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Author(s)	Fountas, Stilianos
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Cointegration Tests of the
Profit-maximising Equilibrium
in Greek Manufacturing 1958–1991

Theodore Lianos[1]   Stilianos Fountas[2] [3]

[1] Athens University of Economics and Business, Athens, Greece.
[2] Department of Economics, University College Galway, Ireland.   email:
steve.fountas@ucg.ie

Abstract

This paper applies the recently developed cointegration techniques to test for a long-run equilibrium among real wages and the average productivity of labour as implied by profit maximisation in the Greek manufacturing sector. We find evidence for a profit-maximising equilibrium and for adjustment towards this long-run equilibrium through nominal wages and labour productivity. We have also provided an estimate of the elasticity of substitution of 0.23 which is consistent with that of other studies using alternative approaches.

Keywords: Profit maximising equilibrium, error-correction model.

JEL Classification: D21, J2

1 Introduction

In economic models the quantities involved are classified as variables, defined according to the economic phenomena under study, behavioral parameters and technological constants. In these models, equilibrium conditions play a dual role. They can be used to derive functional forms as, for example, the demand for labour function under the profit-maximising conditions of equating the marginal product of labour to the wage rate. They can also be used to determine the level at which flow or stock variables will be stabilised as, for instance, in the demand and supply model of a commodity where the equilibrium condition specifies the quantities that would be reproduced every period. The equilibrium condition forces the model to a specific solution but it does not reveal anything about the process of adjustment towards the solution.

It is tempting to use an equilibrium condition as a test for the validity of a model or of a behavioral assumption. For example, one may be tempted to test the maximising behaviour of a firm by observing and comparing the movement through time of wages and marginal products of labour. Some people may find such a methodology questionable on the basis of the argument that a theory should be tested not by its assumptions but by its implications and predictions. Methodological issues aside, if an equilibrium condition involves observable quantities, there is no harm in examining the behaviour of these quantities. In fact, it would be very useful to know if the relationship between two variables appearing in the equilibrium condition is the same as that which is empirically observed. It would also be important to know, if the equilibrium condition does not hold empirically, what are the forces that will eliminate short-run deviations from equilibrium. In this context, recent cointegration techniques can be useful.

Recently, Jenkinson (1986) and MacDonald and Murphy (1992) have used cointegration techniques to estimate a long-run labour demand relationship. Jenkinson (1986), using a neoclassical approach, does not find any evidence for an equilibrium long run labour demand relationship. MacDonald and Murphy (1992) allowing for output effects ih the determination of employment, find a long-run equilibrium relationship for the labour demand function. Their cointegrating vector includes labour, capital, output and relative input prices. However, the approach of testing for cointegration among a set of labour demand variables is subject to the criticism that the labour demand function will be misspecified if some important variables are omitted (Perman, 1991, p. 20). To avoid this problem the present paper considers a cointegrating relationship in the profit-maximising equilibrium of the manufacturing sector. One would expect this relation to hold even if some related variables are omitted since the profit-maximising equilibrium would reflect the effects of omitted variables. In addition, the profit-maximising

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equilibrium is more general as it holds also in cases where the equilibrium does not take place on the labour demand curve as explained later in the paper.

In this paper we use cointegration analysis to examine the demand for labour in the Greek manufacturing sector and the process of adjustment to the long-run equilibrium. The annual statistical data cover the period from 1958 to 1991. The paper is organised as follows: section 2 offers the theoretical background and section 3 discusses the econometric methodology and empirical results. Finally, section 4 summarises the major conclusions of this study.

2 Background and Theory

The standard expression of the equilibrium condition for the profit-maximising firm when the level of employment is determined is the equality of real wage to the marginal product of labour. Depending on the economic and institutional framework, the equilibrium condition may be expressed in various forms. In the simplest case where the firm is a price taker in both the product market and the labour market, the equilibrium condition is:

$$\frac{\partial Q}{\partial L} = \frac{W}{P} \tag{1}$$

where W = nominal wage, P = product price, Q = output, and L = employment. If the assumption of price-taking is dropped and instead it is assumed that the quantity of output produced affects the price level, the equilibrium condition becomes

$$\frac{\partial Q}{\partial L} P \left(1 + \frac{1}{\epsilon}\right) = W \text{ or}$$
$$\frac{\partial Q}{\partial L} \left(1 + \frac{1}{\epsilon}\right) = \frac{W}{P} \tag{2}$$

where ϵ = price elasticity of demand for the product. If employment adjustment costs are introduced, the equilibrium condition becomes more complex. Assuming a given product price, the steady-state demand for labour is given by

$$\frac{\partial Q}{\partial L} P = W + r\alpha \tag{3}$$

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where r = the rate at which employers discount future profits and α is a parameter from the adjustment cost function (Hamermesh, 1993, p. 210).

If the institutional environment includes labour unions and bargaining, the equilibrium position for both the firm and the union will be found on the contract curve formed by the union's indifference map and the firm's isoprofit curves. The specific point on the contract curve that will give an equilibrium position would depend on the assumed bargaining behaviour. One conceptualisation of the game involved here leads to the Nash cooperative solution which is given by the maximisation of the product of the differences between the fall-back levels and the corresponding pay-offs of the two parties. The first-order conditions with respect to wages and to employment taken together provide the equilibrium point. The first-order condition with respect to labour is given by (see Fallon and Verry, 1988)

$$W = \frac{1}{2}\left[\frac{Q}{L} + \frac{\partial Q}{\partial L} - \frac{\pi_0}{L}\right] \tag{4}$$

where π_0 is the fall-back level of profits. In other words, setting $\pi_0 = 0$, at the equilibrium position the nominal wage is equal to the mean of the marginal and average product of labour.

Of course, union strategies may differ. According to the insider-outsider thesis, a union may attempt to secure the employment of the insiders by allowing the wage rate to adjust accordingly. In this case, the equilibrium point will be on the demand curve for labour and condition (1) or (2) will apply.

The equilibrium points for the above cases can be seen in Figure 1. An equilibrium point such as A on the demand curve D can correspond to a firm for which wages and product prices are given, to a firm which affects product prices by its own action but wages are given, or to a firm that deals with a labour union that behaves according to the insider-outsider thesis. At point A the firm has profits equal to an amount indicated by the isoprofit curve π_2. The existence of adjustment costs can be seen as changing the demand curve D, determined by the marginal value product, to a band around it as shown by the dotted lines on both sides of D. Finally, point B shows the equilibrium when bargaining takes place. It is determined by the intersection of the contract curve C_1C_2 and the dotted line through D, on the assumption that the isoprofit π_0 corresponds to zero profits and thus it is the average product curve. The main point here is that under a variety of conditions there is a close relationship between real wages and the marginal product of labour towards which both variables gravitate whenever the equilibrium condition is disturbed by exogenous shocks.

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Earlier literature has attempted to test for the existence of such a relationship empirically and, thus, indirectly test for the validity of the neoclassical model (see e.g., Thurow, 1968; Paris and Lianos, 1975). Since the marginal product of labour cannot be observed empirically as a statistical datum, it was attempted to be derived as the first derivative of the estimated production function with respect to labour. In addition to the problems associated with the measurement of variables, the quality of data, and the specification of the functional form of the production function, this method would not indicate the sources of adjustment if real wages and marginal products diverge. In this paper, we use recent cointegration techniques to test for the power of forces to reestablish equilibrium in the labour market when the equilibrium position is disturbed.

2.1 Economic Equilibrium as an attractor

Equilibrium in the labour market means a certain relationship between real wages and the marginal product of labour. The exact relationship depends on the institutional and economic environment. Theoretically, one would expect these two variables to move together in the long run, as the forces of economic equilibrium would act as an attractor that would bring them together when a disturbance forces them to diverge. In the simplest case of equality between the two, the attractor for the pairs of values in each time period would be a 45 degree line. Since the marginal product of labour is not observable, the average product, which is closely related to the marginal product, can be used instead.

Let us assume a C.E.S. production function of the form

$$Q = A[\beta K^{-\rho} + \gamma L^{-\rho}]^{-\frac{1}{\rho}}$$

where A is a technological parameter, and β, γ, and ρ are parameters. For this function, the marginal product of labour is a nonlinear function of the average product determined by ρ. For the C.E.S. production function, the attractors corresponding to equilibrium conditions (1) to (4) are:

$$\frac{W}{P} = \gamma A^{-\rho} \left(\frac{Q}{L}\right)^{\rho+1} \tag{1'}$$

$$\frac{W}{P} = \left(1 + \frac{1}{\epsilon}\right) \gamma A^{-\rho} \left(\frac{Q}{L}\right)^{\rho+1} \tag{2'}$$

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$$\frac{W}{P} = \gamma A^{-\rho}\left(\frac{Q}{L}\right)^{\rho+1} - r\alpha', \text{ where } \alpha' = \alpha/\mathrm{P} \qquad (3')$$

$$\frac{W}{P} = \frac{1}{2}\left[\frac{Q}{L} + \gamma A^{-\rho}\left(\frac{Q}{L}\right)^{\rho+1}\right] \qquad (4')$$

A relationship between the real wage and the average product of labour can be directly derived if a mark-up pricing policy is assumed. With a mark-up factor τ on labour costs

$$P = (1+\tau)\frac{WL}{Q} \quad \text{or} \quad \frac{W}{P} = \frac{1}{1+\tau}\frac{Q}{L} \qquad (5)$$

In this relationship the determination of the level of employment for profit maximisation is implicit and the marginal product of labour does not appear explicitly. The above relationship is consistent with profit maximisation and it is also more general because it applies to firms in industries that are not perfectly competitive.

The above equations can be expressed in logarithmic form. For example, taking natural logs in equation (1') we have:

$$\ln\left(\frac{W}{P}\right) = w - p = \ln(\gamma A^{-\rho}) + (1+\rho)\ln\left(\frac{Q}{L}\right) = \kappa + \nu(q - l)$$

where $\kappa = \ln(\gamma A^{-\rho}), \nu = 1 + \rho$, and lower-case letters denote logarithms.

Hence, when expressed in log form, all the attractors in equations (1')–(4') and (5) can be shown by the linear relationship $w - p = \kappa + \nu(q - l)$. Of course, this linear relationship specifies an equilibrium condition between three variables, i.e., nominal wage, price level and average product[1], and therefore, the adjustment process that will reestablish equilibrium will take place through the relative changes in these three variables. Adjustments to the average product of labour and to prices are more likely to come from the side of the firm, whereas adjustments to nominal wages would come from both sides, firms and unions, as a result of a bargaining process.

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[1]Obviously, the average product relates output and employment and, therefore, there are four rather than three variables. However, the relationship between Q and L is a technological one and not an equilibrium condition and, therefore, it is better to take (Q/L) as one variable.

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3 Empirical Estimation

3.1 Data

The statistical data for this study are from the Greek manufacturing sector for the period 1958–1991 and are obtained from the Annual Industrial Surveys.[2] Output is measured by value added of firms employing ten or more employees. Employment includes production workers and office employees but not self-employed or unpaid members of the family. Nominal wage is measured by wages and salaries divided by employment. The average product of labour is expressed in constant 1970 prices. All three variables, i.e., prices, nominal wage and average product of labour are expressed in index form. It should be noted that as price level we have taken the producer price index rather than the consumer price index because it is the former that is relevant for the employment decision making of employers. Observations for the above variables are not available for three years (1962, 1978, and 1979). Instead of generating values for the missing observations we prefer to use the data as they are.

3.2 Econometric methodology

In order to test for a long-run equilibrium relationship among prices, nominal wages and the average product of labour we make use of the recently developed cointegration techniques. Engle and Granger (1987) have suggested the use of a two-step, residual-based, cointegration technique where the residuals from the cointegrating regression are tested for a unit root. As is well known, the Engle-Granger approach suffers from some weaknesses. First, it does not allow us to determine *all* possible long-run equilibria among the economic variables. Second, it does not allow us to test for certain linear restrictions imposed on the parameters of the cointegrating vector. Third, the limiting distributions of the Dickey-Fuller and augmented Dickey-Fuller tests used under the two-stage estimation procedure are not well defined implying low power for these tests. These deficiencies are taken into account by a more recent approach to cointegration introduced by Johansen (1988) and Johansen and Juselius (1990). We have chosen to apply the more recent Johansen approach. This section will describe the methodology under this approach.

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[2]For the last few years, the Surveys are not published yet and the data were obtained from the documents of the National Statistical Service of Greece.

3.2.1 Johansen Cointegration analysis

Consider three variables x_t, y_t and z_t, that, according to economic theory, are linked through a linear, long-run equilibrium, relationship: $x_t = a_0 + a_1 y_t + a_2 z_t$. This equilibrium condition may never be observed to hold in actual time series. However, from a statistical point of view, equilibrium among these variables will exist if the deviation from the equilibrium $u_t = x_t - a_0 - a_1 y_t - a_2 z_t$ is a zero-mean stationary process[3], i.e., if the observed relationship among the three variables has been maintained on the average for a long period. In this case, the three variables will be considered to be cointegrated. Formally, cointegration can be defined as follows[4]:

Let $X_t = [x_t \ y_t \ z_t]'$. If the elements of X_t are I(d)[5] and there exists a non-zero vector a such that $u_t = a' X_t \sim I(d - b), b > 0$, then X_t is cointegrated of order d, b, denoted $X_t \sim CI(d, b)$. In the special case where $X_t \sim CI(1, 1)$, the variable u_t is stationary.

To test for cointegration, first, unit root tests are run to determine the integration properties of each individual series. In other words, regressions of the following form are run for each individual series:

$$\Delta x_t = b_0 + b_1 x_{t-1} + b_2 t + b_3 \Delta x_{t-1} + e_t$$

The joint null hypothesis is that $b_1 = b_2 = 0$. Critical values are given in Dickey and Fuller (1981).

Johansen (1988) and Johansen and Juselius (1990) have proposed a maximum likelihood approach that allows for the estimation of *all* cointegrating vectors, as well as, for tests of hypotheses on the cointegrating parameters. Assume a vector autoregressive model in levels

$$X_t = \Pi_1 X_{t-1} + \cdots + \Pi_k X_{t-k} + \mu D_t + e_t \qquad (6)$$

where X_t and e_t are n-dimensional vectors, D_t is a vector of constants (and possibly dummies) and Greek letters represent unknown coefficients. A reparameterisation of the model leads to

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[3] A stationary process has a distribution that does not depend on time.

[4] This definition can be found in several textbooks, e.g. Cuthbertson, Taylor, and Hall (1992).

[5] An I(d) series, i.e., integrated of order d, is stationary provided it is differenced d times.

$$\Delta X_t = \Pi X_{t-1} + \Gamma Y_t + e_t \tag{7}$$

where $\Pi = (\Pi_1 + \Pi_2 + \cdots + \Pi_k - I)$, $Y_t = (\Delta X_{t-1}, \ldots, \Delta X_{t-k+1}, D_t)$, and Greek letters represent unknown coefficients. Provided the series are nonstationary and cointegrated, $0 < \text{rank}(\Pi) < n$. Also, $\Pi = \alpha\beta'$ where α are the adjustment coefficients and β are the cointegrating vectors. Then, the system of equations (7) represents an error-correction model (ECM) and the adjustment coefficients show the size of the adjustment taking place to restore the long-run equilibrium.

Johansen's cointegration approach applies the following reduced rank regression. Regress ΔX_t and X_{t-k-1} on a constant and the lagged differences of ΔX_t (up to k lags) and derive the residuals u_{1t} and u_{2t} respectively. Denote the product moment matrices of the residuals as $S_{ij} = T^{-1} \sum_{t=1}^{T} u_{it} u'_{jt}$, where $i, j = 1, 2$, and T is the sample size. Then, the equation

$$\left| \lambda S_{22} - S_{21} S_{11}^{-1} S_{12} \right| = 0 \tag{8}$$

is solved for the eigenvalues λ. Johansen and Juselius (1990) specify two likelihood ratio (LR) test statistics to test for the number of cointegrating vectors. First, the likelihood ratio test statistic for the hypothesis of at most r cointegrating vectors (CIV) against a general alternative, also called trace statistic, is:

$$-2 \ln Q_r = -T \sum_{i=r+1}^{n} \ln\left(1 - \hat{\lambda}_i\right)$$

where $\hat{\lambda}_i$ are the $n - r$ smallest estimated eigenvalues derived from equation (8). The second LR statistic for the null of exactly r cointegrating vectors against the alternative of $r + 1$ vectors is the maximum eigenvalue statistic:

$$-2 \ln Q_{r,r+1} = -T \ln\left(1 - \hat{\lambda}_{r+1}\right)$$

Critical values for the above test statistics are tabulated in Johansen and Juselius (1990, p. 208-209). The second test is more powerful since the alternative hypothesis is an equality.

Once one finds that two or more variables are cointegrated, restrictions on the estimated cointegrating vector parameters can be tested using a likelihood ratio test also suggested by Johansen and Juselius (1990). The test statistic for the hypothesis of $n - s$ restrictions on all CIV is:

$$-2\ln Q_{n-s} = T\sum_{i=1}^{r}\ln\left\{\left(1 - \tilde{\lambda}_i\right)/\left(1 - \hat{\lambda}_i\right)\right\}$$

where s is the number of independent cointegrating parameters, r is the number of CIV established through the use of the trace and maximum eigenvalue statistics, and $\tilde{\lambda}_i$ and $\hat{\lambda}_i$ are the estimated eigenvalues from the restricted and unrestricted models, respectively. Under the null this statistic follows a χ^2 distribution with $r(n - s)$ degrees of freedom.

3.3 Results

We apply the Johansen cointegration procedure to test for cointegration between the logs of real wages and the average product of labour. Given the log-linear relationship between the average and marginal product of labour implied by, among other, a C.E.S. production function, a cointegrating relationship between the real wage and the average product of labour would be consistent with profit-maximising behaviour on the part of the manufacturing sector.

Empirical testing proceeds in several steps: First, the logs of the two variables, real wage and the average product of labour, are tested for a unit root using the Φ_3 version of the ADF(1) test. We also test for a unit root in the time series of the price level and nominal wage. The results are given in Table 1(a). According to these results the real wage and the average product of labour are I(1), prices are stationary, and nominal wages are I(2). The last two results might seem surprising since it is well known that most macroeconomic time series are integrated of order one. We, therefore, apply an additional unit root test, i.e., the Johansen unit root test, in order to test for a unit root in the nominal wage and the price level. The results reported in Table 1(b) imply that prices are stationary and nominal wages are I(1). One lag was chosen in performing these tests.

Next, assuming nontrended variables, we test for cointegration between the average product of labour and real wages using $k = 1$ lag in the Johansen estimation procedure. This lag choice is justified since, as Bewley and Yang (1993) report, based on their simulation study, a long lag length makes the Johansen test to

over-reject the null hypothesis of no cointegration in small samples. Table 2(a) reports the results of the two tests for the cointegrating rank. According to both tests, there is one cointegrating vector.[6] In Table 2(b) we report the cointegrating vector normalized on the average product of labour. The coefficient on the real wage is an estimate of the elasticity of substitution. Our estimate of 0.23 is in agreement with recent studies with Greek data that use an alternative approach (see Lianos and Daouli, 1995).[7]

We also considered the more general case of non-constant returns to scale where the CES production function takes the form $Q = A[\beta K^{-\rho} + \gamma L^{-\rho}]^{-v/\rho}$, where v is the returns to scale parameter, such that $v > 1$ $(= 1, < 1)$ implies increasing (constant, decreasing) returns to scale. The use of this general CES leads to an equilibrium relationship where $w - p$ depends on $q - l$ and q and the coefficient of q is $\rho(1 - v)/v$. To determine whether our *a priori* assumption that $v = 1$ is valid, we can test for cointegration among $q - l$, $w - p$ and q and, provided cointegration applies, test for a zero coefficient on q in the cointegrating vector. We first established that q is I(1). Our Johansen test gave two cointegrating vectors. A likelihood ratio test on both vectors for the null hypothesis that the coefficient on q is zero in both vectors gave us the Chi-square statistic $\chi^2(2) = 4.15$ with a 5% critical value of 5.99. Hence, the null hypothesis cannot be rejected and the restriction of constant returns to scale imposed in our analysis is valid.

To determine whether labour productivity and/or wages are important in restoring the long-run equilibrium one needs to derive estimates of the adjustment coefficients in the ECM, i.e., the α's mentioned in the definition of π in equation (7). The estimated values of these coefficients provided by *Microfit* are -0.337 and -0.294 for labour productivity and real wages, respectively, indicating that the adjustment to the long-run equilibrium takes place through changes in both variables.

To find out whether prices and/or nominal wages are responsible for the adjustment of the real wage to the long-run profit maximising equilibrium, we make use of the derived unit root and cointegration results. In particular, since real wages and the average product of labour are cointegrated and nominal wages are I(1),

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[6] Engle and Granger (1987) do not find cointegration between wages and prices using US data. However, they speculate that there might be a cointegrating relationship once productivity is included in the cointegrating vector.

[7] Other studies have also looked at the long-run relationship between labour productivity and real wages in a Johansen framework. For example, Hall (1989) extending his previous work (1986) that employed the Engle-Granger cointegration framework and, using British data, looked at the long-run relationship between real wages, productivity, unemployment and average hours worked. In this different set-up, he obtained a long-run coefficient on productivity (assuming normalisation on real wages) of 1.099 which is much different from ours. Hall (1989), however, did not estimate the adjustment coefficients of the error-correction model.

whereas prices are I(0), it must be that nominal wages are responsible for the adjustment to the long-run equilibrium. The argument goes as follows: suppose a shock somewhere in the economy produces a higher long-run equilibrium for the real wage. Since prices are stationary and, hence, subject to mean reversion, the long-run adjustment must be made by nominal wages.

This result can be understood by reference to the institutional nature of the labour market. Nominal wages are fixed through negotiations between labour unions and employers (of the private or public sector) and remain fixed for the time length of the contract. If during a time period the marginal (and average) product of labour and real wages diverge by more that is consistent by long-run equilibrium, the nominal wage cannot adjust during this period and, therefore, the re-establishment of an equilibrium relationship, to the extent that it can be realised by nominal wage changes, needs to wait until the moment that a new wage contract will be negotiated.

4 Conclusions

This paper has used the recently-developed cointegration techniques to test for the profit maximising long-run equilibrium in the Greek manufacturing sector. The cointegration technique that was applied showed that there is indeed a profit-maximising equilibrium between the average product of labour and the real wage rate. The adjustment towards this unique equilibrium is completed through changes in nominal wages, probably because of the institutional nature of the labour market, and changes in labour productivity. The estimate of the elasticity of substitution we have derived (about 0.23) is in agreement with other estimates obtained by alternative methods.

Table 1(a)

Augmented Dickey-Fuller
Unit Root Tests

Variable	Φ_3	
$q - l$	5.44	
$w - p$	2.53	
w	5.27	
p	7.52	**
$\Delta(q - l)$	6.02	*
$\Delta(w - p)$	12.19	***
$\Delta(w)$	2.34	
$\Delta^2(w)$	11.72	***

Note: The estimated regression is $\Delta x_t = b_0 + b_1 x_{t-1} + b_2 t + b_3 \Delta x_{t-1} + e_t$. The joint null hypothesis is that $b_1 = b_2 = 0$. *, ** and *** indicate significance at 10%, 5% and 1%, respectively. The critical values for a sample size of 25 are 5.91, 7.24 and 10.61, for significance levels of 10%, 5% and 1%, respectively (see Table VI in Dickey and Fuller, 1981).

Table 1(b)

Johansen Unit Root Tests

Variable	$H_0 : r = 0$		5% C.V.	10% C.V
		Maximum eigenvalue tests		
w	1.42		3.76	2.69
$\Delta(w)$	4.17	**	3.76	2.69
p	5.58	**	3.76	2.69

Note: The critical values are taken from *Microfit*. ** implies significance at 5%.

Table 2(a)

Johansen Cointegration Tests

Maximum eigenvalue tests

H_0	statistic		5% C.V.	10% C.V
$r = 0$	38.47	**	15.67	13.75
$r = 1$	6.25		9.24	7.53

Trace tests

H_0	statistic		5% C.V.	10% C.V
$r = 0$	44.72	**	19.96	17.85
$r = 1$	6.25		9.24	7.53

Note: The critical values are taken from *Microfit*. ** implies significance at 5%.

Table 2(b)

Johansen Cointegration Vector

$q - l$	$w - p$	intercept
-1	0.233	4.121

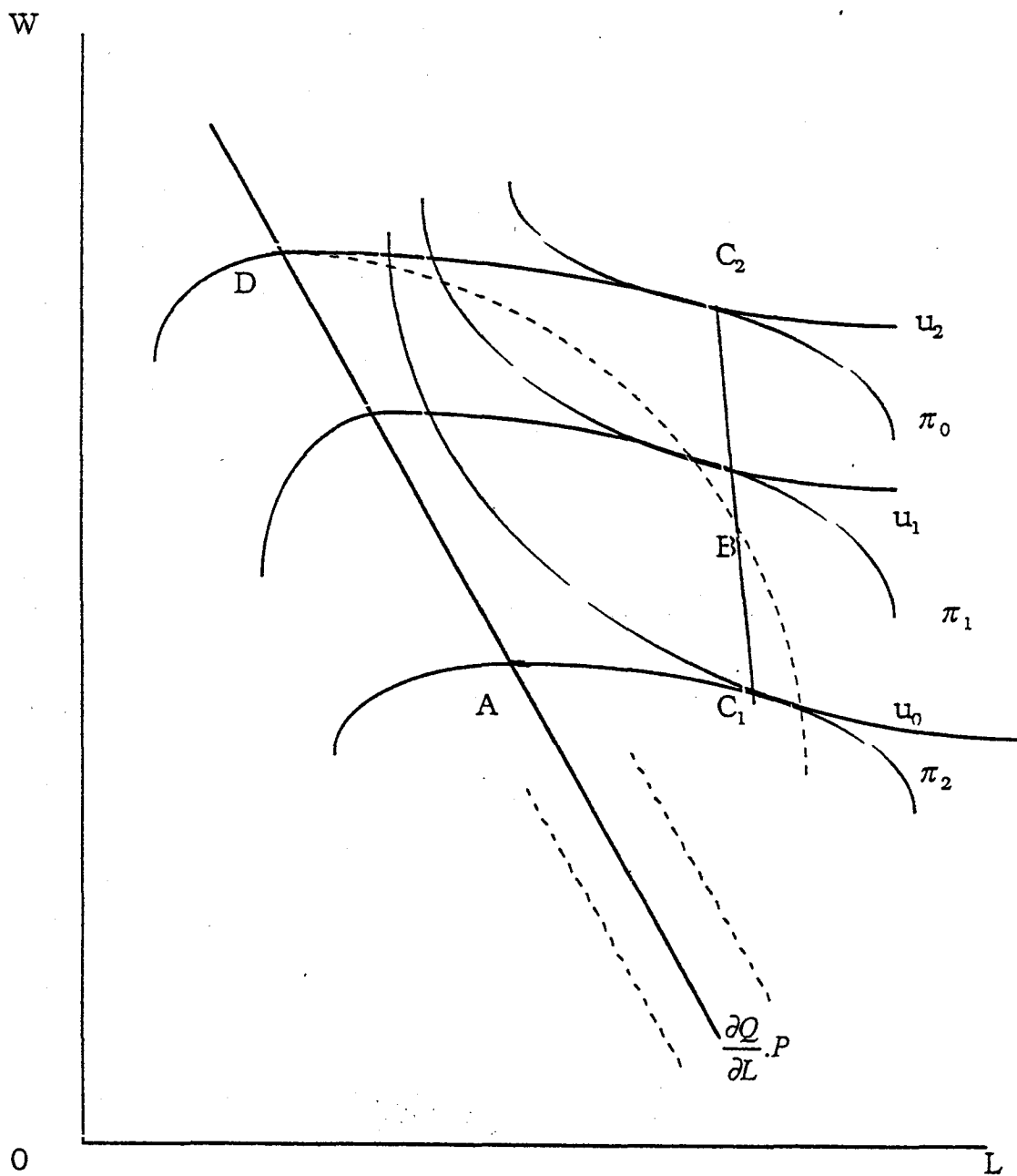Note: The cointegrating vector has been normalised on $q - l$.

Figure 1

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