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Persistence, Asymmetries and Interrelation in Factor Demand

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Abstract

A neoclassical factor demand model for structures, equipment and labour is analyzed in this paper. It incorporates a variety of dynamic specifications, such as a multi-period time-to-build for structures, internal adjustment costs for each production factor, and external investment adjustment costs. First-order conditions of the model are estimated by the generalized method of moments using manufacturing industry data from the US, Canada, West Germany, the UK (all 1960.I–1988.IV), France (1970.I–1992.II) and the Netherlands (1971.I–1990.IV). The results endorse time-to-build for structures, persistence of technology shocks and interrelations in adjustment cost dynamics.

I. Introduction

Persistence in physical capital demand has been emphasized in the literature since Eisner and Strotz (1963). Adjustment costs (AC, for short) are specified by linear-quadratic functions and the resulting first-order autoregressive dynamics in capital stock are statistically endorsed.

Most investment studies, however, do not speak in terms of AC. Jorgenson (1963) models investment gestation lags with higher dynamic structures than the first-order autoregressive representations suggested by standard AC. Kalecki (1935), Kydland and Prescott (1982) and Bertola and Caballero (1994) also draw attention to multi-period investment dynamics. Kalecki analyzes a small theoretical model and Kydland and Prescott analyze an RBC model. They emphasize that construction periods, called time-to-build (TTB, for short), can induce persistent fluctuations in macroeconomic variables. Bertola and Caballero (1994, p. 240) explain investment by measurements of dispersion and conclude by saying "While the fit of our specification is satisfactory, a model where only this mechanism is present leaves unexplained a non-trivial and serially correlated error component. Future research should explore the role of time-to-build lags ...".

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Capital demand equations derived from neoclassical factor demand studies with AC are not capable of fully explaining serial correlation either. Gestation lags (construction lags, TTB) are often mentioned as a possible explanation, although they have rarely been studied empirically in more depth.

The aim of this study is to investigate TTB. For this purpose, a factor demand model with a variety of dynamics is considered: TTB, both external and interrelated internal AC, unequal costs of increasing and reducing the labour force, and persistent technology shocks. "Persistence" in this context is defined as high serial correlation. Neoclassical assumptions are adopted. First-order conditions are estimated using the generalized method of moments, an approach also adopted by e.g. Burda (1991).

Moreover, investment is disaggregated into structures and equipment; see Altug (1989). Structures evidently need to be constructed, which implies the existence of long investment gestation lags. A TTB specification is designated according to Kydland and Prescott (1982). A crucial factor is that business *investment* instead of *physical capital stock* data are used to test for TTB. Investment data incorporate TTB lags whereas capital stock data are artificially constructed. In addition to the TTB dynamics for structures, AC for structures, equipment and labour are specified.

Two asymmetries are incorporated in the dynamic specifications. One asymmetry comes from the TTB and the "irreversibility" of investment. Due to TTB, construction periods are long in comparison with destruction periods. Both periods are costly, due to, for example, irreversibility. Such asymmetry is thus an asymmetry in time. The second asymmetry is a matter of costs instead of time. It is built into the internal AC specification for labour where hiring and firing costs are not necessarily marginally equal; see also Bertola and Bentolila (1990).

The central contribution of this study is the TTB for structures as a source of dynamics that is different from AC in a general factor demand model.[1] We investigate whether TTB can be empirically distinguished from AC, whether TTB turns out to be significant and to what extent TTB is more important than AC. For this purpose, the econometric model with TTB and AC is applied to the manufacturing industry of the U.S., Canada, West Germany, the U.K., France and the Netherlands.

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[1] Palm *et al.* (1993) and Peeters (1997) also investigate the identification of TTB. The models in these studies are far less restricted in the sense that no interrelations in the production function, no interrelations in the adjustment cost function and no asymmetric adjustment costs are specified. A closed form solution could be derived and was estimated. In contrast, the model solution offered here is implicit.

The outline is as follows. Section II specifies an econometric model, Section III presents estimation results and Section IV concludes. An Appendix provides details on the derivation of the Euler equations and the estimation strategy.

II. The Econometric Model

The Objective Function

A representative entrepreneur determines the demand for structures stock (K_t^s), equipment stock (K_t^e) and labour (N_t) by maximizing the discounted profit stream over an infinite horizon. The entrepreneur is rational in the sense that all information available is considered when making decisions. The objective function is given by

$$\mathrm{E}\left\{\sum_{h=0}^{\infty}\left(\prod_{i=0}^{h}\frac{1}{1+r_{t+i}}\right)\right.$$
$$\left.\times\left[P_{t+h}^{q}Q_{t+h}-C_{t+h}^{sn}I_{t+h}^{s}-C_{t+n}^{en}I_{t+h}^{e}-W_{t+h}^{n}N_{t+h}-IAC_{t+h}\right]\mid\Omega_t\right\}, \tag{1}$$

where Ω_t denotes the information set at time t. The term in brackets is the discount factor and r_t is the going nominal interest rate during period t.

P_t^q is the price of the product and Q_t is the total production at t. The output price is assumed to be parametric to the firm, that is $\partial P_t/\partial Q_{t-1}=0$, for $i=1, 2, \dots$. Thus the firm does not influence the product price.

A production function,[2] similar to Sargent's (1978), is specified as

$$Q_t \equiv (\alpha+\lambda_t)'\begin{bmatrix}K_t^s\\K_t^e\\N_t\end{bmatrix}-\tfrac{1}{2}[K_t^s\ K_t^e\ N_t]'A\begin{bmatrix}K_t^s\\K_t^e\\N_t\end{bmatrix} \tag{2}$$

where $\alpha\equiv[\alpha_1\ \alpha_2\ \alpha_3]'$, $A\equiv\{a_{ij}\}$ for $i, j=1, 2, 3$ and $a_{ij}=a_{ji}$.

The parameters α_i and a_{ij} are to be estimated. The term $\lambda_t\equiv[\lambda_{1t}\ \lambda_{2t}\ \lambda_{3t}]'$ represents a stochastic technology shock to the level of production. Concavity of the production function holds iff matrix A is positive semi-definite.

The nominal price of structures investment, the nominal price of equipment investment and the nominal wage are represented by C_t^{sn}, C_t^{en} *and* W_t^n, respectively. Structures investment and equipment investment are represented by I_t^s and I_t^e. The term $C_t^{sn}I_t^s+C_t^{en}I_t^e+W_t^nN_t$ in (1) thus represents the variable costs.

[2]This *linear-quadratic* function has Euler equations that are linear in physical capital stock, thereby enabling the transition from (A1) to (A2) (see Appendix).

The firm has additional costs when the stock of production factors is adjusted. These "internal AC" are defined as

$$IAC_t \equiv \tfrac{1}{2}[I_t^s \; I_t^e \; \Delta N_t]\,\Gamma \begin{bmatrix} I_t^s \\ I_t^e \\ \Delta N_t \end{bmatrix} + \exp(\zeta \Delta N_t) - \zeta \Delta N_t - 1 \tag{3}$$

where $\Gamma \equiv \{\gamma_{ij}\}$, $i, j = 1, 2, 3$ and $\gamma_{ij} = \gamma_{ji}$.

Like the matrix A in (2), Γ is specified symmetrically for reasons of identification. Convexity of IAC_t holds if the hessian is positive semi-definite.

If $\gamma_{ij} = 0$ for $i \neq j$, the AC function is not interrelated. In this case the AC for structures and equipment are given by $\gamma_{11}(I_t^s)^2$ and $\gamma_{22}(I_t^e)^2$, respectively. If in addition $\zeta = 0$, the AC of employment equal $\gamma_{33}(\Delta N_t)^2$, by which the labour AC are symmetric around $\Delta N_t = 0$. If $\zeta \neq 0$, labour adjustment costs are asymmetric. In this case the "net" hiring costs, i.e., costs associated with $\Delta N_t > 0$, can differ from the net firing costs, i.e., costs associated with$\Delta N_t < 0$, of an equivalent reduction in employment. If $\zeta > 0$, costs of hiring are higher than firing costs and vice versa; see Pfann and Palm (1993).

If $\gamma_{ij} \neq 0$ $(i, j = 1, 2, 3)$, costs associated with simultaneous investment and labour adjustments are possible. These interrelated AC represent, for instance, the set-up costs of new product lines. Investment then occurs and labour has to be recruited or becomes redundant.

Asymmetry adjustment costs of investment are not specified because *aggregate* investment time series, which are always positive, are used in the empirical analyses.

Time-to-Build

It can take time to obtain structures and equipment. Figure 1 gives an example of the construction process. It is assumed that the TTB, denoted by J, is three quarters. Construction takes place in stages according to an investment scheme that does not change over time. This investment scheme is 0.5, 0.4, 0.1 denoted by δ_3, δ_2, δ_1. Under these assumptions, a project of 10 units that starts at the beginning of period $t-2$, denoted by $S_{J,t-2}$, will be finished at the end of period t. This holds provided that initial plans are not changed during construction. It is further assumed that at the beginning of periods $t-1$ and t, capital projects of 20 and 30 units start. It then follows that, because of e.g. *stagewise* construction, total investment equals the expenditures in the J projects under construction. Investment is thus a weighted average of the project values under construction. In the example at t, gross investment is 24 since $I_t = 0.5 \times 30 + 0.4 \times 20 + 0.1 \times 10$.

Time-to-build	Investment scheme	Projects started
$J = 3$	$\delta_3 = 0.5$	$S_{J,t-2} = 10$
	$\delta_2 = 0.4$	$S_{J,t-1} = 20$
	$\delta_1 = 0.1$	$S_{J,t} = 30$

Investment

$t-2$	$t-1$	t	$t+1$	$t+2$
5	4	1		
	10	8	2	
		15	12	3

$I_t = 24$

Fig. 1. Example of time-to-build

This construction process is summarized by Kydland and Prescott (1982) by the equations

$$K_t^i = (1-\kappa^i)K_{t-1}^i + S_{1,t}^i \quad \text{with } 0 \le \kappa^i \le 1, \tag{4a}$$

$$I_t^i = \sum_{j=1}^{J^i} \delta_j^i S_{j,t}^i \tag{4b}$$

$$\sum_{j=1}^{J^i} \delta_j^i = 1 \quad \text{with } 0 \le \delta_j^i \le 1 \tag{4c}$$

and

$$S_{j,t}^i = S_{j+1,t-1}^i \quad \text{for } j = 1, 2, \times \ldots J^i - 1, \tag{4d}$$

where index i can equal s (structures) or e (equipment). κ^i in (4a) is the constant depreciation rate. Index j indicates the time away from completion. The expenditures of the capital project that is j periods from completion during period t are represented by $S_{j,t}^i$. The total TTB equals J^i. According to (4b), at each moment J^i current capital projects $S_{j,t}^i$ ($j = 1,2, \ldots, J^i$) exist that can be characterized by their production stage j. At the end of period t, the capital project, $S_{1,t}^i$, is added to the productive capital stock K_t^i (equation (4a)). As explained in the example above, gross investment consists of the sum of the values-put-in-place

$$\delta_j^i S_{j,t}^i \qquad (j = 1, 2, \ldots, J^i)$$

of the current projects during period t. Both the TTB and the investment scheme during the TTB (see (4c)) are assumed to be fixed. The last equality in the specification states that the total expenditures in the projects j periods from completion at time t are the same as the total expenditures in the projects that needed $j+1$ periods to be built in the previous period. As explained above, investment projects that are started can thus not be changed during construction. For this reason, this specification is called a "*fixed* investment plan specification".

Rewriting equations (4d) and (4a) gives

$$S^i_{j,t} = S^i_{1,t+j-1} = K^i_{t+j-1} - (1-\kappa^i)K_{t+j-2},$$

by which equation (4b) becomes

$$I^i_t = \sum_{j=0}^{J^i} \varphi^i_j K^i_{t+j-1}$$

$$\begin{aligned} \text{with} \quad & \varphi^i_0 = (\kappa^i - 1)\delta^i_1, \\ & \varphi^i_j = (\kappa^i - 1)\delta^i_{j+1} + \delta^i_j \quad \text{for } j = 1, 2, \ldots, J^i - 1, \\ & \varphi^i_{J^i} = \delta^i_{J^i}. \end{aligned} \tag{5}$$

The two kinds of capital stock, structures and equipment, suggest that the construction of equipment[3] takes less time than the construction of structures, by which $1 \leq J^e \leq J^s$. Specification (4) can further boil down to the standard (one-period) capital accumulation equation. If $J^i = 1$ it holds that $\delta_1 = 1$ and

$$K^i_t = (1-\kappa^i)K^i_{t-1} + I^i_t \Leftrightarrow I^i_t = \Delta K^i_t + \kappa^i K^i_{t-1}. \tag{6}$$

Here, gross investment is a weighted sum of current and one-period lagged capital stock. Under TTB in (5), on the other hand, gross investment also depends on future capital stock due to the fixed investment plan specification. This holds iff $J^i > 1$ and $\delta^1 \neq 1$.[4]

[3] Instead of TTB, equipment is sometimes assumed to have a certain delivery lag, which can be specified by assuming $\delta_j = 0$ for $j = 2, \ldots, J$ and $\delta_j = 1$ where this lag equals J; see Peeters (1996).

[4] In factor demand models with dynamics of physical capital stock, AC (without interrelations) are sometimes specified as $\gamma(\Delta K_t)^2$ instead of γI_t^2 (see (3)). Under a one-period TTB, these two specifications are equal if no depreciation exists ($\kappa = 0$, see (6)). Under a multi-period TTB, this no longer holds. If $J^i > 1$ and $\delta_1 \neq 1$ (see (6) and (5))

$$\gamma I_t^2 = \gamma \left(\sum_{j=0}^{J} \varphi_j K_{t+j-1} \right)^2 \neq \gamma(\Delta K_t)^2$$

even if $\kappa = 0$.

Price Setting

The firm can be a large consumer of domestic investment goods. In this case investment prices are Granger-caused by investment, denoted as $I_t^i \rightarrow C_t^{\mathrm{in}}$. This Granger causality is modelled (linearly) as

$$C_t^{\mathrm{in}} = \eta_0^i + \sum_{j=1}^{p^i} \eta_j^i C_{t-j}^{\mathrm{in}} + \sum_{j=0}^{q^i} \psi_j^i I_{t-j}^i + \varepsilon_t^i \qquad \text{for } i = \mathrm{s, e}. \tag{7}$$

ε_t^i represents an independently and normally distributed disturbance and the η's and ψ's are parameters to be estimated. This assumption of causality gives rise to "external" adjustment costs, see Brechling (1975).

III. Generalized Method of Moments (GMM) Estimation Results

Euler equations are derived from the econometric model. This derivation is tedious and therefore delegated to the Appendix, along with details of the estimation strategy. In this section, we briefly discuss the model solution, describe the data and report the estimation results.

The Model Solution

The model solution consists of a set of five equations: the Euler equations of structures investment, the equipment investment, the labour demand, as well as the structures price and equipment price equations (7). This set is estimated simultaneously using GMM with time series from an industrial country. All cross-equation restrictions, resulting from interrelations in the production and adjustment cost function and from TTB, are imposed. Each factor demand equation is highly dynamic due to TTB, which is assumed to be three quarters for structures and one quarter for equipment. A crucial factor is that *investment, instead of capital stock data*, are used in the analyses in order to be able to test for TTB (see Appendix).

Data

The data are quarterly time series from the manufacturing industry of the U.S., Canada, West Germany, the U.K. (all 1960.I–1988.IV), France (1970.I–1992.II) and the Netherlands (1971.I–1990.IV). Investment, employment and the associated prices are basically from OECD statistics and the Dutch Bureau of Statistics. Investment is disaggregated into structures and equipment, referred to as I_t^{s} and I_t^{e} respectively. Employment N_t is measured as the number of hours worked. The factor prices C_t^{sn}, C_t^{en} and W_t are in nominal terms.

GMM Estimates

Table 1 presents the GMM results for the countries under investigation. The first panel contains the coefficients of the production function, except for vector α in (2) that is not identified. The second, third and fourth panels contain the parameters of the internal AC function (3), the coefficients of the price equations (7), and the TTB parameters of (4). To identify the TTB parameters δ_j ($j = 1, 2, 3$), the depreciation rate of structures κ^s is set to the value shown at the bottom of Table 1. This value was obtained from OECD statistics and the Dutch Bureau of Statistics. The restriction $\delta_3 = 1 - \delta_1 - \delta_2$ (see (4c)) was imposed and δ_3 was calculated from the estimated parameters δ_1 and δ_2 by asymptotic least squares.

Table 1. *Results of GMM estimates*

	U.S.	Canada	U.K.	West Germany	France	The Netherlands
Production						
a_{11}	−0.25*	−0.13	−0.24*	0.77***	0.08***	−0.47***
a_{12}	0.28	−0.21	−0.51**	−0.05***	0.11**	−0.09*
a_{13}	−0.10	0.03	0.00	0.06***	0.03	−0.23***
a_{22}	−0.44	0.93	−0.28	−0.13	0.01	0.05
a_{23}	0.03	−0.31	−0.05	0.37***	0.16**	1.61***
a_{33}	0.20	0.42*	0.54**	−1.47	0.72**	−6.93***
Int. adjustment						
γ_{11}	0.21	−0.13	0.19	−0.59***	−0.09***	0.00
γ_{12}	0.01	0.60*	0.09	0.02	−0.11*	0.34***
γ_{13}	0.10**	−0.22*	−0.07*	−0.01	−0.14**	0.14
γ_{22}	0.10	−0.71*	−0.13	−0.61**	−0.37***	0.21*
γ_{23}	0.16**	0.04	0.03	−0.12**	0.14**	−0.81**
γ_{23}	−1.31***	−1.59***	−0.09**	−2.85*	−6.48***	−5.86
ζ	−1.14***	1.22***	·	−1.79***	−2.16***	−2.95*
Causal						
ψ_0^s	−0.14**	0.10	0.01	0.05	0.01	0.37***
ψ_1^s	0.14**	−0.05	0.01	0.06***	−0.01	−0.35***
ψ_0^e	0.15	0.06	0.16*	0.21*	0.27***	−0.13**
ψ_1^e	−0.11	−0.08	−0.18**	−0.22*	−0.25***	0.03
Time TB						
δ_1	0.47***	0.22***	0.02*	0.23***	0.29***	0.25***
δ_2	0.14**	0.33***	0.25***	0.38***	0.34***	0.44***
δ_3	0.39**	0.45**	0.73**	0,.39***	0.37***	0.31***
ϕ_0^e	−0.90***	−1.03***	−0.42***	−0.71***	−0.59***	−0.51***
κ^s	(0.0125)	(0.0092)	(0.007)	(0.0108)	(0.0135)	(0.007)
J-stat.	12.92	11.96	13.44	12.92	9.44	8.85

Notes: *, ** and *** signify absolute t-values between 2 and 3, 3 and 5, and larger than 5, respectively. · indicates that ζ could not be estimated due to convergence problems. δ_3 follows from $\delta_3 = 1 - \delta_1 - \delta_2$. Its standard error is calculated by asymptotic least squares. The autoregressive coefficients of the price equations and quarterly dummies are not reported. The numbers in parentheses are the values at which the depreciation rate of structures, κ^s, is fixed.

The last line of Table 1 reports the test statistic for overidentifying restrictions, obtained by multiplying the number of observations by the (optimal) GMM criterium value; see Hansen (1982). It is χ^2-distributed and the number of degrees of freedom equals the number of equations (5) times the number of instruments (10) minus the number of parameters.

Seasonality was accounted for by first estimating equation by equation with the inclusion of seasonal dummy variables. In a second step the model was jointly estimated, restricting the coefficients of the dummy variables to the estimates from the first step. This procedure reduces the total number of parameters considerably. Estimating the system equation by equation, including the dummy variables, shows that parameter estimates do not change much.

Further experiments were carried out to test for the impact of the two oil crises. These structural breaks are observable in the investment, labour and price series, but difficult to account for in the five-variate system. Apart from this, more breaks can be observed, among others clearly around 1984, but no additional dummy variables were included.

For the UK, a convergence problem was encountered due to the asymmetry parameter ζ in the AC specification (see (3)). If the parameters ζ and γ_{33} are small, an identification problem arises.[5] For the UK $\zeta = 0$ is therefore imposed.

Interpretation of the Results

The test statistics of overidentifying restrictions in the last line of Table 1 are not significant. This implies that the estimated model is not rejected for any of the countries.

A comparison of the first panel in Table 1 across countries shows that production of the U.S., Canada and the U.K. has less significant parameter estimates than that of West Germany, France and the Netherlands. Interrelations in levels of labour and investment thus appear to be more important in the continental European countries.

The second panel shows that the asymmetry parameters of the AC are significant. A negative asymmetry is found for the U.S., West Germany, France and the Netherlands, indicating higher firing that hiring costs. For France, West Germany and the U.K. these findings corroborate the results of Bentolila *et al.* (1990). For Canada, hiring costs are found to be marginally higher than firing costs.

[5] For the labour AC (see (3)) it holds that

$$\tfrac{1}{2}\gamma_{33}(\Delta N_t)^2 + \exp(\zeta \Delta N_t) - \zeta \Delta N_t - 1 = \tfrac{1}{2}(\gamma_{33} + \zeta^2)(\Delta N_t)^2 + \tfrac{1}{6}\zeta^3(\Delta N_t)^3 + \tfrac{1}{24}\zeta^4(\Delta N_t)^4 + \dots$$

which causes identification problems of γ and ζ if ζ is small.

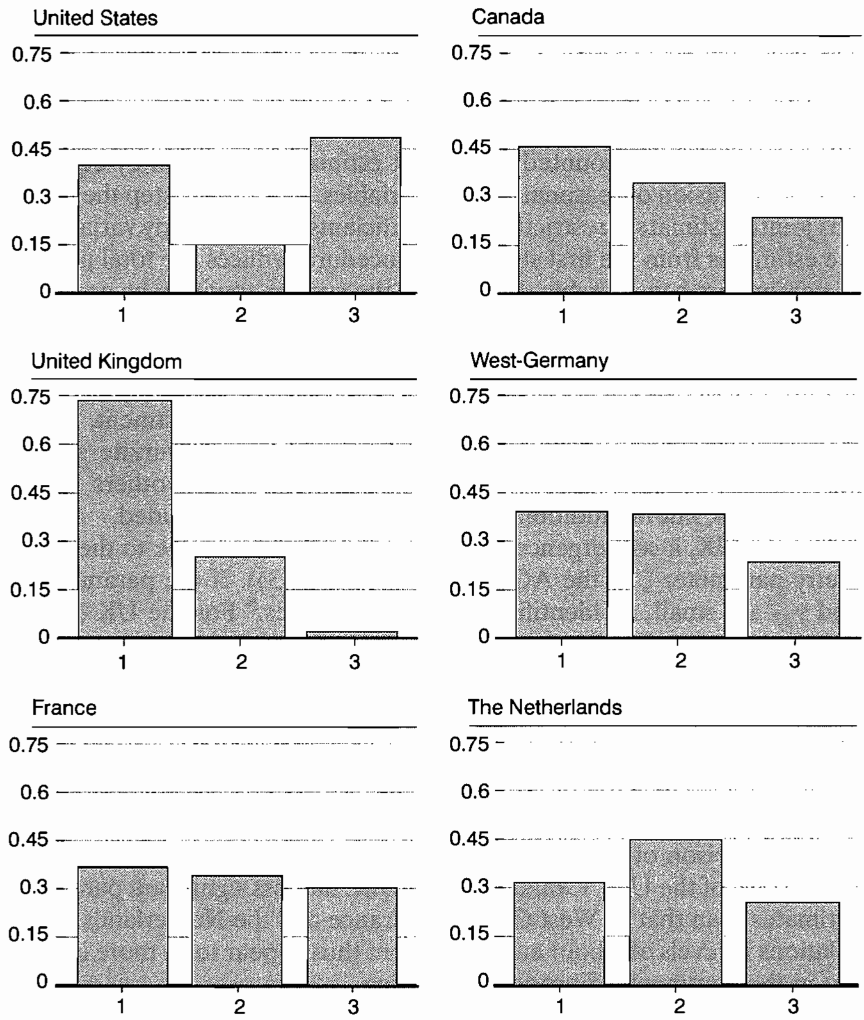

Fig. 2. Investment scheme according to GMM results

The third panel shows that the estimates of the investment price equations (7) are highly significant, except for Canada. This indicates that investment demand influences investment prices.

Most important are the TTB estimates in the fourth panel. The empirical results support the TTB parameters δ_j $(j = 1, 2, 3)$ for all countries. The parameters have the right sign, a value not exceeding one, and are highly significant. The estimated investment schemes, i.e., the distribution of investment during construction, are illustrated in Figure 2. A declining distribution holds for Canada, the U.K., West Germany and France. The U.K. is somewhat of an outlier since investment at the end of the period is very small ($\phi_1^s = 0.02$), though significant. For these four countries, most of the investment occurs at the beginning of *construction*, a scheme also found by Altug (1989). On the contrary, a "U-shape" and a "hump-shape" distribution, respectively, is found for the U.S. and the Netherlands. This indicates that the starting period is not the most expensive period in construction of manufacturing structures in the U.S. and the Netherlands. These differences in investment schemes among countries cannot be explained in depth without more country-specific information regarding tax considerations, building restrictions, etc.

The model was also estimated without TTB for each country. In this case $\phi_1^i = 1$ and parameter ϕ_0^i was estimated (for $i = s, e$). If there is a one-period TTB, both ϕ_0^s and ϕ_0^e should be between -1 and 0 (exactly $\kappa^i - 1$, see (5)–(6)). The estimates for this model (not included here) show differences between ϕ_0^s and ϕ_0^e, supporting the disaggregation of investment into structures and equipment. For the U.K., West Germany and the Netherlands ϕ_0^s is too large, whereas all ϕ_0^e parameters are close to the true value -1. The ϕ_0^e in Table 1 are in the correct range, except for Canada where the coefficient is slightly smaller than -1. This leads to the conclusions that a distinction between structures and equipment is important, that equipment does not need a multi-period TTB and that, for structures, the model without TTB is *not* preferred to the model with TTB.

In econometric terms, the significance of the TTB parameters confirms serial correlation in investment at rather long lags. This serial correlation acts as a *moving average* (cf. the disturbance structure resulting from (A2)). This is in contrast to the specification of AC, which results in an *autoregressive* representation. TTB is thus not as persistent as AC, but rather temporary due to the construction period of three quarters. During the three periods, the TTB affects both equipment and labour demand significantly.

Test Statistics

To test the importance of interrelation, causality and TTB, Wald statistics are calculated and presented in Table 2. First, the hypothesis of no interrelation is tested. For each country the off-diagonal elements of A are imposed to be zero, giving a Wald statistic that is χ^2 distributed with three degrees of freedom. Interrelation in AC, represented by Γ, is similarly tested for; the first and second lines in Table 2 report the Wald statistics. The hypothesis of no interrelation in the production function is not rejected for the U.S. and Canada, whereas it is rejected for all European countries. This implies that substitution between structures, equipment

Table 2. *Interrelation, causality, time-to-build and concavity/convexity tests*

	df	U.S.	Canada	U.K.	West Germany	France	The Netherlands
A diagonal	3	3.82	6.26	18.13**	158.46**	28.65**	78.80**
Γ diagonal	3	33.36**	28.01**	14.39**	27.70**	64.20**	316.35**
det(A)		0.009 [0.68]	−0.054 [−1.27]	−0.104 [−1.11]	0.044 [0.31]	−0.009 [−0.64]	1.501 [5.09]
det(HAC)		−0.006 [−0.84]	0.05 [1.59]	0.003 [0.92]	0.139 [1.77]	−0.024 [−0.18]	−0.427 [−3.49]
$\psi_0^s = \psi_1^s = 0$	2	2.32	3.87	8.94**	84.56**	12.73**	142.78**
$\psi_0^e = \psi_1^e = 0$	2	5.34*	4.86*	23.50**	12.77**	30.70**	84.22**
$\delta_2 = \delta_3 = 0$	2	231.19**	87.94**	2,520.04**	35,761.66**	2,721.21**	1,687.48**

Notes: * and ** denote significant at the 10 percent and 5 percent level, respectively. Rows 1–2 and 5–7: Wald test statistics for the hypotheses in the first column. df are the degrees of freedom. Row 3: determinant of matrix A in (2); row 4: determinant hessian of the AC function (3). The numbers in square brackets are the t-values, estimated by asymptotic least squares.

and labour is stronger in the U.S. and Canada than in Europe. Interrelations are obviously important in the internal AC specification for all countries.[6] Adjusting one production factor thus affects the other two production factors at the same time.

These results indicate that the system of three factor equations cannot be consistently estimated univariately. The simultaneous modelling of investment (or capital stock) and labour demand is important, particularly in dynamics. Studies where only investment demand is modelled, for example q-studies, *or* only labour, for example Burda (1991), probably obtain results that are biased.

The third and fourth lines of Table 2 contain the determinants of matrix A and the hessian of the AC function, calculated from the estimates in Table 1. Their t-values are obtained by asymptotic least squares. In theory, concavity of the production function (2) and convexity of the internal AC function (3) are supposed to hold. This requires that A and the hessian of (3) should be positive semi-definite. A necessary condition is that the calculated determinants are non-negative. As Table 2 shows, these conditions are not satisfied for France. Moreover, except for the Netherlands,

[6] If there are no interrelations, structures stocks do not appear in the equipment and labour equations by which, theoretically, a much lower MA results than in the model of Table 1. Instruments for equations one, two and three could theoretically be nine, five and three quarters lagged instead of ten, eight and seven (see Appendix). Tauchen (1986) investigates the small sample properties of GMM-estimators and finds that more biased, but more efficient, estimators result when using instruments that are lagged more often than presumed by the theoretical model. The Wald statistics can thus be biased upward here.

no significantly positive determinant is found. Thus, for five countries, neither decreasing returns to scale in the production function nor marginally increasing AC are confirmed. These results are striking since in theory, the assumptions of a *strictly* concave production function and a *strictly* convex adjustment cost function are usually made in empirical factor demand studies. The strict convexity of the criterium function is not rejected here, however, since both the external AC and TTB should be considered.

The hypothesis of Granger non-causality of investment demand to nominal prices was also tested. The results for structures and equipment are shown in the third and fourth lines, respectively. For the U.S. and Canada, Granger non-causality from structures investment to the nominal structures price is not rejected (at the 5 percent level) whereas the non-causality from equipment investment to the nominal equipment price is rejected (at the 5 percent level). These results are partly in contrast with those for the European countries, where the influence of price on the structures as well as the equipment market is not rejected (at the 10 percent level). These results indicate that investment prices are *not exogenous* to the manufacturing industry in the European countries. Investment demand by the manufacturing industry on the domestic market might be large. Relations (7) are thus important. As in the case of neglecting interrelations between investment and labour demand (see above), neglecting Granger causal relations from investment to nominal prices can also bias estimation results.

The Wald statistics in the last line of Table 2 test for TTB. The hypothesis is "there is a one-period TTB", i.e., $\delta_1 = 1$ and $\delta_2 = \delta_3 = 0$. The results show the extremely strong rejection of this hypothesis. Consequently, the three-period TTB is accepted against the one-period TTB. The extremely high significance of the statistics might be partly an artefact of the model. The parameters ϕ_j^i (i = s, e and $j = 0, 1, 2, 3$, see (5)) appear in the three Euler equations and are forced to add up to the depreciation rate. These strong restrictions boost the t-values.

IV. Summary, Conclusions and Discussion

The interrelations of investment and employment in the adjustment process and, for European countries, also in production are endorsed by the estimation results. Capital and labour are thus strongly complementary in Europe and significant costs are incurred by simultaneous adjustments. Studies on labour demand, by e.g. Burda (1991), and studies on Tobin's q that fully neglect factor interrelations may obtain biased estimates in the light of these results.

The most important finding concerns TTB, whose significance has already been emphasized by Kydland and Prescott (1982), Park (1984) and Altug (1989). As in Palm *et al.* (1993) and Peeters (1996), TTB is shown here to be a source of dynamics clearly different from AC. Moreover, it is shown here that the investment scheme can be estimated and is even empirically supported in a rich dynamic factor demand model. The autocorrelation often found in residuals of capital demand equations can thus be explained by construction lags.

Some difficulties remain. First, TTB and technology assumptions are observationally equivalent in reduced form models. Highly persistent technology shocks generate long autoregressive dynamics that are similar to the moving average dynamics from multi-period TTB. In this study, TTB parameters are estimated appropriately as *all* parameter restrictions were imposed. Second, extensions of TTB models, e.g. using more general production specifications, seem hardly feasible. Existing capital stock series do not take construction lags into account and using investment series instead complicates the analysis, as shown in this study, due to the many parameter restrictions.

A policy implication of TTB is that investment decisions might be more difficult than often expected. Not only the size, the duration and the estimated benefits of an investment project should be accounted for when taking a decision, but also the lag between the start of an investment and the final point in time when the finished capital good is obtained. In economic policy, this (long) lead time might deserve more attention than other factors for large investment projects.

Another important aspect affecting investment is uncertainty of future returns, as studied in Dixit and Pindyck (1994). This uncertainty is not accounted for at all in the analyses here. For (irreversible) investment projects that take time to be built, future returns might be more uncertain. Interesting research could be pursued in this direction.

Appendix

Derivation of the Euler Equations

The entrepreneur chooses $K^{s}_{t+J^{s}-1}, K^{e}_{t+J^{e}-1}$ and employment N_t such that the discounted profit stream is maximized. $K^{s}_{t+J^{s}-1}(K^{e}_{t+J^{s}-1})$ is the capital decision variable (instead of $K^{s}_{t}(K^{e}_{t})$) due to the TTB of J^{i} periods and the fixed investment plan. To optimize, the TTB equation (5) and the price equations (7) are substituted in (1). The derivative of (1) with respect to structures capital is then

$$\mathrm{E}\Bigg\{\beta_{t+J^s-1}P^q_{t+J^s-1}$$

$$(\alpha_1+\lambda_{1,t+J^s-1}-a_{11}K^s_{t+J^s-1}-a_{12}K^e_{t+J^s-1}-a_{13}N_{t+J^s-1})$$

$$-\sum_{k=0}^{J^s}\beta_{t+k}\varphi^s_{J^s-k}(C^{sn}_{t+k}+\gamma_{11}I^s_{t+k}+\gamma_{12}I^e_{t+k}+\gamma_{13}\Delta N_{t+k})$$

$$-\sum_{k=0}^{J^s+q^s}\beta_{t+k}I^s_{t+k}\sum_{1=\max(0,k-J^s)}^{\min(q^s,k)}\varphi^s_{J^s-k+1}\psi^s_1\,|\,\Omega_t\Bigg\}=0. \tag{A1}$$

The first-order conditions for equipment capital and labour demand are in a similar vein.[7] The last terms in (A1) follow from (5) and (7) since

$$\frac{\partial C^{sn}_{t+k}I^s_{t+k}}{\partial K^s_{t+J^s-1}}=C^{sn}_{t+k}\frac{\partial I^s_{t+k}}{\partial K^s_{t+J^s-1}}+I^s_{t+k}\sum_{1=\max(0,k-q^s)}^{\min(J^s,k)}\frac{\partial C^{sn}_{t+k}}{\partial I^s_{t+1}}\frac{\partial I^s_{t+1}}{\partial K^s_{t+J^s-1}}$$

$$=\varphi^s_{J^s-k}C^{sn}_{t+k}+I^s_{t+k}\sum_{1=\max(0,k-J^s)}^{\min(q^s,k)}\psi^s_1\varphi^s_{J^s-k+1}$$

for $k=0,1,\dots,J^s+q^s$ where $\phi^i_{J^s-k}=0$ if $k>J^s$.

In order to test for TTB, it is crucial that physical capital stock (K^s_t and K^e_t) in (A1) be expressed in terms of gross investment. Physical capital stock data are constructed by bureaus of statistics according to a one-period TTB, called the "perpetual inventory method". This method is not in line with (4) if $J^i>1$. For this reason, *investment*, *but not capital stock*, series are used in the empirical analyses.

To transform capital into investment, the first-order conditions (A1) are divided by the output price and the filter (5) is applied. This yields

$$\mathrm{E}\Bigg\{\alpha^*_1-a_{11}\sum_{i=0}^{J^e}\varphi^e_{J^e-i}I^s_{t-i}-a_{12}\sum_{j=0}^{J^s}\varphi^s_{J^s-j}I^e_{t-j}$$

$$+\sum_{i=0}^{J^e}\varphi^e_{J^e-i}\sum_{j=0}^{J^s}\varphi^s_{J^s-j}[\lambda_{1,t+J^s-1-j-i}-a_{13}N_{t+J^s-1-j-i}]$$

$$-\sum_{i=0}^{J^e}\varphi^e_{J^e-i}\sum_{j=0}^{J^s}\varphi^s_{J^s-j}\sum_{k=0}^{J^s}\frac{\beta_{t+k-j-i}}{P^q_{t+J^s-1-j-i}\beta_{t+J^s-1-j-i}}$$

$$\times\varphi^s_{J^s-k}(C^{sn}_{t+k-j-i}+\gamma_{11}I^s_{t+k-j-i}+\gamma_{12}I^e_{t+k-j-i}+\gamma_{13}\Delta N_{t+k-j-i})$$

---

[7] Suppressed here but obtainable on request.

$$
- \sum_{i=0}^{J^e} \varphi^e_{J^e-i} \sum_{j=0}^{J^s} \frac{\varphi^s_{J^s-j}}{P^q_{t+J^s-1-j-i}} \sum_{k=0}^{J^s+q^s}
$$

$$
\left. \times \beta_{t+k} I^s_{t+k-j-i} \sum_{1=\max(0,k-J^s)}^{\min(q^s,k)} \varphi^s_{J^s-1} \psi^s_1 | \Omega_t \right\} = 0, \tag{A2}
$$

where $\alpha^*_1 = \kappa^e \kappa^s \alpha_i$ because (see (5) and (4c))

$$
\sum_{j=0}^{J^s} \varphi^s_j = \kappa^s.
$$

Equipment investment appears in the structures investment equation (A2). Structures as well as equipment investment also appear in the labour demand equation (not presented here). These interrelations are important in that they result from the interrelations in the production and adjustment cost functions. They entail rich dynamics in *each* Euler equation if the construction period for structures (equipment) is long, i.e., $J^s(J^e)$ is large.

The Moving Average (MA) Orders

A closed form solution cannot be derived due to the asymmetric labour adjustment costs as well as the above-mentioned interrelations in combination with TTB. The implicit model solution is estimated instead using the GMM method of Hansen (1982). This method also facilitates imposing cross-equation restrictions.

At period t, $K^s_{t+J^s-1}$ and $K^e_{t+J^e-1}$ are determined and cannot be changed due to the fixed investment plan. In (A1) at time t, expectations of variables of at most J^s+q^s future periods are included. In the equipment and labour equations, these are J^e+q^e and one period(s), respectively.[8] Hence, replacing the expectations by the observed variables in (A1) gives rise to an MA forecast error of order J^s+q^s. Application of the filter in (A2) leads to an MA of order $2J^s+J^e+q^s$. For the equipment and labour equations, these orders are $J^s+2J^e+q^e$ and J^s+J^e+1, respectively. These MAs are taken into account when calculating the weighting matrix and choosing the instruments.

In order to estimate (A2), the technology shock λ_t in (2) is assumed to be first-order integrated,

$$
\Delta\lambda_t = \varepsilon^\lambda_t, \tag{A3}
$$

[8] If $J^s > 1$, the unknown variables at t in (A1) are P_{t+J^s-1}, $\lambda_{1,t+J^s-1}$, $K^e_{t+J^s-1}$, N_{t+J^s-1}, C^s_{t+k}, I^e_{t+k}, ΔN_{t+k} and β_{t+k} for $k = 1, 2, \ldots, J^s$ and I^s_{t+k} *for* $k = 1, 2, \ldots, J^s+q^s$. Similarly for the equipment investment equation, but if $J^s > J^e$, $K^s_{t+J^e-1}$ in this equation is known at t. The only unknown variables at t in the labour equation are I^s_{t+1}, I^e_{t+1}, ΔN_{t+1} and β_{t+1}.

where ε_t^λ represents the vector of technological innovations.[9] Taking first differences of (A2) eliminates the unit root of the (unobservable) λ_t. The resulting MA is of order $2J^s+J^e+q^s+1$. For the equipment and labour equations, these are $J^s+2J^e+q^e+1$ and J^s+J^e+2, respectively.

Nominal investment prices can be affected by investment demand, as we assume $p^s=p^e=4$ and $q^s=q^e=1$ (see (7)). These Granger-causality assumptions are based on tests in Mosconi and Giannini (1992). The price equations are jointly estimated with (A2) to identify the parameters ψ_j^i.

Finally, the TTB lags for structures (J^s) and equipment (J^e) are assumed to be three quarters and one quarter, i.e., $J^s=3$ and $J^e=1$. These assumptions are in line with Kydland and Prescott (1982), Park (1984) and Altug (1989). They all refer to Mayer (1960), who showed evidence from US surveys on lead times of plants including equipment. Evidence for US and Dutch construction projects are given in Montgomery (1995) and Peeters (1996, 1998), respectively. Experiments show that results do not change much when taking $J^s=4$ or $J^s=5$.

Instruments

Ten instruments were chosen from a set of the own country's variables, among which production factors and prices. Using the principal components method, the set of variables that explains most of the variance is chosen. On average, there was about 60 percent correlation with the endogenous variables. Non-stationary instrument variables were taken in first differences.

The MA order is nine in the structures, seven in the equipment and six in the labour equation. The instruments are therefore lagged ten, eight and seven quarters. By this choice, the instruments and the error (including the technology shock innovation) are uncorrelated, provided that the technology shock is indeed as in (A3) where ε_t^λ is white noise.

Despite the differences in MA orders across equations, the longest MA (i.e., nine) is taken into account in each equation when calculating the optimal weighting matrix with the GMM procedure of TSP. Different lag orders even preclude the use of a kernel to obtain a positive definite weighting matrix. Moreover, (cross-) correlations should equal zero (where they theoretically are zero) if the model under investigation is correct. Conditional heteroskedasticity is corrected for and the Parzen kernel is used to guarantee the positive definiteness of the covariance matrix, where the optimal bandwidth equals the number of observations to the power 1/5. Using the Bartlett kernel does not lead to significantly different results.

References

Altug, S.: Time-to-build and aggregate fluctuations: Some new evidence. *International Economic Review 30*, 889–920, 1989.

Bentolila, S. and Bertola, G.: Firing costs and labour demand: How bad is Eurosclerosis? *Review of Economic Studies 57*, 381–402, 1990.

[9] The I(1) assumption is made because estimating the model with a first-order autoregressive (diagonal) process for λ_t, after quasi-differencing, yields technology parameter estimates that do not differ significantly from one.

Bertola, G. and Caballero, R. J.: Irreversibility and aggregate investment. *Review of Economic Studies 61*, 223–246, 1994.
Brechling, F.: *Investment and Employment Decisions*. Manchester University Press, Manchester, 1975.
Burda, M. C.: Monopolistic competition, costs of adjustment, and the behavior of European manufacturing employment. *European Economic Review, 35*, 61–79, 1991.
Dixit, A. and Pindyck, R. S.: *Investment under Uncertainty*. Princeton University Press, Princeton, NJ, 1994.
Eisner, R. and Strotz, R. H.: Determinants of business investment. In Commission on Money and Credit, *Impacts of Monetary Policy, Prentice-Hall, Englewood Cliffs, NJ, 60–337, 1963.*
Hansen, L. P.: Large sample properties of generalized method of moments estimators. Econometrica 50, 1029–1054, 1982.
Jorgenson, D. W.: Capital theory and investment behavior. *American Economic Review 53*, 47–56, 1963.
Kalecki, M.: A macrodynamic theory of business cycles. *Econometrica 3*, 327–344, 1935.
Kydland, F. E. and Prescott, E. C.: Time to build and aggregate fluctuations. *Econometrica 50*, 1345–1370, 1982.
Mayer: T., Plant and equipment lead times. *The Journal of Business 33*, 127–132, 1996.
Montgomery, M. R.: 'Time-to-build' completion patterns for nonresidential structures, 1961–1991. *Economics Letters 48*, 155–163, 1995.
Mosconi, R. and Giannini, C.: Non-causality in cointegrated systems: representation estimation and testing. *Oxford Bulletin of Economics and Statistics 54*(3), 399–417, 1992.
Palm, F. C., Peeters, H. M. M. and Pfann, G. A.: Adjustment costs and time-to-build in factor demand in the U.S. manufacturing industry. *Empirical Economics 18*, 639–671, 1993.
Park, J. A.: Gestation lags with variable plans : an empirical study of aggregate investment, Ph.D. dissertation, Carnegie-Mellon University, 1994.
Peeters, H. M. M.: Investment gestation lags: The difference between time-to-build and delivery lags. *Applied Economics 28*, 203–208, 1996.
Peeters, H. M. M.: The Dynamics of Investment and Labour Demand: Theoretical Issues and an Application to the Dutch Manufacturing Industry, forthcoming in *Economic Modelling*, 1998.
Pfann, G. A. and Palm, F. C.: Asymmetric adjustment costs in non-linear labour demand models for the Netherlands and U.K. manufacturing sectors. *Review of Economic Studies 60*, 397–412, 1993.
Sargent, T. J.: Estimation of dynamic labor demand schedules under rational expectations. *Journal of Political Economy 86*, 1009–1044, 1978.
Tauchen, G.: Statistical properties of Generalized Method-of-Moments estimators of structural parameters obtained from financial market data. *Journal of Business and Economic Statistics 4*, 397–416, 1986.

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