chemical industry and Metallurgy competitiveness is less volatile than the real exchange rate although they move in the same direction. This means that the firm's export price reacts less to the exchange rate than the domestic price does. This may be due to either nominal price rigidities, or local currency price stability stemming from pricing-to-market behavior.[14]

We see significant co-movement of employment and real exchange rate for the Food and tobacco and the Chemical industry. In particular, a weaker forint is associated with a labor expansion. No pattern is visible for Metallurgy and even a reversed response can be seen in the case of Machinery. This may be due to the high import share of this industry: a weaker forint raises the price of inputs, thereby lowering the demand for labor. Let us now turn to an econometric evaluation of these findings.

Methodology

Recall the estimable equation from /11/. We have subtracted $l_{i,t-1}$ from both sides.

$$\Delta l_{i,t} = \theta_0 + (\mu - 1) l_{i,t-1} + \eta q_{i,t-1} + \theta_1 p^F_{comp,it} + \\ + \theta_2 p^H_{comp,it} + \theta_3 w_{it} + \theta_4 r_{it} + \theta_5 p_{M,it} + u_{it} \qquad /11a/$$

where i indexes firms, t indexes time, and u_{it} is the error term. Let us discuss some of the methodological problems of estimating /11a/.

– *Endogeneity of factor prices*. If the firm's size is not negligible relative to its factor markets, then factor prices may be correlated with the error term. Consider a firm-specific shock that raises the firm's demand for labor. (Macroeconomic shocks are controlled for by using time dummies.) This may well increase the equilibrium wage rate, and may also alter the other factor prices. Since the cost of imported materials is measured as a European average price (see Appendix 1), it is not likely to be affected by a small-country firm. In the case of capital, we argue that the large degree of capital mobility equates capital costs across regions, so the individual firm has little effect on its capital cost. This argument does not hold for labor, since it is rather immobile within Hungary. Hence we used an Instrumental Variable (IV) approach to correct for the endogeneity of wages. Current wage of the firm was instrumented by lagged wage and regional supply shifters, as unemployment rate and labor activity rate.

[14] See *Goldberg–Knetter* (1997) for an overview of the pricing-to-market literature.

– *Firm-specific error*. If there are omitted firm-specific factors that affect labor demand (e.g., firm-specific assets, managerial skills), then the error term is correlated with lagged employment, thus making the OLS estimation inconsistent. We can incorporate firm-specific error terms if we estimate the model with one of the panel methods. A fixed effect model is immediately ruled out, since the lagged dependent variable renders the estimation inconsistent.[15] A random effect specification can be employed, and the maximum likelihood estimator remains consistent in this case, as described in Appendix 2.[16]

To tackle the previous problems, the following estimation procedure was adopted. First, we fitted the wage rate on all the exogenous labor demand shifters herein, as well as supply shifters, such as lagged wage and regional measures of unemployment and labor force activity. We used the predicted wage instead of the actual wage in all of the model specifications later. This two-step procedure is equivalent to the standard IV-method if the second step is a linear estimation. If it is not, then the estimation is still consistent by a method-of-moments argument.[17] However, the asymptotic covariance matrix of the estimator may be different if we treat the predicted wage as given and do not take into account that it was estimated in the auxiliary regression. It can be argued that if the second estimator is close to linear, this bias of the covariance matrix should be negligible. Otherwise, we should bear this caveat in mind when testing the significance of coefficients.[18]

To test the specification of the labor demand model, we also estimated an equation for the production of the firm, using equation /12/ (and subtracting $q_{i,t-1}$ from both sides):

$$\Delta q_{it} = \alpha_0 + (\lambda-1)\, q_{i,t-1} + \alpha_1\, p^F_{\text{comp},\, it} + \\ + \alpha_2\, p^H_{\text{comp},it} + \alpha_3\, w_{it} + \alpha_4\, r_{it} + \alpha_5\, p_{M,\, it} + w_{it}. \qquad /12a/$$

If we have omitted variables important to both production and labor demand decisions then the two error terms, u_{it} and w_{it} are likely to be correlated. This is why the seemingly unrelated regressions (SUR) technique is to be applied.

To test whether export exposure affects the demand channel of the exchange rate, we split the sample in two parts: those firms whose share of exports in total sales is above 50 percent are termed 'High export share' firms, the others have 'Low export share.' A dummy controls for high export share. The coefficient of foreign prices and domestic prices are allowed to vary with export share. We would expect that a high export share increases the effect of foreign prices and reduces that of domestic prices.

Results

Table 3 displays the results of the random effect estimation. Since industries differ with respect to their trade exposure and production function, we estimate the labor demand equation for each of them separately.

[15] This is known as the *incidental parameters* problem, see *Chamberlain* (1984) for a discussion.

[16] For a similar panel-problem while estimating investment response to exchange rates, *Nucci* and *Pozzolo* (2001) use GMM instead of the ML procedure described here.

[17] The first part of the moment function is the orthogonality condition of the auxiliary regression and the second part is derived from the second step, e.g., a maximum likelihood estimation.

[18] We have also tried the error component two-stage least squares procedure suggested by *Baltagi* (1995) and it did not change the results qualitatively.

Table 3

Random effect model, maximum likelihood estimates

Employment, difference	Pooled sample	Food and tobacco	Chemical	Metallurgy	Machinery
Lagged employment	-0.1642***	-0.2235***	-0.1123**	-0.1728***	-0.2433***
	(0.0250)	(0.0372)	(0.0536)	(0.0650)	(0.0446)
Lagged production	0.0696***	0.1034***	0.0146	0.0928*	0.1310***
	(0.0222)	(0.0348)	(0.0485)	(0.0514)	(0.0408)
Foreign prices	0.0186*	0.0363**	-0.0030	0.0268	0.0057
	(0.0099)	(0.0146)	(0.0186)	(0.0223)	(0.0300)
Domestic prices	0.0836	-0.0089	0.0788	0.0237	-0.1121
	(0.0512)	(0.1329)	(0.1294)	(0.1188)	(0.2056)
Wage rate	-0.1377*	-0.2726***	-0.0161	-0.2418*	-0.1753
	(0.0720)	(0.0963)	(0.1669)	(0.1399)	(0.1445)
Rental cost	-0.0217	0.0095	-0.0444	-0.0042	-0.0597
	(0.0219)	(0.0421)	(0.0456)	(0.0394)	(0.0413)
Import cost	-0.0038	0.0030	-0.0034	0.0149	-0.0405**
	(0.0068)	(0.0101)	(0.0120)	(0.0111)	(0.0186)
Foreign prices × High export share	-0.0187	0.0676	0.0098	-0.0977***	-0.0138
	(0.0136)	(0.0629)	(0.0247)	(0.0251)	(0.0380)
Domestic prices × High export share	-0.0582	-0.1706	-0.0390	0.1385	0.2150
	(0.0640)	(0.1809)	(0.0901)	(0.1416)	(0.2115)
	Short-run exchange rate elasticity				
Low export share	0.0148	0.0393**	-0.0064	0.0417*	-0.0348
High export share	-0.0039	0.1070*	0.0034	-0.0560***	-0.0487*
	Approximate long-run exchange rate elasticity				
Low export share	0.090	0.176**	-0.057	0.241	-0.143
High export share	-0.024	0.479	0.030	-0.324	-0.200
	Restrictions				
H_0: demand = cost = 0 [a)]	3.53	6.47**	0.13	4.00	4.85*
	Descriptives				
Number of observations	707	174	184	114	235
$\chi^2(16)$ [a)]	171.40***	65.44***	66.67***	60.57***	69.34***
$\sigma (v_i)$	0.1161***	0.0000	0.1245***	0.1549***	0.1284***
$\sigma (u_{it} - v_i)$	0.2144***	0.1831***	0.1520***	0.1152***	0.2735***
$\sigma (\Delta l_{it})$	0.2690	0.2217	0.2187	0.2115	0.3455
R^2	0.1785	0.3179	0.1929	0.1669	0.2352

Notes: All variables are in logs. The significance of coefficient or test: * 10 percent, ** 5 percent, *** 1 percent.
[a)] Likelihood ratio test, χ^2 distribution.

For all the industries except for the Food and tobacco industry we find that the firm-specific error term is highly significant. It explains a large fraction of the variation in annual change of employment. This validates the use of the random effect model.

The short-run wage elasticity of labor demand is of the expected negative sign and significantly different from zero in the case of Food and tobacco industry and Metallurgy. As for the magnitude, it is somewhat smaller than that was found by *Kőrösi* (1998), who uses a slightly different dynamic formulation for labor demand estimation on a larger Hungarian dataset.[19] The coefficient on lagged production, $\mu-1$, is rather high, that is, significantly greater than -1. This means that the speed of employment adjustment is fairly slow, just as in *Kőrösi*'s analysis (1998). Also note that lagged production enters significantly into three of the industries, suggesting that production adjusts sluggishly, too. Let us now turn to the parameters of key interest.

Although foreign prices enter with a significant positive coefficient in the pooled sample, it is only the Food and tobacco industry that has a significantly positive demand-side exchange rate elasticity (0.0363 for the low export share firms). This means that a 10 percent real depreciation of the HUF causes labor demand to rise by 0.36 percent in the same year. This number is higher for high export share firms, although not significantly. We do not find support for the hypothesis that export share affects exchange rate exposure.[20] It affects neither the coefficient on foreign prices, nor that on domestic prices. This may be due to several reasons. Firstly, as shown in Table 2, export and import shares are highly correlated across industries, meaning that a higher export share also means more pronounced cost effect thereby offsetting the increase in the demand effect. However, we expect the export and import shares to be less correlated within industries (we do not test this because we only have a crude measure of import share for separate firms) making this explanation unreasonable. Secondly, firms exporting more to the EU may have more market power in their foreign market. Then they absorb exchange rate fluctuations more in their markup than in their level of production and employment.

Import cost only affects labor demand of Machinery significantly. Here a 10 percent HUF depreciation implies that employment is cut by 0.41 percent the same year. It is important to note that this number may potentially be dampened by an incomplete exchange rate pass-through. As documented by *Goldberg* and *Knetter* (1997), it may well be the case that the price of imported inputs reacts less than one to one to exchange rate movements.

The overall effect of exchange rate on labor demand remains ambiguous. The null hypothesis that there is no effect whatsoever is only rejected in Food and tobacco industry and Machinery (the former exhibiting a positive, the latter a negative effect). Low export share firms in the Food and tobacco industry and Metallurgy have a total short-run exchange rate elasticity around 0.04. This number goes up to 0.11 for high export share Food and tobacco industry firms and falls down to -0.05 for firms in Machinery. On the other hand, the speed of labor adjustment is very slow (the reported $\mu-1$ coefficient and hence μ is large), especially in the case the Chemical industry and Metallurgy. This means that the *long-run* effect of exchange rate may be 4 to 9 times higher than the short-run. The approximate long-run elasticities are also reported in Table 3.

Table 4 and 5 report results from the estimation of the employment and the production equations. We use the SUR method to estimate the two equations jointly. That is, we allow the two error terms to be correlated but we do not allow them to be firm specific.

[19] *Slaughter* (1997) may also serve as a basis for comparison.
[20] This negative result is in line with the findings of *Dekle* (1998) but contradicts those of *Klein et al.* (2000).

This may introduce a bias in the estimates since, as we saw in the previous model, there is a significant firm-specific component of the error term. Nonetheless, the parameters in the employment equation are remarkably stable when compared to the random effect estimates, suggesting that this bias may be small. Short-run overall exchange rate elasticity varies between 0.04 and 0.12, which increase to 0.13 and 0.42 in the long run.

Table 4

SUR estimates: Employment equation

Employment, difference	Pooled sample	Food and tobacco	Chemical	Metallurgy	Machinery
Lagged employment	-0.1489***	-0.2755***	-0.0794*	-0.0601	-0.2166***
	(0.0206)	(0.0353)	(0.0441)	(0.0630)	(0.0388)
Lagged production	0.0694***	0.1434***	0.0063	0.0135	0.1248***
	(0.0190)	(0.0337)	(0.0400)	(0.0535)	(0.0365)
Foreign prices	0.0193**	0.0336**	-0.0040	0.0317	0.0087
	(0.0093)	(0.0154)	(0.0172)	(0.0222)	(0.0307)
Domestic prices	0.0891*	0.0174	0.0571	-0.1600	-0.1103
	(0.0481)	(0.1412)	(0.1301)	(0.1652)	(0.2063)
Wage rate	-0.1348**	-0.3622***	-0.0181	-0.0729	-0.1546
	(0.0623)	(0.0956)	(0.1411)	(0.1672)	(0.1334)
Rental cost	-0.0151	0.0148	-0.0164	0.0564	-0.0537
	(0.0201)	(0.0441)	(0.0403)	(0.0413)	(0.0395)
Import cost	-0.0026	0.0021	0.0133	0.0204	-0.0348*
	(0.0069)	(0.0108)	(0.0127)	(0.0161)	(0.0190)
Foreign prices × High export share	-0.0149	0.0807	-0.0048	-0.0679**	-0.0088
	(0.0131)	(0.0661)	(0.0251)	(0.0272)	(0.0384)
Domestic prices × High export share	-0.0880	-0.2396	-0.0454	0.3106	0.1736
	(0.0642)	(0.1824)	(0.1007)	(0.2040)	(0.2242)
	Short-run exchange rate elasticity				
Low export share	0.0167*	0.0358**	0.0093	0.0521**	-0.0261
High export share	0.0018	0.1165*	0.0045	-0.0159	-0.0349
	Approximate long-run exchange rate elasticity				
Low export share	0.112*	0.130*	0.117	0.867	-0.120
High export share	0.012	0.423*	0.057	-0.265	-0.161
	Restrictions				
H_0: demand = cost = 0 [a]	2.22	2.47*	0.56	2.90*	1.69
	Descriptives				
Number of observations	704	172	184	114	234
$F(K, N–K–1)$	11.02***	7.23***	3.43***	1.73*	4.54***
$\sigma(u_{iti})$	0.2468	0.1927	0.2002	0.2032	0.3125
$\sigma(\Delta l_{it})$	0.2690	0.2217	0.2187	0.2115	0.3455
R^2	0.1779	0.3142	0.2259	0.1912	0.2344

Notes: All variables are in logs. The significance of coefficient or text: * 10 percent, ** 5 percent, *** 1 percent.
[a)] *Wald* test, *F* distribution.

The production equation fits much better than the employment equation. Also, we find that production adjusts slower than employment does. As expected, the error terms of the two equations are positively correlated. This may be due to the omission of variables affecting labor demand and the scale of production in the same direction. The coefficients on domestic prices and rental cost are often significant with the wrong sign, most probably because of the poor proxies that we use.

Table 5

SUR estimates: Production equation

Employment, difference	Pooled sample	Food and tobacco	Chemical	Metallurgy	Machinery
Lagged production	-0.0943***	-0.1694***	-0.1268***	-0.0742**	-0.0724**
	(0.0139)	(0.0374)	(0.0226)	(0.0314)	(0.0291)
Foreign prices	0.0369**	0.0426	0.0065	0.1164***	0.0817*
	(0.0152)	(0.0306)	(0.0317)	(0.0391)	(0.0468)
Domestic prices	-0.3436***	-1.0569***	-0.0030	-0.7347**	-0.8773***
	(0.0789)	(0.2788)	(0.1706)	(0.2879)	(0.3204)
Wage rate	-0.3958***	-0.3792**	-0.5055***	-0.2412*	-0.3689**
	(0.0669)	(0.1466)	(0.1228)	(0.1290)	(0.1581)
Rental cost	0.0865**	0.1124	0.2260***	0.1987***	0.0143
	(0.0339)	(0.0877)	(0.0719)	(0.0727)	(0.0613)
Import cost	-0.0098	-0.0212	0.0517**	-0.0114	-0.0476*
	(0.0117)	(0.0215)	(0.0234)	(0.0283)	(0.0287)
Foreign prices × High export share	-0.0403*	0.3039**	-0.0462	-0.1252***	-0.0617
	(0.0222)	(0.1316)	(0.0462)	(0.0477)	(0.0598)
Domestic prices × High export share	-0.0311	0.3292	-0.1104	0.2329	0.2093
	(0.1090)	(0.3611)	(0.1851)	(0.3584)	(0.3484)
	Short-run exchange rate elasticity				
Low export share	0.0271*	0.0214	0.0582*	0.1050***	0.0341
High export share	-0.0132	0.3254**	0.0120	-0.0202	-0.0276
	Approximate long-run exchange rate elasticity				
Low export share	0.287	0.126	0.459	1.415	0.471
High export share	-0.140	1.921**	0.095	-0.272	-0.381
	Restrictions				
H_0: demand = cost = 0 [a]	2.96*	1.34	2.92*	4.75***	2.43*
	Descriptives				
Number of observations	704	172	184	114	234
$F(K, N–K–1)$	18.14***	6.84***	9.12***	6.23*	10.29***
$\sigma(u_{iti})$	0.4188	0.3827	0.3695	0.3558	0.4860
$\sigma(\Delta l_{it})$	0.4806	0.4526	0.4521	0.4174	0.5334
R^2	0.2548	0.3392	0.3796	0.3570	0.2161
	Cross-equation tests				
Correlation of error terms [b)]	0.4154***	0.3946***	0.4219***	0.4509***	0.4161***
H_0: No exchange rate effect in either equation [a)]	1.89	1.62	1.49	3.17**	1.78
H_0: Constant returns and no substitution effect [a)]	0.44	1.37	3.21*	1.55	0.22

Notes: All variables are in logs. The significance of coefficient or test: * 10 percent, ** 5 percent, *** 1 percent.
[a)] *Wald* test, *F* distribution.
[b)] *Breusch – Pagan* test, χ^2 distribution.

Foreign demand affects production significantly in the Food an tobacco industry, Metallurgy and Machinery. Demand effect ranges from 0.04 to 0.30. Import cost has a significant impact on Machinery only. Embarrassingly, export share does not explain exchange rate exposure; only in the Food and tobacco industry do we find that firms with higher export share react more to foreign demand. The overall exchange rate elasticity of production ranges from 0.03 to 0.33 in the short run. The cross equation hypothesis that exchange rate affects neither employment, nor production can only be rejected in the case of Metallurgy, an industry, which shows no significant effects of labor response to exchange rate.

We have also tested whether the coefficients on import cost are significantly different in the two equations. If we assume constant returns to scale (β_1=1), this would mean that there is some substitution between labor and imported inputs. In Table 5, we report the test of the joint hypothesis of constant returns and no substitution. Only the Chemical industry is significant, in which the coefficient of import cost is of the wrong sign.

4. CONCLUSION

The paper estimates labor demand of Hungarian exporting firms in response to real exchange rate movements. The use of firm-level export–import data enables us to separate two channels through which the exchange rate affects labor demand. First, a real depreciation raises the forint-equivalent price of foreign competitors, thereby boosting demand for the firm's export and, hence, the firm's demand for labor. Second, by raising the cost of imported inputs, a depreciation has an adverse effect on employment through the *cost channel*. A higher marginal cost induces a decrease in production and thus shrinks labor demand. Since firms with higher export share tend to import more, this latter negative effect might offset the former positive one.

We find that the short-run elasticity stemming from the demand effect is around 0.04. That is, a 10 percent real depreciation causes labor demand to rise by around 0.4 percent the same year. This effect is most pronounced in the case of the Food and tobacco industry. Machinery, on the other hand, exhibits a cost effect of roughly the same magnitude but of opposite sign. Since labor demand adjustment is sluggish, the long-run effect of the exchange rate can be an order of magnitude higher than the short-run.

Surprisingly, we do not find support for the hypothesis that export share affects exchange rate exposure. This may be either because a higher export share also means a higher import share and cost effect, thereby offsetting the increase in the demand effect, or because firms exporting more have more market power in their foreign market.

The results suggest that the analysis of market power deserves more attention. This could be accomplished by a more thorough investigation of the pricing behavior of exporting firms and its interconnection with employment decisions.

APPENDIX

Here we provide definitions of the primary and the constructed variables. The datasource is given in brackets.

1. VARIABLE DEFINITIONS

– *Industries*. Industries are identified by their two-digit classification. Food and tobacco is 15 and 16, Chemical is 23 through 26, Metallurgy is 27 and 28, and Machinery is 29 through 35. (Earnings statement.)

– *Products*. A product is defined as a HS6 category. Though some of these categories are rather broad, this is the deepest possible, internationally comparable classification. Prices of different products are then averaged geometrically for each firm and year pair. (Customs Statistics.)

– *Production*. The level of production is defined as the value of sales at 1991 HUF prices. Export and domestic sales are deflated by the appropriate industry producer price index. Since material inputs are incorporated into the model, total sales, not value added is used to measure production. (Earnings statement, Statistical Yearbook of Hungary, 1993, 1995, 1997.)

– *Foreign price*. Foreign competitors' price is calculated as the CIF (Cost Insurance Free) value of total import shipments to the European Union divided by the net weight of the shipments (unit value). The values are originally expressed in ecus, and are converted to HUF with a firm-specific exchange rate using the following procedure.

Because sales are unevenly distributed throughout the year, different firms face different average nominal exchange rates within a year. Since the value of export shipments is reported in both dollars and HUFs, we have a firm-specific HUF–USD exchange rate for each product. From this we can calculate the *estimated month of shipment* within the year (as if the shipment were made in a single month), and use that month's average HUF–ecu exchange rate to convert EU-prices to HUF. This procedure ensures that we do not impose a common, average exchange rate on the firms thereby losing information. The EU prices of products are then averaged for each firm and year to get firm-specific foreign price indexes. We use geometric average with the net weight of exports as weights. (EUROSTAT, National Bank of Hungary.)

– *Domestic price*. The domestic producers' price index in the 4-digit SIC industry of the firm. (Statistical Yearbook of Hungary, 1993, 1995, 1997.)

– *Real exchange rate*. Real exchange rate is measured as the price of foreign competitors relative to domestic prices. If relative foreign prices go up, the real exchange rate rises, that is, we have a real depreciation. (EUROSTAT, Customs Statistics.)

– *Competitiveness*. With data on the actual unit value of each shipment, we are able to construct a better measure of external competitiveness. This is calculated as the price of foreign competitors relative to the export price charged by the firm. (EUROSTAT, Customs Statistics.)

– *Wages*. Total labor cost over average annual number of workers. (Earnings statement.)

– *Capital cost*. Capital cost is proxied by depreciation cost divided by the stock of fixed assets. Here we follow the lead of *Kőrösi* (1998), who uses the same proxy in his labor demand estimations. (Earnings statement, Balance sheet.)

– *Price of imported inputs*. The ecu price of an imported product is calculated as the FOB value of exports of the product from the EU divided by the total net weight. It is converted to HUF as outlined former. A price index is calculated as a weighted geometric average of individual prices. (EUROSTAT, Customs Statistics.)

2. ESTIMATION PROCEDURE

Let v_i denote the firm-specific error term of the equation. Assume that the error terms are jointly normally distributed and are independent of the explanatory variables. In particular,

$$v_i \,|x_{i1},\ldots x_{iT}, l_{i0} \overset{i.i.d.}{\sim} N\left(0,\tau^2\right),$$

$$u_{it} \,|\, x_{i1}, x_{i2},\ldots,x_{it}, l_{i0},\ldots l_{i,t-1} \overset{i.i.d.}{\sim} N\left(v_i,\sigma^2\right),$$

that is, the error term (u_{it}) is independent of the exogenous variables and past employments, *conditional* on knowing the firm-specific omitted variable, v_i. In the estimation we treat l_{i0}, i.e., the first realization of employment as given, and express all the distributions conditional on it.[21]

[21] Here we have also assumed that v_i is independent of l_{i0}. For a more general error structure and an endogenous treatment of l_{i0}, see *Chamberlain* (1984, 1999).

The joint density of the error terms for firm i conditional on the firm-specific omitted variable is the product of the per-period conditional density functions.

$$f\left(u_{i1},u_{i2},\ldots u_{iT} \mid x,l_{i0},\nu_i\right)=$$
$$=f\left(u_{i1} \mid x,l_{i0},\nu_i\right)f\left(u_{i2} \mid u_{i1},x,l_{i0},\nu_i\right)\ldots f\left(u_{iT} \mid u_{i1},u_{i2},\ldots,u_{iT},x,l_{i0},\nu_i\right)=$$
$$=\prod_{t=1}^{T} f\left(u_{it} \mid u_{i1},u_{i2,}\ldots,u_{i,t-1},x,l_{i0},\nu_i\right) \qquad \text{/App. 1/}$$

The marginal probability density function of (the vector) u_i is obtained from the joint density of v_i and u_{it} (which is the product of the previous two densities since v_i and u_{it} are independent) by integrating out v_i.

$$f\left(u_{i1},u_{i2},\ldots,u_{iT} \mid x,l_{i0}\right)=\int_{-\infty}^{\infty} f\left(u_{i1},u_{i2},\ldots,u_{iT} \mid x,l_{i0},\nu_i\right)dF\left(\nu_i\right)=$$
$$=\left(2\pi\right)^{-T/2}\det\left(\mathbf{\Sigma}\right)^{-1/2}\exp\left[-\frac{1}{2}\mathbf{u}_i'\mathbf{\Sigma}^{-1}\mathbf{u}_i\right], \qquad \text{/App. 2/}$$

where $\mathbf{u}_i=(u_{i1},u_{i2},...,u_{iT})^T$ is the vector if error terms for firm i and

$$\mathbf{\Sigma}=\begin{bmatrix} \tau^2+\sigma^2 & \tau^2 & \tau^2 & \ldots \\ \tau^2 & \tau^2+\sigma^2 & \tau^2 & \ldots \\ \tau^2 & \tau^2 & \tau^2+\sigma^2 & \ldots \\ \vdots & \vdots & \vdots & \ddots \end{bmatrix}$$

is its covariance matrix.

One may observe that this likelihood contribution for firm i is the same as in a model without a lagged dependent variable with the minor difference that the standard panel likelihood is a product of independent marginal densities while here we have a product of conditional densities. Since the functional form is the same, the standard maximum likelihood estimation procedure can be used for this dynamic version of the model.

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