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INPUT PRICE SHOCKS AND THE SLOWDOWN IN ECONOMIC  
GROWTH: THE CASE OF U.K. MANUFACTURING

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The Case of U.K. Manufacturing

ABSTRACT

This paper provides a theoretical and empirical analysis of the effects of input price shocks on economic growth, with a focus on United Kingdom manufacturing in the 1970s. The theoretical model predicts a discrete decline in output and productivity after an input price rise, and a longer-run slowdown in productivity growth, real wage growth, and capital accumulation. These features characterize the United Kingdom and most other OECD economies after 1973. The empirical results confirm the important role of input prices in recent U.K. adjustment, but also point to an important role for other supply and demand factors.

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Two types of explanations have been offered for the sharp deterioration in U.K. economic performance in the past decade, focusing respectively on demand and supply factors. A standard Keynesian view holds that macroeconomic demand management has been either too expansionary or too contractionary, and that rising unemployment and falling output reflect the burden of anti-inflationary policies. An alternative view holds that various supply shocks are the main source of the poor output performance. In this interpretation, higher raw material prices (particularly oil), competition from the newly-industrializing countries (NICs), and perhaps an independent decline in productivity growth, all have lowered output growth and raised unemployment.

There is little doubt that both supply and demand shocks played their roles in the recent experience, and that their relative importance has varied over time. Buiter and Miller [1981] have argued persuasively, for example, that the sharp rise in unemployment during the Thatcher experiment (since 1979) is largely the result of demand restraint. In general, however, there is no settled macroeconomic framework for disentangling which factors are at work in particular cyclical episodes. The theoretical analyses in Malinvaud [1977, 1980] and related studies offer a promising advance in this direction, though they remain far from empirical implementation.

In this study, we focus our attention on the supply shocks, particularly raw material price increases, to see if they alone can take us far in understanding the recent experience. Qualitatively, the answer is a resounding "yes", since a model of input price shocks predicts a short-run decline in output and productivity after such a disturbance, and a longer-run slowdown in productivity growth, capital accumulation, and real wage growth. All of these features

characterize Britain, and most other OECD economies, since 1973. Quantitatively, the answer is mixed. The evidence strongly suggests that raw material price increases have had significant output, employment, and productivity effects, and that these effects have worked mainly through profitability and the incentive to produce and invest, rather than through aggregate demand. But there is also evidence that: (1) the raw material price increases alone do not explain Britain's recent productivity debacle; and (2) demand explanations are needed to account for deep recessionary episodes (such as 1975 and 1980-81).

Table 1 highlights the decline in performance of U.K. manufacturing since 1973, and Table 2 depicts the severe squeeze in profitability that has accompanied that decline. From the first table note that the slowdown in growth of gross output reflects a growth slowdown in capital and labor inputs, as well as an apparent decline in total factor productivity (TFP) growth. Unfortunately, there is no published volume index of intermediate inputs, so that we were forced to create our own variable. For a number of reasons (see data appendix) we regard our constructed index and thus our estimates of TFP, as subject to fairly large error. It must be emphasized that a TFP slowdown cannot easily be accounted for by an input price shock (aside from appeal to various measurement errors that such a shock might induce); to the extent that such a slowdown has occurred, it will require an explanation outside of our framework below.

Table 2 provides the basis for the supply shock view of U.K. performance. On a variety of measures, we see evidence for a deep and sustained squeeze on profitability in U.K. production that goes far beyond short-run cyclical fluctuations in labor's share of value. In the 1960s, the wage relative to product

Table 1. Output, Inputs, and Productivity  
in U.K. Manufacturing<sup>1</sup>

	Output	Capital Input	Labor Input	Labor Productivity	Apparent Inter- mediate Input	Total Factor Productivity
1960-73	3.0	3.7	-.9	3.9	2.5	.8
1973-75	-3.9	2.2	-2.6	-1.3	-4.6	-1.9
1975-78	1.3	1.8	0.0	1.8	2.5	-1.5
1973-78	-.8	2.0	-1.0	.2	-.4	-1.7

<sup>1</sup> Percentage changes, at annual rate.

Source: Dicks-Mireaux data.

Table 2. Profitability in U.K. Manufacturing

	Product <sup>1</sup> Wage	Product Price of Intermediate Inputs	Labor Share of Value-Added (Average)	Pre-tax Profit Rate (Average)	Net Valua- tion Ratio (Average)
1960-72	4.4	-.5	.72	9.5	.69
1972-75	3.7	5.3	.77	5.5	.37
1975-78	-0.2	-1.4	.78	4.0	.27
1972	6.8	-.4	.73	7.8	.64
1973	3.4	14.3	.72	7.6	.48
1974	1.5	11.0	.81	3.3	.27
1975	6.3	-8.0	.81	3.1	.11
1976	.7	5.3	.80	3.2	.33
1977	-8.0	-3.2	.77	4.7	.27
1978	7.1	6.1	.77	5.0	.37

<sup>1</sup> Percentage change per year.

Source: Columns 1-3, Dicks-Mireaux data.

Column 4, from W.E. Martin and M. O'Connor, Table B2, p. 23.

Column 5, from Summers and Poterba [1981], Table 1, p. 30.

prices (henceforth the "product wage", denoted  $W_p = W/P$ ) grew at about the rate of productivity increase. Labor's share of value in manufacturing, and the rate of return to capital remained fairly stable. Between 1969 and 1975, product wage growth accelerated substantially, squeezing profits sharply. Moreover, when intermediate input prices rose in 1973, and TFP growth declined, real wages failed to decelerate, further intensifying the profit squeeze. Product wage growth slowed sharply under the Labour Government incomes policies during 1976-77, but then rebounded during 1978-80. The final column, denoted "valuation ratio", records the valuation of corporate capital (in "industrial and commercial companies") relative to the replacement cost of corporate capital. This ratio, often denoted "Tobin's q", is an indicator of market expectations of future profitability of the existing capital stock. Under specific conditions, described below, it is also a good measure of the incentive to invest. Clearly, it has fallen very sharply in the 1970s.

The essence of the supply-side argument is that low output growth in the 1970s reflects poor incentives to supply output, rather than insufficient demand. Low investment rates, similarly, are deemed to reflect low expectations of future profitability. On a purely statistical basis, there is a strong link between profitability and output (Morley [1979] has also examined this link). The following regressions attest to this correlation; the theoretical models below provide a structural basis for such relationships:<sup>1</sup>

$$\begin{array}{l} \log (Q_t) = 5.8 + .033 \text{ Time} + .35 (\text{Profit Share})_{t-1} \\ \quad (46.1) \quad (20.1) \quad (5.6) \end{array} \quad \begin{array}{l} R^2 = .97 \\ \text{d.w.} = 1.39 \end{array}$$
$$\begin{array}{l} \log (Q_t) = 7.2 + .036 \text{ Time} + .33 (\text{Profit Rate})_{t-1} \\ \quad (21.1) \quad (19.3) \quad (6.2) \end{array} \quad \begin{array}{l} R^2 = .97 \\ \text{d.w.} = 1.67 \end{array}$$

In certain circumstances, the supply argument would per force be true. To the extent that U.K. manufacturers are price-takers on a large world market, output fluctuations must reflect supply rather than demand constraints. Similar evidence would be an inverse relationship between import demand for manufactured goods and domestic production of manufactures. A decline in aggregate demand would likely reduce the demand for both home and foreign goods, while a decline in aggregate supply should raise foreign imports at the expense of home goods. The growing import penetration ratios for U.K. manufacturing attest to such a process [see ( ) for details]. A simple correlation of manufacturing output with manufacturing imports (with both measured as deviations from trends) yields a highly significant  $r = \underline{\quad\quad}.^2$

The preceding evidence is at best circumstantial. We now turn to formal analysis. The first goal is to build up a model of dynamic output supply for a competitive firm using capital, labor, and an intermediate input. Using that model, we depict the time path of adjustment to a rise in the product price of intermediate inputs. This adjustment is studied under alternative assumptions of real wage stickiness and full labor market clearing. In the succeeding section, the various equations of the model are estimated. The short-run and long-run effects of a supply shock are measured, and various numerical simulations are undertaken. In a concluding section, we consider some models which better integrate supply and demand features into the analysis.



I. Theory of an Input Price Shock

(a) The Value-Maximizing Competitive Firm

Our analysis of input price shocks begins with the supply behaviour of a value-maximizing competitive firm. The firm produces gross output  $Q$  according to the well-behaved constant returns to scale production function  $Q = Q(L, K, N)$  using labour,  $L$ , capital,  $K$ , and a raw material,  $N$ . The price of output is  $P$ , and that of the raw material is  $P_N$ . For the time being assume that the relative price  $\pi_n = P_N/P$  is given (as is the case if both  $N$  and  $Q$  are tradeable goods in a small open economy). We denote the product price of labour as  $W_p = W/P$ , the nominal cost of capital as  $r$ , and the real cost of capital as  $R (= \dot{r}/P)$ , where the dot signifies rate of change.

As a basic model, assume that the firm can costlessly and instantaneously adjust the inputs of  $L$  and  $N$ , while it can adjust  $K$  only subject to convex costs of adjustment. The treatment of  $K$  as a quasi-fixed factor and  $L$  as a pure variable factor is admittedly extreme, and is relaxed in some of the empirical work later on. Denote the rate of gross capital formation as  $J$ , and the rate of depreciation as  $d$ , so the  $\dot{K} = J - dK$ . Total investment expenditure,  $I$ , includes payments on  $J$ , as well as adjustment costs. Let  $P_j$  be the cost of a unit of physical capital, and  $\pi_j (=P_j/P)$  its real price. Following Hayashi [1982], adjustment costs per unit of  $J$  are assumed to rise as a function of  $J/K$ , so that  $I = \pi_j J + \phi(J/K)J$ , where  $\phi(\cdot)$  is the per-unit adjustment cost.

Under conditions of perfect foresight, the real market value of the firm is simply the discounted value of cash flow:

$$(1) \quad V = \int_0^{\infty} e^{-\Delta t} [Q - W_p L - \pi_n N - I] dt$$

where  $\Delta = \int_0^t R(\tau) d\tau$ .

The goal of the firm is to maximize  $V$  subject to the production technology, and the costs of adjustment in capital accumulation. The results of this maximization are straightforward: for a given  $K$ , the firm should short-run profit maximize, hiring  $L$  and  $N$  to the point where marginal productivities equal current factor costs. Investment should be undertaken as a function of the entire future profit stream, which depends on the entire future path of factor costs. The dependence of  $L$  and  $N$  on current costs, and  $I$  on expected future costs, results of course from the assumption about costs of adjustment.

The specific conditions for optimization are:<sup>3</sup>

$$(2) (a) \quad Q_L = W_P$$

$$(b) \quad Q_N = \pi_N$$

$$(c) \quad J = \phi(\tau) \cdot K$$

$$(d) \quad \tau = \int_0^{\infty} e^{-\tilde{\Delta}t} [Q_K + (J/K)^2 \phi'(J/K)] dt, \text{ where } \tilde{\Delta} = \int_0^t [R(s) + d] ds$$

$$(e) \quad V = \tau K$$

$$(f) \quad \dot{K} = J - dK$$

(2)(a) and (b) define short-run factor demands. (2)(c) is the investment equation, with  $J/K$  a rising function of Tobin's  $q$ , denoted as  $\tau$ , the real equity value of a unit of the firm's capital. The value of  $\tau$  may be written as in (2)(d), as the discounted value of the marginal productivity of capital. Notice that this marginal product is the sum of  $Q_K$  and  $(J/K)^2 \phi'(J/K)$ , where the latter term is the contribution of an increment of  $K$  to a reduction in adjustment costs.

(2)(e) shows that the value of the firm is simply  $\tau K$ .

In the specific case of linear adjustment costs, with

$$\phi = \frac{\phi_0}{2} \cdot \frac{J}{K},$$

the investment function is given by  $J/K = (\tau - \pi_J)/\phi_0$ . In the steady state,  $(\bar{J}/\bar{K}) = d$ , so  $\bar{\tau} = \pi_J + \phi_0 d$ . (The notation  $\bar{x}$  will signify the steady state value of  $x$ .) From (2)(d), we may therefore derive that  $\bar{Q}_K$  must equal  $(R+d)\pi_J + dR\phi_0 + \phi_0 d^2/2$  (note that  $Q_K = R\pi_J$  for  $d = 0$ ). We will denote this critical long-run value of  $Q_K$  by  $\tilde{R}$ . Clearly,  $\tau$  and therefore investment will tend to be high if  $Q_K$  is expected to exceed  $\tilde{R}$  for an extended period.

In the simulations later we will modify the investment function to allow for certain features of the (post-1973) U.K. tax provisions on corporate earnings, depreciation, and investment. Specifically, for corporate tax rate  $t_C$ , full expensing of new capital investment, and full equity financing, the investment equation is changed slightly to be  $J/K = (\tau + t_C - \pi_J)/[\phi_0(1-t_C)]$ . Summers and Poterba [1981] provide a detailed account of how U.K. tax provisions affect the form of the  $J/K$  function.

(b) The Factor Price Frontier

The effects on supply of a shift in  $\pi_n$  are governed by (2), which can best be understood by appeal to the factor price frontier (FPF).<sup>4</sup> The FPF summarizes the information about the gross output technology in terms of the maximal combinations of the three marginal factor products,  $F(Q_L, Q_K, Q_N) = 0$ , which by substitution of (2)(a) and (b) may be written as  $F(\bar{W}_P, Q_K, \pi_n) = 0$ . The curve  $F_0$ , drawn in  $\bar{W}_P$ - $Q_K$  space (see Figure 1) for a given relative raw-material price

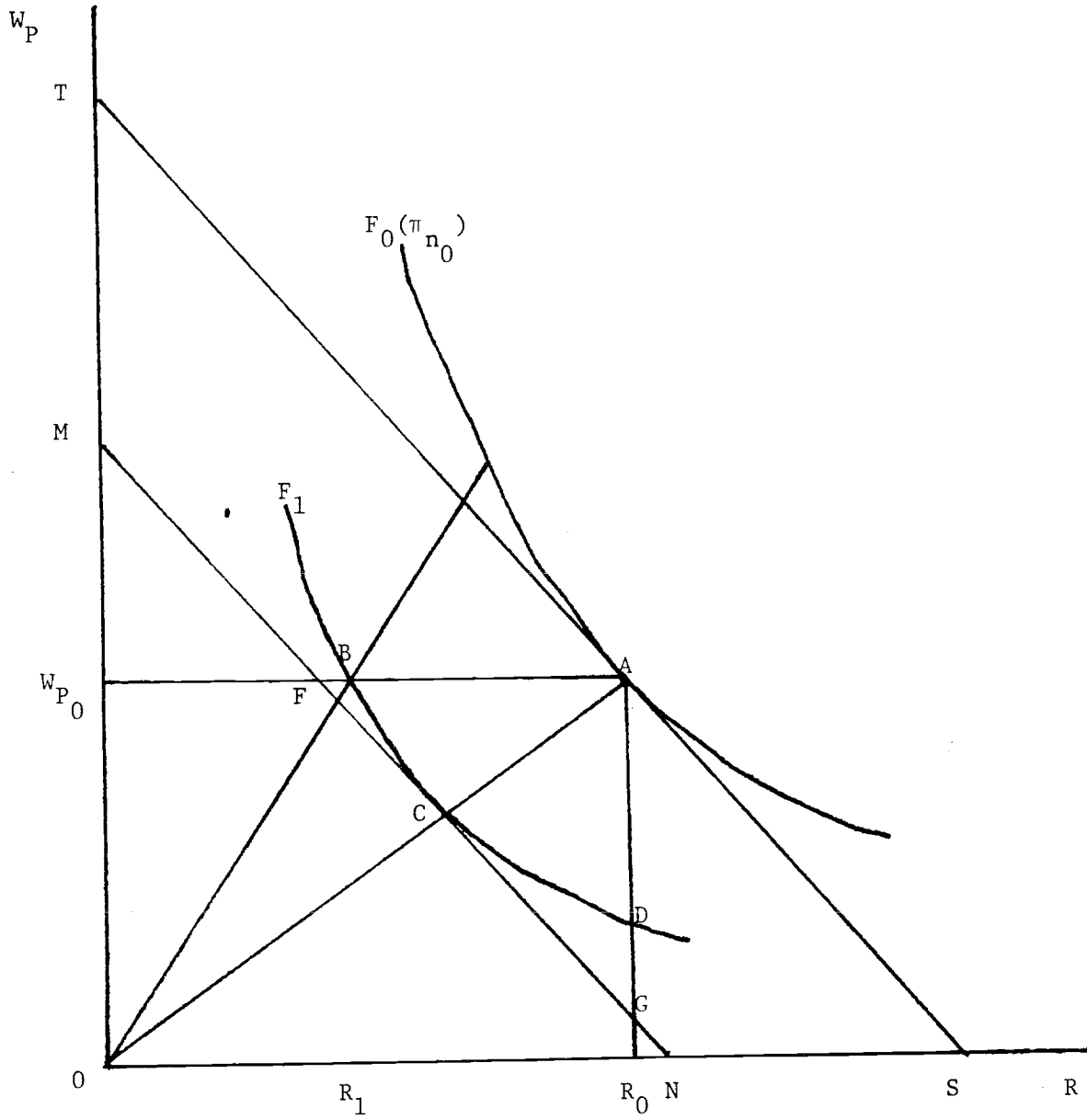


Figure 1. The Factor Price Frontier

$\pi_{n0}$  is downward sloping and convex to the origin. The slope of the tangent at the point A measures the capital/labour ratio that corresponds to the pair of factor returns  $(Q_K, W_{P0})$ , and its intercept on the  $W_P$  axis (OT) measures  $Y/L$ . Likewise, the intercept on the  $Q_K$  axis (OS) measures  $Y/K$ . The elasticity of FPF at the point A = SA/TA measures the relative shares of capital and labour in  $Y$ .

Weak separability of the production function  $\{Q = Q[V(L,K), N]\}$  implies weak separability of the dual FPF, i.e.,  $F_0$  takes the form  $F[f(W_P, Q_K), \pi_n] = 0$ . A raw-material price increase, like Hicks-neutral technical regress, is thus represented by a homothetic inward shift of  $F_0$  to  $F_1$ . At the point C on the new FPF, on the ray OA, the capital/labour ratio is the same as at A. Thus, for  $K = K_0$  and  $L = L_0$ , a rise in  $\pi_n$  shifts the factor returns from A to C. We will call C the point of short-run adjustment (when  $K = K_0$ ,  $L = L_0$ ). Following a rise in  $\pi_n$  marginal factor products at C are reduced by the same ratio from their original level at A. Total real income per unit of labour ( $Y/L$ ) falls by the same proportion from OT to OM (and  $Y/K$  from OS to ON). Since  $Q_K < \tilde{R}$ , there will tend to be disinvestment at A. The case of real wage rigidity at  $W_{P0}$ , which may be termed the very short run, is represented by the point B where  $Q_K$  and  $Y/K$  must of necessity fall by more than at C and the capital/labour ratio is higher than at C. At the given capital stock,  $K_0$ ,  $L$  will fall and unemployment will emerge.<sup>5</sup>

The polar case to the very short run ( $W_P = W_{P0}$ ) is that of an externally imposed long-run real rate of return ( $Q_K = \tilde{R}$ ). This is represented by the point D, to be termed the long run, at which the real wage and the capital/labour ratio are below their levels at C. In contrast to C, the point D represents an equilibrium steady-state level after capital has adjusted downward to the given

real rate of return,  $\tilde{R}$ . With full employment of labour, capital and output (gross and net) at D are both lower than at the initial point A.

Of course, the designations of very short run, short run, and long run responses to a change in  $\pi_N$  are stylizations that must be flushed-out in a fully dynamic model. To get such a model, we must append a wage equation to (2) (a)-(e), as we do in section (e) below. We will consider two types of wage equations: continuous market clearing, and a Phillips curve mechanism.

First, however, the graphical representation can be given full analytical content. Consider any m-factor constant returns production function whose output (in logs) is q. Let the (log) quantity and product price of factor i be denoted by  $a_i$  and  $w_i$  ( $i = 1, 2, \dots, m$ ), respectively.<sup>6</sup> Next, denote the cost share of the i<sup>th</sup> factor by  $s_i$  and let the Hicks-Allen elasticity of substitution be  $\sigma_{ij}$  where  $\sigma_{ij}s_j = (w_j/a_i)(\partial a_i/\partial w_j)$ . Using dots for rates of change, the unit factor demand functions are:

$$(3) \quad \dot{a}_i - \dot{q} = \sum_{j=1}^m \sigma_{ij}s_j\dot{w}_j$$

and

$$\sum_{j=1}^m \sigma_{ij}\dot{w}_j = 0 \quad \text{for all } i = 1, 2, \dots, m.$$

Next we write down the factor-price-frontier in rate of change form:

$$(4) \quad \sum_{j=1}^m s_j\dot{w}_j = 0.$$

Equation (4) can be substituted into equation (3) to solve out for the case in which one of the factors (say, the m<sup>th</sup>) is fixed (in our

case: capital is fixed in the short run). Thus, equation (3) can be rewritten:

$$(3') \quad \dot{a}_i - \dot{q} = \sum_{j=1}^m (\alpha_{ij} - \alpha_{im}) s_j \dot{w}_j \quad (i = 1, 2, \dots, m)$$

Applying equation (3') to the three factor case (L, N, K), we get

$$(5) \quad \dot{l} - \dot{q} = s_\ell (\sigma_{\ell\ell} - \sigma_{\ell k}) \dot{w}_p + s_n (\sigma_{\ell n} - \sigma_{\ell k}) \dot{\pi}_n$$

$$(6) \quad \dot{n} - \dot{q} = s_\ell (\alpha_{n\ell} - \alpha_{nk}) \dot{w}_p + s_n (\alpha_{nn} - \alpha_{nk}) \dot{\pi}_n$$

$$(7) \quad \dot{k} - \dot{q} = s_\ell (\alpha_{k\ell} - \alpha_{kk}) \dot{w}_p + s_n (\alpha_{kn} - \alpha_{kk}) \dot{\pi}_n$$

Equation (7), when reversed in sign ( $\dot{q} - \dot{k}$ ), is the short-run supply function.

Since  $\alpha_{kk} < 0$ , this readily shows that output (per unit of capital) is a negative function of the raw material price ( $\pi_n$ ) when capital and raw materials are co-operant factors ( $\alpha_{kn} > 0$ ). Also, it is a negative function of the real wage ( $w_p$ ) if capital and labour are co-operant factors ( $\alpha_{k\ell} > 0$ ).

By subtracting equation (5) from equation (7), we get an expression for the labour/capital ratio and likewise find that L/K is negatively related to  $w_p$  (for a given  $\pi_n$ ) if  $\sigma_{\ell k} > 0$ , and is negatively related to  $\pi_n$  (at given  $w_p$ ) as long as  $\alpha_{kn} + \alpha_{n\ell} \geq \sigma_{\ell n} + \alpha_{k\ell}$ . The latter condition is automatically satisfied in the case of raw material separability ( $\sigma_{\ell n} = \alpha_{kn}$ ) to which we now turn.<sup>7</sup>

When separability  $Q[V(L,K),N]$  is assumed, these equations can be further simplified. Since now  $\alpha_{n\ell} = \alpha_{nk}$ , equation (6) now becomes:

$$(6') \quad \dot{n} - \dot{q} = -\sigma \dot{\pi}_n$$

where  $\sigma = s_n(\alpha_{nk} - \alpha_{nn}) = \alpha_{nl} = \alpha_{nk}$  is the elasticity of substitution between V and N in Q. Similarly, it is easy to show that  $s_l(\alpha_{kl} - \alpha_{ll}) = s_k(\alpha_{kl} - \alpha_{kk}) = \alpha_1$ , is the elasticity of substitution between L and K in V. We can now write down the output supply per unit of capital and labour demand per unit of capital in the following simplified form:

$$(7') \quad \dot{q} - \dot{k} = -\alpha_1 \dot{w}_p - s_k^{-1} s_n \alpha_1 \eta \dot{\pi}_n$$

$$(8) \quad \dot{l} - \dot{k} = -\alpha_1 (1 + s_k^{-1} s_l) \dot{w}_p - s_k^{-1} s_n \alpha_1 \dot{\pi}_n$$

where  $\eta = (1 - s_n)^{-1} (s_l + \alpha_1^{-1} \alpha s_k) \leq 1$ , if  $\alpha_1 \geq \sigma$ . These equations can also be obtained more directly (see below).

Let us now reconsider the implications of a raw material price increase under the various time specifications. In the very short run, if the real wage is rigid and the capital stock is held constant, we move from the point A to B in Figure 1. One gets an output and employment reduction, respectively, of

$$\begin{aligned} \dot{q} &= -(s_k^{-1} s_n \alpha_1 \eta) \dot{\pi}_n, \\ \dot{l} &= -(s_k^{-1} s_n \alpha_1) \dot{\pi}_n. \end{aligned}$$

When the real wage is allowed to adjust downwards, so as to maintain full employment at a given capital stock (this was termed the "short-run":  $\dot{l} = \dot{k} = 0$ ), the economy moves to the point C in Figure 1. From the equation for  $\dot{l} - \dot{k}$  we get  $\dot{w}_p = -(1 - s_n)^{-1} s_n \dot{\pi}_n$  and therefore the output reduction is mitigated by the amount  $(1 - s_n)^{-1} s_n \alpha_1 \dot{\pi}_n$ .<sup>8</sup>



Finally, as we move to the long run at point D in Figure 1, we have  $Q_K = \tilde{R}$ ,  $L = \bar{L}$ , i.e.,  $\dot{\rho} = \dot{\lambda} = 0$ , (where  $\rho = \log(Q_K)$ ). A constant rate of return implies, by (4) that  $\dot{w}_p = -s_\ell^{-1} s_n \pi_n$ . Therefore, the drop in  $\dot{q} - \dot{k}$  of the very short run is now recovered by the larger amount  $s_1^{-1} s_n \alpha_1 \pi_n > (1-s_n)^{-1} s_n \alpha_1 \pi_n$ , i.e.,  $Q/K$  at D must be higher than at C, but it is most probably still lower than than at the starting point A.

Since K now falls, total output never rebounds to the level at D. The total long-run change in output from A to D can be written down directly by observing the symmetry with the case of the very short run with capital now replacing the role of labour. Exchanging the subscripts in the coefficient of  $\pi_n$  in equation (7) or (7') we have for the total output drop:

$$\dot{q} = -s(\sigma - \sigma_{\ell\ell}) \pi_n = -(1 - s_n)^{-1} (s_k^{-1} s_\ell \alpha_1 + \sigma) \pi_n$$

while the output drop in the very short run can be written as

$$[-s_k^{-1} s_n \alpha_1 \eta] \pi_n = [-(1 - s_n)^{-1} (s_\ell s_k \alpha_1 + \sigma)] \pi_n$$

There is partial output recovery in the long run from the very short run as long as  $s_\ell/s_k > s_k/s_\ell$ , a condition on the relative labour share which empirically usually holds.

### (c) A Two-Level CES Production Function

A logical sequel to the production framework discussed in the previous section is the nested (or two-level) CES production function for which the elasticities of substitution  $\sigma$  and  $\alpha_1$  (but not necessarily the factor shares) are assumed constant. Thus we assume  $Q = Q[V(K,L),N]$ , where the intermediate input (N) is separable from real value added (V) and consider Q to be a CES function in

V, N, with constant elasticity of substitution  $\sigma$ , and V to be CES in K, L with constant elasticity  $\alpha_1$ . As before, we use the convention of applying small letters (where capital letters also appear) to denote the natural logarithms and use dots for the time derivatives (e.g.,  $\dot{\ell} = \ln L$ ,  $\dot{\ell}' = L^{-1} \partial L / \partial t$ ). We now denote the output elasticity of labour ( $s_\ell$ , etc.), the intermediate input, and capital by  $\alpha$ ,  $\beta$ , and  $\gamma$ , respectively, and again assume constant returns to scale ( $\alpha + \beta + \gamma = 1$ ).

For any production function we have (ignoring technical progress) the rate of change of output:

$$(9) \quad \dot{q} = \alpha \dot{\ell} + \beta \dot{n} + \gamma \dot{k}$$

and for the dual price structure (letting  $\rho = \ln(Q_K)$ ):<sup>9</sup>

$$(10) \quad 0 = \alpha \dot{w}_p + \beta \dot{\pi}_n + \gamma \dot{\rho}$$

which leads to the factor-price-frontier in rate-of-change form:

$$(11) \quad \dot{\rho} = -\gamma^{-1}(\alpha \dot{w}_p + \beta \dot{\pi}_n)$$

In the discussion that follows we shall introduce technical progress in labour-augmenting form (at the rate  $\lambda$ ). This implies that instead of L, we write  $L' = L e^{\lambda t}$  and  $\dot{\ell}' = \dot{\ell} + \lambda$  and similarly write  $W'_p = W_p e^{-\lambda t}$  (and  $\dot{w}'_p = \dot{w}_p - \lambda$ ) instead of  $W_p$ . Thus, equation (11) will take the form:

$$(11') \quad \dot{\rho} = -\gamma^{-1}[\alpha(\dot{w}'_p - \lambda) + \beta \dot{\pi}_n] .$$

We rewrite the rate of change of output supply [equation (7')] and labour demand [equation (8)] in the following revised form:

$$(12) \quad \dot{q}^s = -\gamma^{-1} \alpha [\alpha \dot{w}_p - \lambda] + \beta \eta \dot{\pi}_n + \dot{k}$$

$$(13) \quad \dot{x}^d = -\gamma^{-1} \alpha [(1-\beta)(\dot{w}_p - \lambda) + \beta \dot{\pi}_n] + \dot{k} - \lambda$$

where  $\eta = (1-\beta)^{-1}[\alpha + \alpha^{-1}\sigma\lambda]$  and  $\eta \leq 1$  for  $\alpha \geq \sigma$ .

These equations reveal the danger of measuring total factor productivity by subtracting weighted inputs of labor and capital, but not intermediate goods, from a measure of output. The "conventional" measure yields:

$$(14) \quad \dot{q} - (1-\beta)^{-1}(\alpha \dot{\lambda} + \dot{\gamma} \dot{k}) = (1-\beta)^{-1}(\alpha \lambda - \beta \sigma \dot{\pi}_n)$$

Thus, the measure confounds the normal technical progress term,  $\alpha \lambda$ , with technical regress due to the rise in raw material input prices,  $-\beta \sigma \dot{\pi}_n$ . We suspect that some of the apparent slowdown in TFP growth in manufacturing in the industrial countries in the 1970s can be ascribed to this term.

#### (d) The Dynamic Adjustment Process

The last step in the theoretical analysis is to describe the explicit adjustment paths of factor prices, employment, output, and the capital stock, between the very short run and the long run. We will work with the case of weak separability of  $N$  in the gross output function; it is straightforward to extend the analysis to the general case. We have seen that output and employment can be written as functions of  $K$ ,  $\pi_n$ , and  $w_p$ , while  $\dot{K}$  is a function, through Tobin's  $q$ , of the future paths of  $\pi_n$  and  $w_p$ . We will continue to take  $\pi_n$  as exogenous, but will now specify the wage dynamics in order to close the model. At many points in the following discussion we will drop inessential constant terms that arise from linearization.

The alternative assumptions are:

$$(15)(a) \quad \ell = \ell^f \quad \text{Continuous Full Employment}$$

or

$$(b) \quad \dot{w}_p = \theta(\ell - \ell^f) \quad \text{Phillips Curve}$$

In case (b), we assume that firms' demand for labour at the posted wage is always satisfied, so that  $\ell$  may exceed  $\ell^f$  in the short term. (15)(a) or (b), together with (2) defines a complete dynamic model.

In the full employment case,  $\dot{\ell} = 0$ , so according to (8) we see that:  $\dot{w}_p = [\dot{k} + s_k^{-1} s_n \alpha \dot{\pi}_n] / [\alpha(1 + s_k^{-1} s_\ell)]$ . By integrating this expression, we can write (with  $w_p^f$  the full-employment wage):

$$(16) \quad w_p^f = w_{p0} + [(k - k_0) + s_k^{-1} s_n \alpha (\pi_n - \pi_{n0})] / [\alpha(1 + s_k^{-1} s_\ell)]$$

Weak separability is sufficient to ensure that  $w_p^f$  is an increasing function of  $k$ , and a decreasing function of  $\pi_n$ . As a first-order approximation, the FPF can be written as:

$$(17) \quad \rho - \rho_0 = -(s_n/s_k)(\pi_n - \pi_{n0}) - (s_\ell/s_k)(w_p - w_{p0})$$

Next, use (16) and (17) to write:

$$(18) \quad \rho = \rho_0 - (s_n/s_k)(\pi_n - \pi_{n0}) - (s_\ell/s_k)[(k - k_0) + s_k^{-1} s_n \alpha (\pi_n - \pi_{n0})] / [\alpha(1 + s_k^{-1} s_\ell)]$$

Therefore, with continuous market clearing,  $\rho$  is a decreasing function of  $k$  and  $\pi_n$ , which we will write as  $\rho = -ak - b\pi_n$ .

From the firm's valuation equation,  $\dot{\tau} = R\tau - [Q_k - (\tau-1)^2/(2\phi_0)]$ , which can be linearized around  $\bar{\tau} = 1 + \phi_0 d$  (see page 9) as  $\dot{\tau} = (R + \zeta)\tau - Q_k$ , with  $\zeta$  a positive constant. Since  $\rho = \log(Q_k) = ak - b\pi_n$ , we can approximate  $Q_k$  by linear function in  $k$  and  $\pi_n$  as well. Ignoring constants, and linearizing around  $Q_k = \tilde{R}$ , we have  $Q_k \approx -a\tilde{R}k - b\tilde{R}\pi_n = -\tilde{a}k - \tilde{b}\pi_n$  ( $\tilde{a} = a\tilde{R}$ ,  $\tilde{b} = b\tilde{R}$ ).

Substituting into the equation for  $\tau$ , we have  $\dot{\tau} = (R + \zeta)\tau + \tilde{a}k + \tilde{b}\pi_n$ .

Together with (2)(f) we have a 2x2 linear differential equation system in  $\tau$  and  $k$ :

$$(19) \quad \begin{bmatrix} \dot{k} \\ \dot{\tau} \end{bmatrix} = \begin{bmatrix} 0 & 1/\phi_0 \\ \tilde{a} & R + \zeta \end{bmatrix} \begin{bmatrix} k \\ \tau \end{bmatrix} + \begin{bmatrix} 0 \\ \tilde{b} \end{bmatrix} \pi_n + \text{constants}$$

The system is shown graphically in Figure 2. Adding the phase plane arrows to the figure, we see immediately that the system is saddlepoint stable, with the trajectory given by the dashed line. The equation for  $\tau$  as an integral of future profitability, (2)(d), is equivalent to the condition that the stock market price  $\tau$  always adjusts to keep the economy on the stable trajectory after an unanticipated shift in  $\pi_n$ .<sup>10</sup>

Figure 3 examines such a shift in  $\pi_n$ . The figure depicts an unanticipated, once-and-for-all jump in  $\pi_n$ , under the assumption that  $K$ ,  $L$ , and  $N$  are all co-operant factors, so that  $dk/d\pi_n < 0$ . The  $\dot{\tau} = 0$  locus shifts to the left, moving the long-run equilibrium from  $E_0$  to  $E_1$ . At the time of the change in  $\pi_n$ , the equity price falls from  $\bar{\tau}$  to  $\tau(0)$ , giving the signal to firms to reduce gross fixed capital formation. Over time,  $k_0$  falls to reach a new lower level

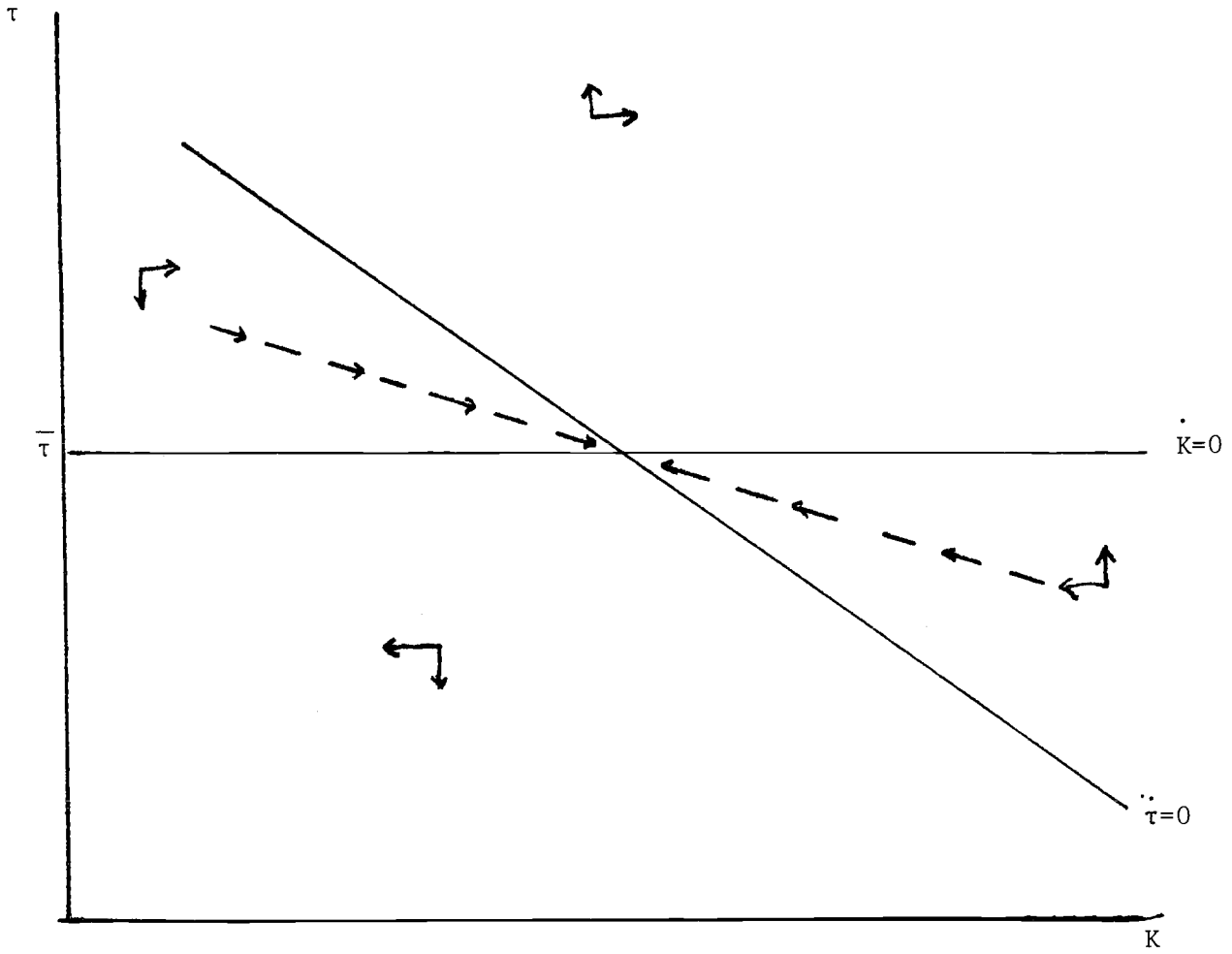


Figure 2. Dynamic Path of  $K$  and  $\tau$

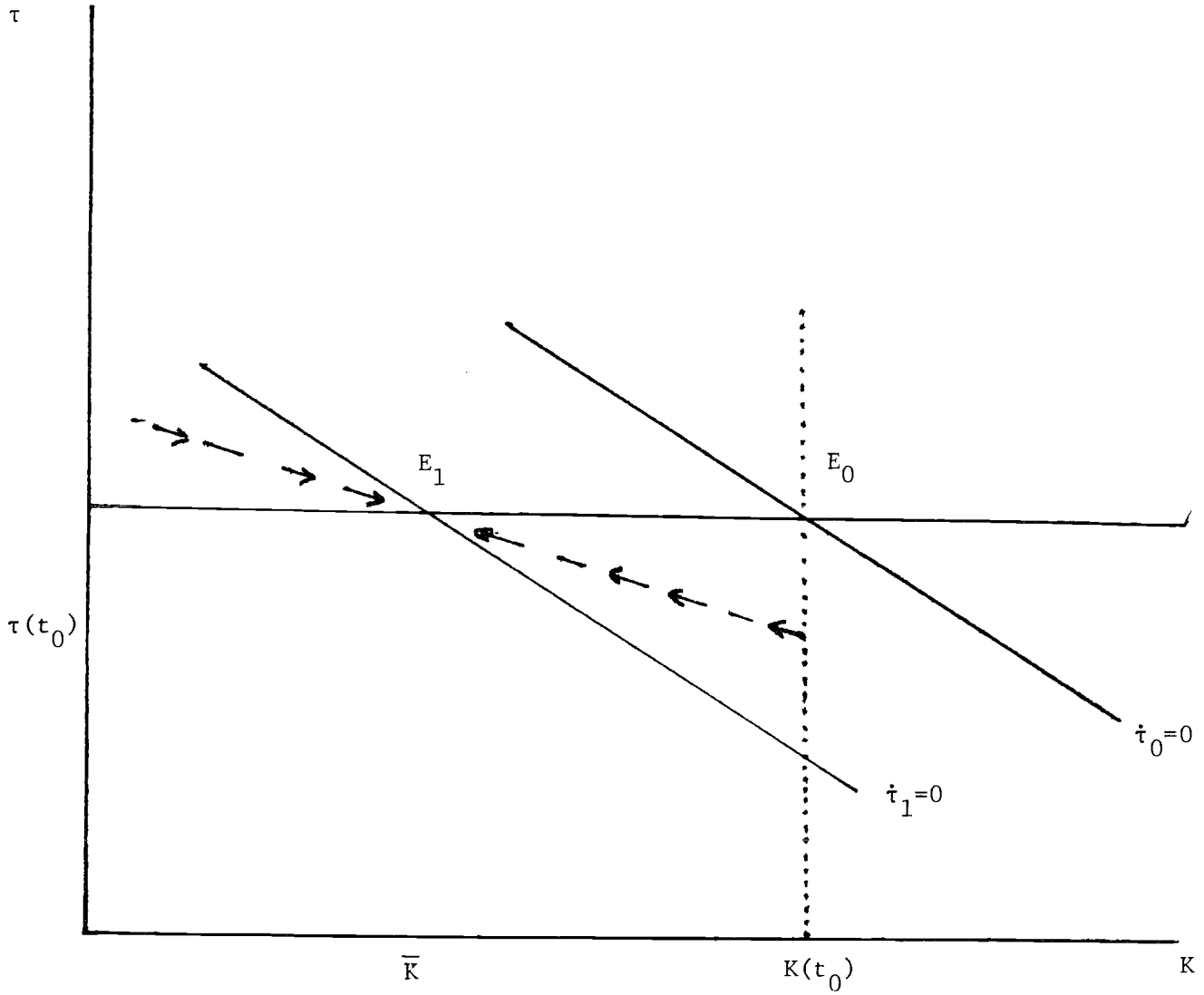


Figure 3. Dynamic Response to a Rise in  $\pi_N$

at  $E_1$ , as  $\tau$  rises back to  $\bar{\tau}$ . What about real wages? On impact, we have a shift in  $w_p$  and  $\rho$  as shown from A to C in the FPF, Figure 1. Over time,  $w_p$  moves as in (16), and so  $\dot{w}_p < 0$  along the entire path to  $E_1$ .

When the model is extended to include sluggish wage adjustment, both its realism and analytical complexity increase. First, we use the labour demand schedule in (8) to write employment as a function of  $k$  and  $\pi$ :

$$(20) \quad \ell = \ell_0 + (k-k_0) - \alpha_1(1+s_k^{-1}s_\ell)(w_p-w_{p0}) - s_k^{-1}s_n\alpha_1(\pi_n-\pi_{n0})$$

Substituting this equation into the Phillips curve relationship (15)(b) we have

$$(21) \quad \dot{w}_p = \theta(k-k_0) - \theta\alpha_1(1+s_k^{-1}s_\ell)(w_p-w_{p0}) - \theta s_k^{-1}s_n\alpha_1(\pi_n-\pi_{n0})$$

also, from the FPF,  $\rho - \rho_0 = -(s_n/s_k)(\pi_n - \pi_{n0}) - (s_n/s_k)(w_p - w_{p0})$ . Since  $\dot{\tau}$  is  $(R+\zeta)\tau - Q_k$ , and  $Q_k \approx \tilde{R}\rho$  (see above), we can write

$$(22) \quad \dot{\tau} = (R+\zeta)\tau + \tilde{R}(s_n/s_k)(\pi_n - \pi_{n0}) + \tilde{R}(s_\ell/s_k)(w_p - w_{p0})$$

Equations (21) and (22), together with the capital accumulation equation describe a 3x3 differential equation system in  $\tau$ ,  $w_p$ , and  $k$ :

$$(23) \quad \begin{bmatrix} \dot{\tau} \\ \dot{k} \\ \dot{w}_p \end{bmatrix} = \begin{bmatrix} R+\zeta & 0 & (s_\ell/s_k)\tilde{R} \\ 1/\phi_0 & 0 & 0 \\ 0 & \theta & -\theta\alpha_1(1+s_k^{-1}s_\ell) \end{bmatrix} \begin{bmatrix} \tau \\ k \\ w_p \end{bmatrix} + \begin{bmatrix} \tilde{R}(s_\ell/s_k) \\ 0 \\ -s_k^{-1}s_n\alpha_1 \end{bmatrix} \pi_n + \text{constants}$$

Once again, the dynamic system is saddlepoint stable,<sup>11/</sup> so that  $\tau$  always jumps after an unanticipated shock to keep the economy on a unique trajectory to long-



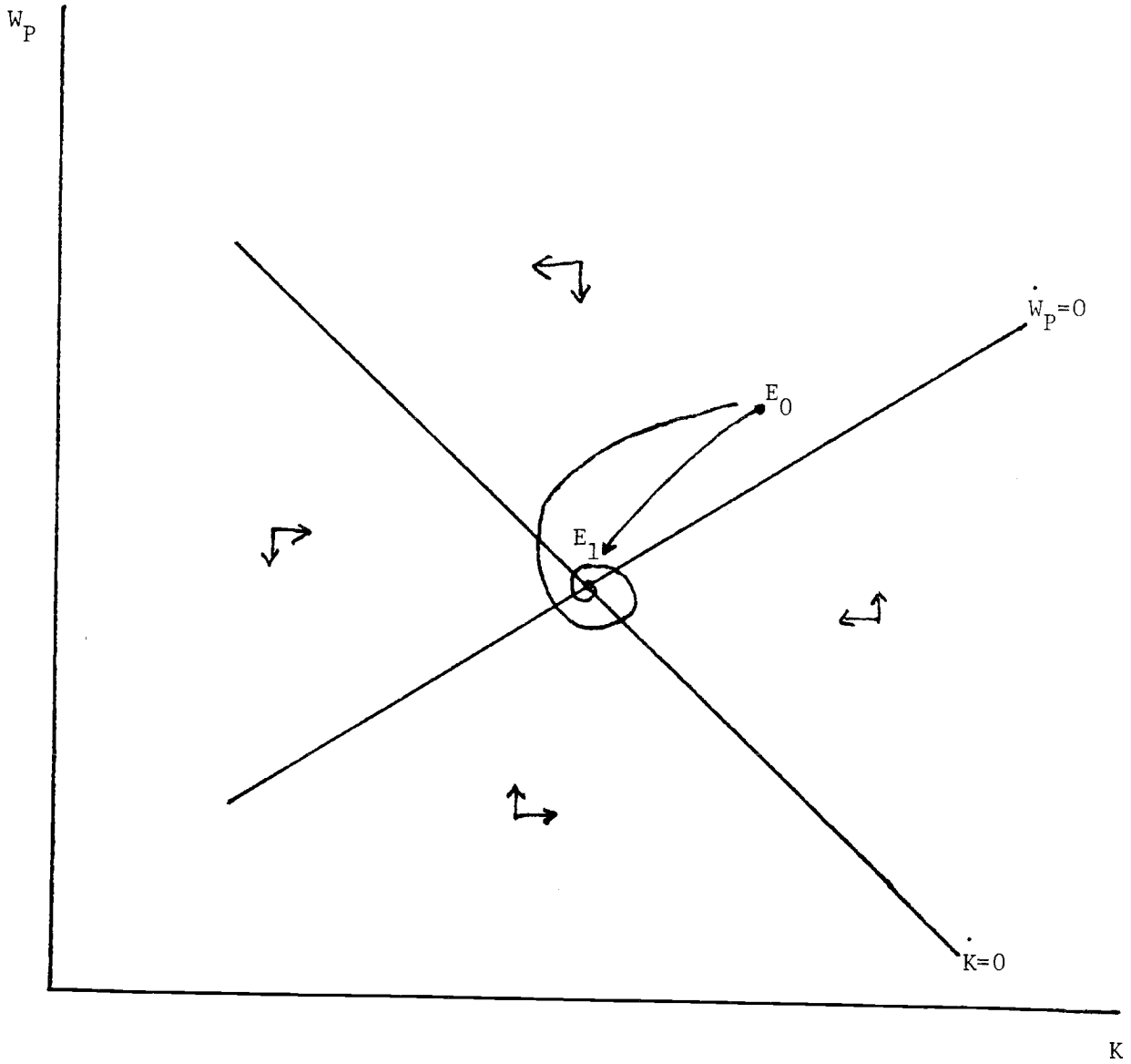


Figure 4. Direct and Oscillatory Approaches to Equilibrium

run equilibrium. Because the system is 3x3, a graphical solution for the unique trajectory is not available.

For one time, once-and-for-all jumps in  $\tau_n$ , we can determine  $\tau$  according to a method suggested by Dixit [1981]. He shows that  $\tau - \bar{\tau}$  is a linear combination of  $k - \bar{k}$  and  $w_p - \bar{w}_p$ , where the weights are the elements of the eigenvector corresponding to the positive characteristic root in (23). Thus

$$(24) \quad \tau - \bar{\tau} = a_1(k - \bar{k}) + a_2(w_p - \bar{w}_p)$$

where  $a_1$  and  $a_2$  are equal to

$$a_1 = a_2 \theta / \lambda < 0$$

$$a_2 = -(s_\ell / s_k) \tilde{R}(\theta \alpha (1 + s_\ell / s_k) + \lambda) < 0$$

$\lambda$  is the positive eigenvalue in the matrix in (23).

Notice that  $\tau - \bar{\tau}$  is a negative function of  $k - \bar{k}$  and  $w_p - \bar{w}_p$ . When  $\tau_n$  rises, both of these latter terms are positive under our assumptions, so that  $q - \bar{q}$  correspondingly becomes negative. On impact, therefore,  $\dot{k}$  must be less than zero. At time zero, with  $k$  and  $w_p$  as yet unchanged, the disturbance in  $\tau_n$  is exactly the very short run shock that was formally analyzed earlier.

To trace out the longer-run dynamic implications of the  $\tau_n$  increase, we may substitute (24) back into (23) to get

$$(25) \quad \begin{bmatrix} \dot{k} \\ \dot{w}_p \end{bmatrix} = \begin{bmatrix} (1/\phi_0)a_1 & (1/\phi_0)a_2 \\ \theta & -\theta\alpha(1+s_k^{-1}s_\ell) \end{bmatrix} \begin{bmatrix} k - \bar{k} \\ w_p - \bar{w}_p \end{bmatrix}$$

Observe that (25) is globally stable, as confirmed by the phase diagram in Figure 4. Depending on  $\phi_0$  and  $\rho$ , the approach to equilibrium, say from  $E_0$  to  $E_1$ , may be direct or oscillating. The traverse for these two cases is illustrated in the figure.

## II. Empirical Evidence on Input Price Shocks: The Case of U.K. Manufacturing

The goal of this section is to give a quantitative assessment of the dynamic responses in U.K manufacturing to higher input prices in the 1970s. An investment equation, wage equation, and short-run production block are estimated using the framework of the previous section. The gross output technology is specialized to the CES case, and an output supply, labour demand, and FPF equation are jointly estimated with the appropriate cross-equation restrictions. A fully efficient estimation procedure would include the wage and investment equations in the jointly estimated block, but given the complexity of the resulting restrictions we did not pursue joint estimation of the complete model. The simplification is at the cost of some efficiency, but not consistency of the parameter estimates. One basic problem with the model as it now stands is the fact that while (11')-(13) are correct as written in rate-of-change form, the coefficients (i.e., elasticities) derived from output elasticities ( $\alpha$ ,  $\beta$ ,  $\gamma$ ) may vary (unless we are in a Cobb-Douglas world). One simplified approach, which we pursue here, is to consider a linear approximation of each equation around some fixed elasticities, which amounts to estimation of the equations in level form, and adding an intercept.<sup>12</sup> We shall consider both single equations and jointly estimated equations done on this basis.

To recapitulate, we estimate the following three equations for the gross output function:

$$(26) \quad \rho = \gamma_0 - (\alpha/\lambda)(w_p - \gamma t) - (\beta/\lambda) \pi_n \quad (\text{factor-price frontier})$$

$$(27) \quad q = \gamma_1 - (\alpha\alpha_1/\lambda)(w_p - \lambda t) - (\beta\eta\alpha_1/\lambda) \pi_n + k \quad (\text{output supply})$$

$$(28) \quad \lambda = \gamma_2 - [(1-\beta)\alpha_1/\lambda](w_p - \lambda t) - (\beta\alpha_1/\lambda) \pi_n + k - \lambda t \quad (\text{labor demand})$$

The  $\gamma_0$ ,  $\gamma_1$ ,  $\gamma_2$  parameters are inessential constants. These equations are simply the level forms of (11'), (12), (13). Regression 1 in Table 3 shows a single-equation estimate of (26), reported earlier in Bruno [1981]. Regressions 2 and 3 show related estimates for Germany, and Japan. The estimates for the labor-augmenting productivity factor,  $\lambda$ , the share of profits in value-added,  $\phi = \gamma/(1-\beta)$ , and the share of intermediate goods in total costs,  $\beta$ , all have the right orders of magnitude. Figure 5 gives a graphic representation of the estimated factor price profile for the U.K. The chart is drawn in terms of the actual profit rate ( $Q_K$ ) and the detrended product wage ( $W_P' = W_P e^{-\lambda t}$ ), using the estimated  $\lambda$ . There is a clear upward movement in  $W_P'$  (at the expense of  $R$ ) more or less along a given FPF before 1972, and a clear shift, to a new FPF after 1972. The U.K. evidences short-run real wage rigidity after the shift, during 1973-76, and then a steep decline in  $W_P'$  in 1977. Data for 1978-80 suggest that the product wage has more than recovered, and that  $R$  has continued to fall.

Notice that the estimated equation assumes a constant trend growth of TFP during 1961-77. All shifts in labor-productivity after 1973 are therefore attributed to the higher level of  $\pi_n$  or a lower growth in  $(K/L)$ , rather than to other productivity-reducing factors. While such a procedure yields plausible estimates, there is some worry that the method might attribute an independent decline in TFP to  $\pi_n$ . Since the apparent decline in TFP growth is so closely timed to the material price shock, we were not able to separate the two effects in our econometric estimates. We attempted to allow for a shift in  $\lambda$  after 1973, but the high multicollinearity of the time shift and  $\pi_N$  led to unstable parameter estimates and high standard errors.

Table 3. Single-Equation Estimation of Factor-Price Frontier,  
Output Supply, and Labor Demand Schedules, 1956-1978

Dependent Variable	Output Supply				Labor Demand Schedules				Implied Parameters		
	$\log(w)_{-1}$	$\log(\pi)_{-1}$	$\log(K)$	time	$(S/Q)_{-1}$	$\lambda$	$\beta$	$R^2$	$\beta$	$R^2$	d.w.
1. $\rho$ , United Kingdom	-4.994 (2.8)	-2.364 (3.8)	-	.168 (2.3)	-	.034	.167	.283	.78	2.29	
2. $\rho$ , Germany	-3.698 (3.6)	-2.902 (3.4)	-	.220 (3.1)	-	.059	.213	.382	.88	1.80	
3. $\rho$ , Japan	-1.426 (2.3)	-1.686 (3.3)	-	.134 (1.8)	-	.094	.407	.410	.78	1.25	
4. $\log(Q)$	.1 (.5)	-.19 (1.1)	.98 (2.2)	-.01 (.5)	-					.97	1.5
5. $\log(Q)$	-.1 (.7)	-.4 (3.1)	.93 (3.0)	.006 (.55)	-.25 (4.5)					.99	2.16
6. $\log(L)$	-.3 (2.0)	-.01 (.1)	.5 (1.9)	-.1 (1.7)	-					.91	1.88
7. $\log(L)$	-.3 (2.0)	-.03 (.3)	.5 (1.9)	-.01 (1.3)	0.0 (.4)					.91	1.8

1 Numbers in parenthesis are t-statistics.

Source: Equations 1-3 are reproduced from Bruno [9181], Table 11, p. 36.  
Equations 4-7 are for the United Kingdom, using Dicks-Mireaux data.

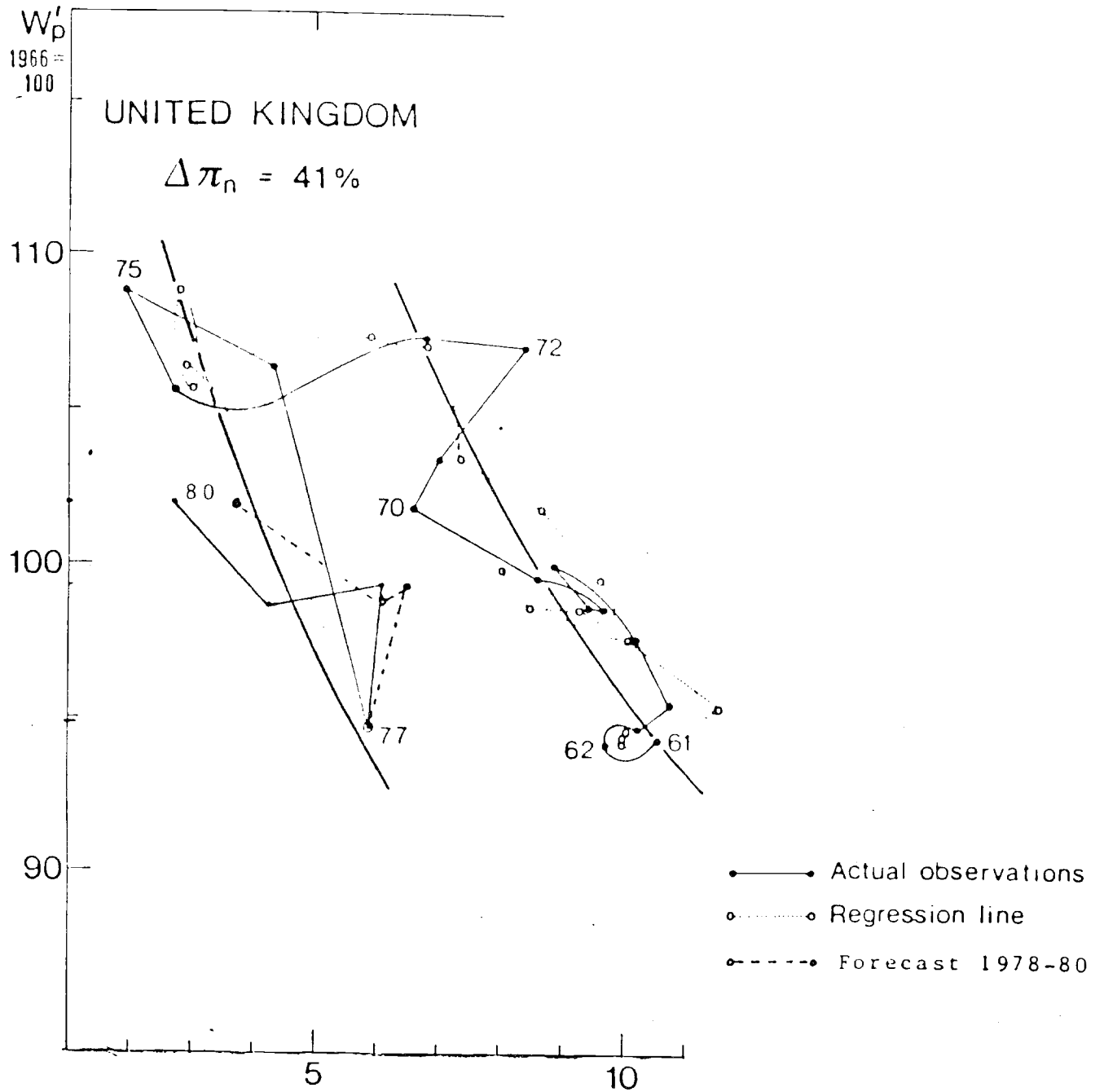


Figure 5. The Factor-Price-Frontier for the U.K.

Regressions 5-6 show two versions of the single-equation estimation of the output supply function, and regressions 7-8 show analagous regressions for the labor demand schedule. These are annual ordinary-least-squares regressions for 1956-78. After some experimentation with OLS and SLS versions of the equations, we determined that lagged rather than current factor prices were more decisive for output supply and labor input. The importance of these lags probably reflects costs of adjustment in altering the variable factor inputs and/or a lead time in production planning. The simple equations do not perform particularly well, as the wage is insignificant in the output equation and the intermediate input is insignificant in the labor demand equation. The capital stock is significant, or nearly significant at  $P = .05$ , in all of the equations. Our estimates with cross-equation restrictions improve upon these results markedly.

In regressions 5 and 7, we add the lagged inventory-output ratio ( $S/Q$ ) as a regressor, and find a strongly significant effect in the output equation. Inventories have been cited in a number of recent studies as the channel through which demand shocks lead to serially correlated output fluctuations. An initial demand disturbance causes a large unexpected accumulation of inventory stocks. Part of the response to these shocks is de-stocking, and part is a reduction in output, until inventory levels are back to normal. In this case, the variable may proxy for the effects of demand disturbances on output. Note that it is highly significant, and that it raises the coefficient and significance on  $\pi_h$ , in the output equation. It also markedly improves the Durbin-Watson statistic, suggesting that it helps to explain the serially correlated fluctuations in  $Q$ .



Table 4 presents estimates of the FPF, output supply, and labor demand, in which the cross equation restrictions are imposed. A variety of models are estimated: model A is as shown in earlier; model B adds the lagged inventory-output ratio to each of the regressions; and model C adds the inventory variable to the labor and output variables alone. When the system is estimated as a whole, the parameter estimates are almost all highly significant, and almost always are in the reasonable range for factor shares ( $\alpha, \beta, \gamma$ ) and labor productivity growth ( $\lambda$ ). The estimated substitutability of value-added and the intermediate input ( $\sigma$ ) is between .28 and .41, a plausible range that is in line with earlier estimates of Bruno [1981]. More surprising are the exceedingly low estimates of  $\sigma_1$ , the elasticity of substitution between K and L in value added. The estimate in model A is the highest, at a mere .31; and they fall to only .12 in model C. While these estimates are indeed far from the standard Cobb-Douglas assumption, they of course do no more than reflect the sharp rise in labor's share of value added, from an average of .72 during 1960-72 to .77 during 1972-75, and up to .78 during 1975-78.

We can use the regression estimates in order to compute the components of change in q-k in terms of the underlying explanatory variables. The first panel in Table 5 gives the component breakdown by sub-period for model C.

Table 4. Linearized CES Model for U.K. Manufacturing

	Factor Price Frontier			Model Version and Equation			Labour Equation		
	A	B	C	A	B	C	A	B	C
<u>Coefficient Estimates</u>									
Constant	-9.163 (0.318)	-9.215 (0.395)	-6.685 (0.879)	-5.247 (0.084)	-4.268 (0.121)	-3.753 (0.222)	-6.029 0.085	-4.648 0.186	-4.583
$w_P$	-2.714 (0.359)	-2.617 (0.438)	-1.941 (0.597)	-0.841 (0.091)	-0.437 (0.065)	-0.227 (0.115)	-1.50 (0.104)	-0.605 (0.080)	-0.345 (0.161)
$\pi_N$	-1.044 (0.233)	-1.453 (0.225)	-2.098 (0.371)	-0.318 (0.104)	-0.337 (0.058)	-0.417 (0.099)	-0.323 (0.077)	-0.243 (0.048)	-0.246 (0.092)
$t$	0.0796 (0.0132)	0.0785 (0.0167)	0.0683 (0.0231)	0.0247 (0.0034)	0.0131 (0.0023)	0.0080 (0.0037)	0.0044 (0.0031)	-0.0119 (0.0025)	-0.0231 (0.0072)
$V_{-1}$	-	-	-0.837 (0.281)	-	-0.246 (0.036)	-0.388 (0.060)	-	-0.341 (0.053)	-0.274 (0.083)
<u>Statistics</u>									
SE	0.1162	0.1122	0.0945	0.0399	0.0231	0.0290	0.0366	0.0233	0.0266
DW	1.3037	1.3714	1.9262	0.8430	1.3188	1.7352	0.9980	1.3142	1.1651
Mean of Dependent Variables	-6.82493	-6.82493	-6.82493	-4.52453	-4.52453	-4.52453	-5.47869	-4.47869	-4.47869
<u>Estimated Parameters</u>									
$\alpha$	0.5704 (0.0424)	0.5162 (0.0470)	0.3852 (0.0752)				$\lambda$	0.0300 (0.0018)	0.0352 (0.0031)
$\beta$	0.2194 (0.0415)	0.2866 (0.0395)	0.4164 (0.0618)				$\sigma$	0.4010 (0.1559)	0.3572 (0.1449)
$\gamma$	0.2102 (0.0191)	0.1973 (0.0194)	0.1984 (0.290)				$\sigma_1$	0.1672 (0.0262)	0.1172 (0.0529)

Table 5. Components of Change in Output and  
Labor Input: U.K. Manufacturing, 1956-1978

	(annual percentages) <sup>1</sup>				
	1956-64	1964-73	1973-76	1976-78	1973-78
Gross output ( $\Delta q$ )	3.4	2.9	-2.2	1.2	-.8
Capital stock ( $\Delta k$ )	4.2	3.5	2.0	2.0	2.0
Manhours ( $\Delta \ell$ )	-.2	-1.0	-2.3	.8	-1.0
Output per unit of capital ( $\Delta q - \Delta k$ )	-.7	-.5	-4.1	-.7	-2.7
of which:					
Real wage ( $\Delta w_p - \lambda$ )	-.1	-.2	0.0	1.7	.7
Material prices ( $\Delta \pi_n$ )	.7	.1	-2.2	-.4	-1.5
Inventory-output ratios ( $\Delta(v-q)$ )	-1.8	-.3	-1.4	-1.0	-1.2
Unexplained residual	-.5	-.1	-.4	-.9	-.7
Employment per unit of capital ( $\Delta \ell - \Delta k$ )	-4.2	-4.3	-4.1	-1.1	-2.9
of which:					
Real wage <sup>2</sup>	-2.5	-2.7	-2.4	.2	-1.3
Material prices ( $\Delta \pi_n$ )	.4	.1	-1.3	-.2	-.9
Inventory-output ratio	-1.2	-.2	-1.0	-.7	-.9
Unexplained residual	-.9	-1.5	.6	-.4	-.2

1 The numbers are calculated on the basis on model C.

2 This incorporates a constant employment-reducing effect of technical progress of 1.2 percent per annum.

These estimates suggest that during the period 1973-78, raw material prices directly explain over half of the 15 percent fall in output per unit of capital. The "demand" variable accounts (inventories) for another 45 percent. Real wages, relative to the productivity trend, were fairly rigid during 1973-76 (especially when compared to the contemporaneous developments in some other industrial countries, like Japan and the U.S.; see Bruno and Sachs [1981]). Only in the latter part of the period, 1976-78, did they mitigate the output-depressing effect of raw materials somewhat.<sup>13</sup> For the period 1973-78 as a whole, the average contribution was slightly positive (.7 relative to -2.7). There is an unexplained residual component of about 25 percent which may be due to productivity slowdown or other deflationary elements that are unaccounted for in this model.

The second part of Table 5 provides a similar breakdown for manhours per unit of capital. Real wages and technical progress account for most of the fall in the labor/capital ratio throughout the period 1956-78, with raw material prices taking up about 1/3 after 1973. The model over-explains the relative employment slowdown in 1973-76, which may be evidence of labor hoarding, constituting the other side of the unexplained productivity residual.

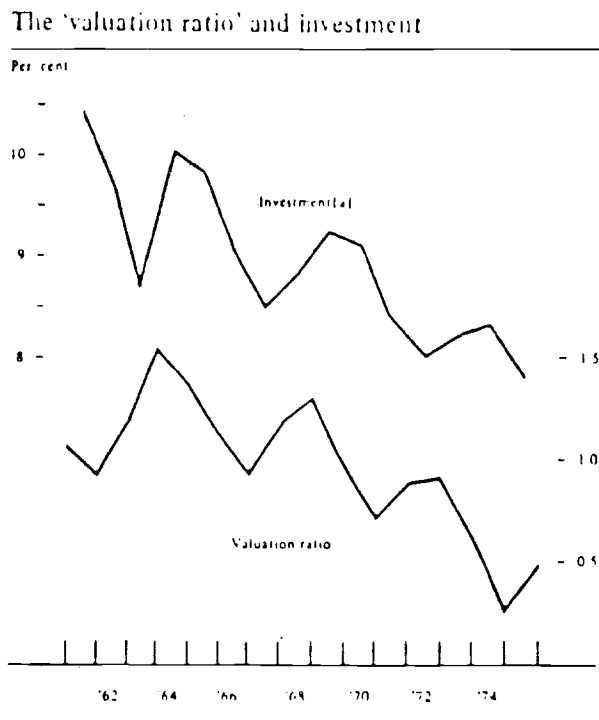
It should be stressed that the direct attribution of one half of the change in  $q-k$  to raw material prices at best represents only the direct short-term effect from the supply side. To this one should add the indirect effect of the profit squeeze on investment and capital stock, as we do in the simulations that follow. This point is best illustrated by appealing to the distinction made in

Section I between the various time horizons. Using model C parameters the elasticity of response of output to a 1 percent increase in  $\pi_n$  is  $-.40$  in the very short run ( $\dot{w}_p = \dot{k} = 0$ ),  $-.33$  in the short run ( $\dot{l} = \dot{k} = 0$ ), and  $-1.3$  in the long run ( $\dot{l} = \dot{k} = 0$ ).<sup>14</sup> Finally, one may add the depressing effect of rising relative import prices on real incomes as well as on initiating contractionary macropolicies, which play their role here (if at all) through the inventory variable.

Next, we need numerical estimates of the investment and wage functions. There is now a growing literature that confirms the link between Tobin's  $q$  and investment in the United Kingdom (see especially Flemming [1976a,b] for pioneering estimates of  $\tau$ ; Oulton [1978]; Jenkinson [1981]; and Poterba and Summers [1981]). The potential for a strong econometric relationship is clearly evident in Figure 6, which is reproduced from Flemming [1976b]. The investment rate is closely tied to fluctuations in  $\tau$ , which seems to lead by about a year.

Some simple regressions between  $J/K$  and  $\tau$  are shown in Table 6. The regressions are reproduced from Poterba and Summers [1981]. These authors make various adjustments to the valuation ratio (the market value of the firm relative to the replacement cost of capital) to take account of U.K. tax laws. While the theory presented earlier argues for a contemporaneous relationship of investment and  $\tau$ , the regression estimates clearly point to a lagged effect of  $\tau$  on  $J/K$  as well. Tobin's  $q$  is shown to have a highly significant effect, though the low Durbin-Watson statistics suggest some misspecification in the basic equation. When the equations are re-estimated with corrections for first-order and second-order serial correlation, the estimated effect of  $\tau$  diminishes somewhat, but still remains significant.

Figure 6. Investment and Tobin's q: 1960-76,  
from Flemming [1976b]



[a] Industrial and commercial companies' gross domestic fixed-capital formation as a percentage of capital stock (at replacement cost).

Table 6. Investment and Real Wage Equations

Investment Equations	$q$	$q_{-1}$	Second-Order Serial Correlation $\rho_1$	$\rho_2$	R <sup>2</sup>	d. w.
1. J/K, Annual 1950-80	.0133 (3.5)	.010 (2.7)	-	-	.66	.46
2. J/K, Annual 1950-80	.0094 (4.9)	.0054 (2.8)	1.28 (7.5)	-.50 (2.9)	.91	1.70
3. J/K, Annual 1950-72	.0102 (5.1)	.0053 (2.5)	1.33 (6.7)	-.55 (2.9)	.93	1.65
4. J/K, Annual 1950-80	.0110 (5.0)	.0069 (3.5)	.63 (1.9)	-.51 (1.6)	.79	1.83

Wage Equation	$\log(L)_{-1}$	$\log(L)_{-2}$	$\log(W/CPI)_{-1}$	Time	First-Order Serial Correlation $\rho$	R <sup>2</sup>	d. w.
5. $\log(W/CPI)$	.46 (1.8)		.05 (.14)		.42 (1.1)	.99	1.87
6. $\log(W/CPI)$	.61 (2.3)	-.47 (1.8)	.53 (1.5)	.017 (1.3)	-.09 (.2)	.99	1.99
7. $\log(W/CPI)$	.79 (2.9)	-.69 (2.9)	1.0 (constrained)	.002 (.67)	-.25 (1.0)	.25 <sup>a</sup>	2.04

Source: Equations 1-4 are reproduced from Summers and Poterba, Table 2, p. 34. For Equations 5-7, W is the rate of hourly compensation and L is manhours, both for manufacturing from the U.S. Bureau of Labor Statistics [1981]. The CPI is from the International Financial Statistics of the International Monetary Fund.

<sup>a</sup> LHS variable is  $\log(W/CPI) - \log(W/CPI)_{-1}$ .

A surprising feature of the regressions is the extremely small magnitude of the coefficients on  $\tau$ . A drop of  $\tau$  from 1.0 to 0.5 is calculated to result in a fall in  $J/K$  from about 0.09 to 0.075 (using regression 1). Such small effects of  $\tau$  have also been reported for U.S. data (in Summers [1981], for example). The coefficient (or sum of coefficients) on  $\tau$  measure the inverse of the adjustment cost parameter, according to the linear-adjustment cost model. Thus, the estimates of  $\beta_1 + \beta_2 = .02$  suggest a  $\phi_0$  of 50, which seems very high.

There is little doubt that data problems in part account for a downward bias on the  $\tau$  coefficient, but theoretical problems also play a role. In the investment model we use, the observed firm value (subject to some important tax adjustments) is always the appropriate indicator of marginal investment decisions. In a world of vintage or putty-clay capital, however, it is possible for stock market movements to signal changes in the value of quasi-rents on old capital that do not affect investment decisions on new capital. In the jargon of the investment literature, "marginal Tobin's  $q$ " does not equal "average Tobin's  $q$ " (i.e., observed values of  $\tau$ ). Unfortunately, we remain a long way off from a convincing and empirically tractable vintage model of production with intermediate inputs.

Next, we turn to the wage equation. As thoroughly explained in Grubb, Jackman and Layard [1981], the form of the wage equation is both unresolved and enormously important to the questions at hand! Most importantly we must know: (1) whether the degree of labor market slack affects the rate of real wage increase; and (2) whether real wage growth responds to the difference of actual real wages and some "target" or "aspiration" level of real wages (the so-called Sargen effect). And if the target-wage model is correct, do target wages them-



selves respond adaptively to the history of actual wage growth? These questions remain subject to enormous dispute in the U.K. literature, with opposite answers reached by numerous authors on each of the issues.

For us the relevant question is whether temporary labor market slack is necessary and sufficient to reduce the path of real wages following an input price shock. Under what circumstances can real wage targets be reduced by a bout of unemployment? Some very simple, and imprecise evidence is gathered in the final three regressions of Table 6. Labor market slack is measured by the deviation of (log) manhours in manufacturing from a linear trend. Because lagged real wages are insignificant in regression 5, the equation implies that labor market slack leads to a reduction of real wages but not to a steady decline in real wages growth. If the model  $\log(w_p) = \alpha + \beta \log(L)$  is correct, as is implied, then an input price shock permanently lowers the employment level in U.K. manufacturing. In the next regression, there is a modest effect of slack on real wage change. According to the equation, a one percent decline in manhours (relative to trend), sustained for five years, results in a fall in  $w_p$  of only 0.33 percent relative to trend. Finally, in regression 7 we see again that changes in U.K. real wages are basically tied to changes in employment, but not closely to the employment level itself.

These results are suggestive but rather crude, as sophisticated wage equations must better account for: the difference of the real consumption wage and producer's labor costs; the timing of contract negotiations; pre-tax versus post-tax labor earnings; inflation expectations; incomes policies; and problems in measurement of labor market slack. Still, there is a strong feeling that

downward real wage adjustment is not likely to be a smooth, costless process in the U.K. economy.

The complete supply-side model is now simulated, using (approximately) the parameters that we have estimated. Model C of the joint estimates is selected for the gross output block. The simulation model is shown in full in Table 7. Two labor market equations are used, representing the alternatives of instantaneous market clearing and sluggish real wage adjustment. Three simulations are undertaken from an initial steady state: (1) a 10 percent, unanticipated permanent rise in  $\pi_n$  in 1980, with full employment of labor assumed; (2) the same increase in  $\pi_n$ , but with slow real wage adjustment; and (3) a 10 percent rise in  $\pi_n$ , announced in 1980 and commencing in 1983. The simulations yield the time paths of output, employment, investment, equity prices and wages following the given shock. They will be reported as percentage deviations from an initial full-employment steady-state growth path.

As pointed out above, the complete model exhibits saddlepoint stability, and the tricky part of the simulation exercise involves finding the particular initial value for Tobin's  $q$  that drives the system to a new steady state (all other values of  $\tau$  lead to an explosive divergence from steady state). We use the method of multiple shooting, described in Lipton, Poterba, Sachs and Summers [1980], to find the saddlepoint-stable trajectory.

The results of the simulations are shown in Table 8. In the full-employment case, the rise in  $\pi_n$  causes an immediate fall in real wages of 6.9 percent, and in productivity of 2.5 percent. Since  $Q_k$  is reduced below its long-run value, the stock market price falls, in this case a modest 2.7 percent.

Table 7. Simulation Model

Equations

1.  $V = \mathbb{K}$
2.  $J/K = (1/\beta_0)(\tau - 1 + t_c)/(1-t_c) + (d+n)$
3.  $\phi = 0.5 \beta_0 (J/K - d - n)^2 / (J/K)$
4.  $Q = (\mu_V Va^{\rho_2} + \mu_N N^{\rho_2})^{1/\rho_2}$
5.  $Va = (\mu_L L^{\rho_1} + \mu_K K^{\rho_1})^{1/\rho_1}$
6.  $P = (\mu_V^{\rho_2} P_V^{(1-\rho_2)} + \mu_N^{\rho_2} P_N^{(1-\rho_2)})^{1/(1-\rho_2)}$
7.  $W = W_P \cdot p$
8.  $L = (1-\mu_L)^{1/\rho_1} K \cdot [(W/\mu_L \cdot P_V)^{\rho_1} / (1-\rho_1)]^{1/\rho_1}$
9.  $N = Va \cdot (\mu_N/\mu_V)^{\rho_2} (P_V/P_N)^{\rho_2}$
10.  $Div = \gamma \cdot (1-t_c) \cdot (Q - w_P L - \tau_N N - dK)$
11.  $S = Div + J \cdot (1-t_c + (1-t_c)\phi) - (1-t_c)(Q - w_P \cdot L - \tau_N N)$
12.  $V_{t+1} = [V_t + S + (RV_t - (1-c)Div)/(1-c)]/(1+n)$
13.  $K_{t+1}(1+n) = J + (1-d) \cdot K$
- 14.(a)  $L = 1$
- 14.(b)  $W_P = (L_{t-1})^{0.8} (L_{t-2})^{-0.6} (W_P)_{t-1}$

Variable Definitions

S	New equity issues
Div	Total dividend payments
c	Capital gains tax rate
Va	Real value added
V	Value of the firm
n	Growth rate of efficiency labor
R	Required rate of return on corporate equity
d	Rate of depreciation
$\phi$	Per unit cost of adjustment
$\gamma$	Dividend payout ratio

(Continued on next page)

Table 7 (continued)

Parameter Values

$\beta_0$  50.0

c .15

s .06

$\gamma$  .5

n .02

R .06

$\rho_1$  -8

$\rho_2$  -1.8

$\sigma_2$  .4

$t_c$  .5

$\mu_L$  .7

$\mu_K$  .7

$\mu_N$  .4

$\mu_V$  .6

Table 8. Simulation Results<sup>1</sup>

	<u>1980</u>	<u>Simulation</u>		
		<u>1</u>	<u>2</u>	<u>3</u>
Q		-2.5	-4.2	0.0
Q/L		-2.5	-1.7	0.0
W <sup>P</sup>		-6.9	0.0	0.0
L <sup>P</sup>		0.0	2.6	0.0
K		-2.7	-13.0	-8.2
Tobin's q				
	<u>1985</u>			
Q		-2.6	-4.4	-4.7
Q/L		-2.6	-4.4	-4.7
W <sup>P</sup>		-2.6	-2.1	-2.0
L <sup>P</sup>		-7.5	-3.4	-2.5
K		-0.2	-1.0	-1.0
Tobin's q		-1.7	-7.3	-8.8
	<u>1990</u>			
Q		-2.6	-4.5	-4.8
Q/L		-2.6	-2.3	-2.3
W <sup>P</sup>		-7.9	-5.3	-4.7
L <sup>P</sup>		0.0	-2.1	-2.4
K		0.0	-1.6	-1.6
Tobin's q		-1.0	-3.2	-4.0
<u>Steady-State</u>				
Q		-2.6	-2.6	-2.6
Q/L		-2.7	-2.7	-2.7
W <sup>P</sup>		-8.4	-8.4	-8.4
L <sup>P</sup>		0.0	0.0	0.0
K		-0.6	-0.6	-0.6
Tobin's q		0.0	0.0	0.0

1 All variables are measured as a percentage deviation from the initial steady-state growth path.

Source: Simulation 1: Ten-percent permanent rise in  $\pi_n$  in 1980; flexible  $w_p$ .

Simulation 2: Ten-percent permanent rise in  $\pi_n$  in 1980; Phillips curve adjustment of  $w_p$ .

Simulation 3: Ten-percent permanent rise in  $\pi_n$  in 1983; anticipated in 1980; Phillips curve adjustment of  $w_p$ .

Far-sighted investors know that the marginal productivity of capital will rise in the future, so that they do not place too much weight on the immediate sharp deterioration of profitability ( $Q_k$  falls from \_\_\_ percent to \_\_\_ percent in 1980). Over time,  $K$  continues to fall, pushing the real wage and productivity even further below the initial trend.  $Q_k$  rises, on the other hand, and Tobin's  $q$  approaches its initial value. In the long run, the real wage falls by 8.4 percent; productivity,  $Q/L$ , by 2.7 percent; and the capital stock,  $K$ , by .6 percent. The very modest long-run decline in  $K$  reflects the low value of  $\sigma_{KL}$  in the value-added function (set at .11 for the exercise). Since  $K$  must remain in almost fixed proportion to full-employment  $L$ , it changes little over the course of time. Were  $\sigma_{KL}$  assumed to be 1.0 initially, with all other parameters the same, the long-run decline in  $K$  would equal .

Simulation 2 dramatically indicates the depressing effect of real wage resistance on the adjustment to a supply shock. Most directly, 1980 output falls more than in the first simulation (4.2 percent rather than 2.5 percent), and the unemployment rate rises to 2.6 percent. Since the higher real wage reduces profitability and since forward-looking investors correctly perceive a very slow decline in future wages, the 1980 level of Tobin's  $q$  falls more sharply than in the market-clearing case (down 13 percent rather than 2.7 percent). As a consequence, the real-wage rigidity leads to a steep process of capital decumulation. In the first simulation,  $K$  falls slowly to .6 percent below the baseline. With wage rigidity,  $K$  falls steeply to -1.8 percent below trend, and then slowly recovers as real wages fall. The model exhibits a strongly damped oscillation of the sort demonstrated in Figure 4. Since real

wages decline so slowly,  $K$  falls below its long-run level; in turn,  $w_p$  is pulled below  $\bar{w}_p$ , which eventually pushes  $K$  above  $\bar{K}$ , etc. (The oscillation is in fact so damped that there is almost direct convergence to equilibrium.)

In the third simulation, the increase in  $\pi_n$  is anticipated (in 1980) three years before it actually occurs (in 1983). The stock market immediately capitalizes the decline in future profitability, as Tobin's  $q$  declines 8.2 percent. Since equity prices drive the investment process, the decumulation of capital starts in 1981, two years before the price increase. Of course, as  $K$  falls, employment is also reduced in the rigid real-wage case. In 1972, the unemployment rate stands at .3 percent. When the shock finally hits, the unemployment rate jumps and productivity falls, while the stock market hardly responds. The remaining adjustment profile is very similar to that of simulation 2.

These numerical simulations demonstrate the feasibility of specifying, estimating, and solving a dynamic non-linear supply model with forward-looking agents. In our papers, Bruno and Sachs [1982] and Sachs [1982] the approach is extended to a complete macromodel of the economy, with optimizing households as well as firms.

### III. Conclusions

This paper develops a theoretical model of the effects of input price shocks, and applies the model to the case of U.K. manufacturing. With the theoretical model we trace out the dynamic adjustments to the price shock, and show that the paths of output, employment, and capital stock depend crucially on the responsiveness of real wages to labor market slack. Even with full labor-market clearing, an input price shock causes a fall in output, productivity, real wages and real equity prices on impact, and leads to a continued decline in the capital stock and output over time. When real wages are sticky, these effects are greatly magnified, and unemployment as well as reduced output becomes a major effect of the shock. With greater real wage stickiness, profitability is more sharply affected by the rise in input prices, and investment tends to be more sharply squeezed.

There is abundant evidence that higher input prices have played a significant role in the slowdown in economic growth since 1973 throughout the OECD. Most major economies have experienced a serious squeeze in profits and investment that dates from around the first oil shock (see Sachs [1979] and Bruno [1981b] for details). We develop this case in some detail for the U.K. by estimating a gross output function, investment equation, and real wage equation for the manufacturing sector, based on the theoretical model. Estimates of the factor-price frontier show a sharp shift in the frontier after 1973, in line with the observed drop in profitability from about 9.5 percent return on capital during 1960-72 to under 5.0 percent during 1973-78 (see Table 2). Estimates of output supply also confirm the large role for input prices. We estimate that



over half of the growth slowdown in output per unit capital ( $Q/K$ ) after 1972 can be attributed to higher input prices. Moreover, the slowdown in  $K$  itself can be traced in large part to the higher input prices via reduced profitability. To show the complete dynamic effects, we simulate a small non-linear model based on the econometric estimates, and once again we find large effects of the input shock, particularly in the case of real wage resistance.

These are major shortcomings that remain at the conclusion of this work, involving: (1) lags in factor adjustment; (2) the productivity puzzle; and (3) the integration of demand factors into the supply-side framework. We touch on these in turn. With respect to factor adjustments, there is widespread evidence and a long tradition holding that labor, like capital, is adjusted only slowly over time in response to an exogenous shock. Indeed in our empirical work, we found it necessary to relate current employment and output to lagged factor prices. In his excellent study of labor demand in U.K. manufacturing, Symons [1981] also finds a lagged adjustment pattern. Conceptually, this slow adjustment is readily handled, by supposing convex costs of adjustment to labor as in Sargent [1978] as well as capital. Empirically, though, the problem is trickier, as now labor demand depends on expectations of future real factor prices, and not just their current level.

An even more central empirical problem is our treatment of productivity developments since 1973. That labor productivity growth has deteriorated there is no doubt, but the allocation of that slowdown to various factors is still very much in doubt. On our limited post-1973 data we could make little progress in evaluating whether reduced capital and intermediate input utilization can

explain the slowdown, or whether an exogenous slowdown in total factor productivity (TFP) growth had occurred. The implications of an input shock or exogenous TFP slowdown for output, unemployment, real wage growth, and investment are actually very similar, since an input price shock is analogous to technical regress. But for quantitative assessments it is important to know the sources and size of the productivity slowdown. Our Table 1, and regressions in Bruno [1981] suggest that  $K$  and  $\pi_n$  cannot fully explain the U.K. productivity experience. In future empirical work, the TFP developments must be better integrated with the input price shock.

The greatest conceptual problem lies in the proper integration of supply and demand factors in the study of the macroeconomic adjustment process. Our model assumes that profit-maximizing firms are always on their supply schedules, so that fluctuations in output can always be attributed to shifts in the capital stock or factor prices. Pure demand disturbances, in which firms are rationed in the output market and hence off of their supply schedules, are not allowed. This treatment is extreme, though no more so than the typical Keynesian position which treats all fluctuations as pure demand disturbances. A more sensible position, no doubt, would allow for both supply and demand shocks to play distinct roles, whose importance varies over time. We would surmise that the deep recessions of 1975 and 1980 represent cases in which firms were pushed off of supply schedules by tight demand, while the rest of 1973-onward basically reflects the type of supply squeeze that we depict in the paper. We are now attempting to formulate a dynamic model that will allow for that possibility.

Appendix: Data Appendix\*

For source abbreviations, see glossary at the end of this appendix.

Input-Output Accounts for U.K. Manufacturing, 1954-78

The manufacturing sector is defined as Orders III, V-XIX of the Standard Industrial Classification. Order IV, "Coal and Petroleum Products", was excluded. Inputs were divided into four categories: labor, capital, energy, and non-energy intermediate inputs. Definitions of the constructed variables are as follows.

Gross Output ( $P_Q Q$ )

Price and quantity indices for output were constructed and then normalized to equal the value (£ million) of gross output, excluding stock appreciation (source: Table 21, DAE1), in 1968. Before normalization,  $P_Q$  = Wholesale Price Index of Home Sales, all manufactured products, 1975 = 100; ETAS 1980. Exclusion of the contribution of SIC Order IV was not possible with available data.

$Q$  = Index of Industrial Production, Manufacturing, 1975 = 100; ETAS 1980. Using the Index for Coal and Petroleum Products (MDS, various) and appropriate weights the contribution of SIC Order IV was subtracted from  $Q$ .

Before normalization it was observed that the ratio of  $P_Q Q$  to gross output (DAE1) for 1954-68 was stable taking on values of 7.3 to 7.6.

\* Data construction and data appendix prepared by Mr. Louis-David Dicks-Mireaux.

Labor ( $P_L L$ )

Before normalization,  $P_L$  = Index of hourly compensation, manufacturing, 1967 = 100; USBLS.  $L$  = Index of total hours worked in manufacturing, 1967 = 100; USBLS. These were then normalized to equal the 1968 value of wages and salaries in manufacturing less that accruing in SIC Order IV (BB), plus employers' national insurance contributions (BB). An estimate for these contributions in SIC Order IV was estimated by a proportion of the total equal to the ratio of "employees in employment" in Order IV to total manufacturing. The ratio  $P_L L$  to the constructed labor compensation series for 1954-78 varied from .77 to .80.

Capital ( $P_K K$ )

Define:

$P_K K$  - BB: Profits in total manufacturing after stock appreciation, before depreciation; (BB various); no exclusion of SIC Order IV; 1954-78.

$P_K K$  - DAE: As above excluding SIC Order IV (Table 25, DAE1). Only available for 1954-68.

$P_K K$  - BD:  $(P_K K - BB)(\text{Average value of 1954-68 of } (P_K K - \text{DAE}) / (P_K K - \text{BB}))$ .  $P_K K$  was constructed as  $P_K K - \text{DAE}$  (1954-68) and  $P_K K - \text{BD}$  (1969-78).

To construct K, define:

NK70: Net capital stock all manufacturing, 1970 prices. (STUDOS).

PNK70: Price index defined as ratio of current and constant (1970 as base year) price series for gross domestic fixed capital formation (BB).

ADJUST:  $\text{NK70} * 0.0347$ , where 0.0347 equals the average value for 1954-68 (period for which data was available) of the ratio of gross capital

stocks in "mineral oil refining and coke ovens" to all manufacturing, Table 34-37, DAE1.

Giving us K defined as the nominal net capital stock equal to

$K = (NK70 - ADJUST) * PNK70$ , and  $P_K$  as an internal rate of return:

$$P_K = P_K K / K.$$

### Energy ( $P_E E$ )

E: Energy consumption (millions of therms) by final user all industries (excluding fuel producing ones). The available data for "all industry" includes "construction", "water", "other manufacturing and quarrying" for which disaggregate numbers are not available. Source, UKESD).

$P_E$  was constructed as  $P_E E / E$  where  $P_E E$  was derived as follows.  $P_E E$  by final users is only available post 1968 (see UKESD, 1980), and so a series was calculated by multiplying several disaggregate quantity and price series. Quantity series, as in E, were from UKESD. Price series were taken from : for 1954-63, "Purchasers average prices of fuel in U.K." (p. 115, DAE2); for 1963-79, "Prices of fuels used by manufacturing industry" (UKESD, 1977, 1980). In calculating expenditure the following assumptions were made: the price of coal, coke and breeze, other solid fuel was taken to be that of coal; the price of all types of gas was taken to be the published price; the price of petroleum and creosote-pitch neocture taken to be that of heavy fuel oil. This constructed series was used as an estimate of  $P_E E$ .

Non-Energy Intermediate Inputs ( $P_M^M$ )

$P_M^M$  was derived as the residual from  $P_Q^Q - P_L^L - P_K^K - P_E^E$ , and M as  $P_M^M/P_M$ .

$P_M$  is defined as  $P_M^M = W_{NM} * P_{NM} + W_M * P_Q$  a weighted average of intermediate purchase from outside and from within the manufacturing sector, where

$P_Q$  = as above, wholesale price index of home sales.

$W_M$  = share of manufacturing non-energy purchases in manufacturing gross output in 1973. Calculated from 1973 Input-Output Tables (ET, June 1978).  $W_M = 0.3547$ .

$W_{NM}$  = same as  $W_M$  for nonmanufacturing non-energy purchases.  $W_{NM} = 0.6453$ .

$P_{NM}$  =  $(P_{BM} - W_E * P_{IE}) / (1 - W_E)$ , where

$P_{BM}$  = Wholesale Price Index of Materials purchased by manufacturing industry, average of monthly figures, 1970 = 100; MDS.

$P_{IE}$  = Unit Value Index of Fuel Imports, U.K., average of quarterly figures, 1970 = 100; MDS.

$W_E$  = Share of purchases of coal and crude petroleum (considered as materials not fuels in  $P_{BM}$ ) by the mineral oil refining and coke oven industries is total non-energy intermediate input purchases by manufacturing, for 1973.  $W_E = 0.03696$ .

$P_{NM}$  is therefore the material input price index for manufacturing excluding SIC Order IV.

Intermediate Inputs, Total (Energy and Non-Energy) ( $P_N^N$ )

When the accounting framework is reduced to three inputs, aggregating energy and non-energy intermediate inputs, a price index ( $P_N^N$ ) was calculated as,

$$P_N = 0.06076 * P_{NM} + 0.0684 * P_E + 0.3340 * P_Q$$

where the coefficients are the shares, calculated from the 1973 Input-Output Tables (ET, June 1978), of non-manufacturing, energy, and manufacturing inputs respectively, in gross output. N is then calculated as  $(P_E E + P_M M) / P_N$ . (When a division index was used to create N, the change was trivial.)

#### Glossary of Source Abbreviations

- BB: National Income and Expenditure, C.S.O.
- DAE1: "Structural Change in the British Economy, 1948-68," A Programme for Growth No. 12, Department of Applied Economics, University of Cambridge; Chapman and Hall, May 1974.
- DAE2: "The Demand for Fuel, 1948-75," A Programme for Growth No. 8, Department of Applied Economics, University of Cambridge; Chapman and Hall, 1968.
- ET: Economic Trends, monthly, CSO.
- ETAS: Economic Trends Annual Supplement, CSO
- MDS: Monthly Digest of Statics, CSO
- STUDOS: New Contributions to Economics Statistics, Ninth Series. Studies in Official Statistics No. 33, 1977, CSO. Appendix II updated with more recent BB figures.
- UKBLS: British Labour Statistics Year Book (1975); Appendix H "New estimates

of employment on a continuous basis: United Kingdom," Department of Employment.

UKESD: U.K. Energy Statistical Digest, Department of Energy. Early issues were Ministry of Power Statistical Digest, Ministry of Power.

USBLS: Unpublished data prepared by the U.S. Department of Labor, Bureau of Labor Statistics, Office of Productivity and Technology.



Footnotes

1 Profit share is the ratio of gross trading profits in manufacturing to gross output. The profit rate is the ratio of gross trading profits to the nominal value of the manufacturing capital stock. Both series are from the Dicks-Mireaux data.

2

3 See Sachs [1980] for details. The derivation is a straightforward application of the optimum conditions for the Hamiltonian H:

$$H = e^{-\Delta} [(Q - W_p L - \tau_n N - I) + \lambda (J - dK)]$$

4 A more detailed analysis for the single sector case and alternative technological assumptions is given in Bruno (1981).

5 In the putty-clay case in which the capital/labour ratio cannot immediately adjust to the new factor prices, the various solutions are given along the line FCG, i.e., in the rigid real wage, rigid capital/labour case the economy will be at F and not at B, the rate of profit falling by more and L by less than at B.

6 Here and elsewhere we shall adopt the convention of using lower-case letters for the natural log of a capital-lettered variable (e.g.,  $q = \ln Q$ , etc.).

7 While the case of weak separability of intermediate inputs may be relevant for most industrial raw materials, it is most probably not applicable to the case of energy inputs, E, for which separability may take the alternative form  $Q[L, G(K, E)]$  [see Bernt and Wood, 1979]. Here energy combines with capital to form a composite from which labour (and other raw materials, here left out) are separable. By analogy, the resulting factor price frontier in the  $Q_E - R$  space will now contract along the R axis at a rate which will be independent of the real wage. While the short-run implications may be different (e.g., L/K need not fall with a rise in energy prices), the long-run implications are qualitatively the same.

8 As will be seen, for realistic orders of magnitude of the parameters this is unlikely to reverse the output drop from the initial pre-shock level.

9 The full symmetry of the two dual expressions can be seen by writing (9) in the form:  $0 = \alpha(\dot{l} - \dot{q}) + \beta(\dot{n} - \dot{q}) + \gamma(\dot{k} - \dot{q})$ .

- 10 The two conditions  $\dot{\tau} = r\tau - [Q_k + (J/K)^2 \phi'(J/K)]$  and  $\lim_{t \rightarrow \infty} e^{-Rt} \tau(t) = 0$  are equivalent to equation 2(d).
- 11 Saddlepoint stability in (23) requires that the matrix have two negative and one positive eigenvalue.
- 12 E.g., an equation like  $\dot{z} = ax + by$  is transformed into  $\dot{z} = c + ax + by$ , where  $\bar{x} = x - \bar{x}$ , etc., and  $c = \bar{z} - a\bar{x} - b\bar{y}$ .
- 13 Note that during the earlier growth periods 1954-64 and 1964-73, capital deepening was accompanied by an increase in real wages (net of productivity), a point which is also apparent from direct inspection of the factor price profile (Figure 2). See also Sargent (1979); Glynn and Sutcliffe (1972).
- 14 If model A estimates are used instead, with the higher value of  $q_k$  (.31 rather than .11), the values become: -.00 in the very short run, -.00 in the short run, and -.00 in the long run. The difference between short-run and long-run is magnified, since there is greater long-run substitution away from  $k$ .

References

- Berndt, E. R. and D. O. Wood (1979), "Engineering and Econometric Interpretation of Energy-Capital Complementarity," American Economic Review, 69, June 342-54.
- Bruno, M. (1981a), "Price and Output Adjustment: Micro Foundations and Aggregation," Journal of Monetary Economics, 5, April, 187-211.
- Bruno, M. (1981b), "Raw Materials, Profits and the Productivity Slowdown," Discussion Paper No. 812, Jerusalem: Falk Institute, April. (Also appeared as NBER Working Paper No. 660.)
- Bruno, M. and J. Sachs (1981), "Supply Versus Demand Approaches to the Problem of Stagflation," Discussion Paper No. 796, Jerusalem: Falk Institute, 1979 (appeared in Macroeconomic Policies for Growth and Stability, Institute fur Weltwirtschaft, Kiel).
- Bruno, M. and J. Sachs (1982), "Energy and Resource Allocation: A Dynamic Model of the 'Dutch Disease'," Review of Economic Studies, forthcoming.
- Buiter, W. and M. Miller (1982), "The Thatcher Experiment: What Went Wrong?," Brookings Papers on Economic Activity, forthcoming.
- Dixit, A. (1980), "A Solution Technique for Rational Expectations Models with Applications to Exchange Rate and Interest Rate Determination," University of Warwick, mimeo, November.
- Flemming, J. (1976a), (with L. Price and S. Byers) "Trends in Company Profitability," Bank of England Quarterly Bulletin, March.
- Flemming, J. (1976b), (with L. Price and S. Byers) "The Cost of Capital, Finance and Investment," Bank of England Quarterly Bulletin, June.
- Glyn, A. and B. Sutcliffe (1972), Capitalism in Crisis, New York: Random House.
- Grubb, D., R. Jackman, and R. Layard, "Causes of the Current Stagflation," Review of Economic Studies, forthcoming.
- Hayashi, F. (1982), "The q Theory of Investment: A Neoclassical Interpretation," Econometrica, January.
- Jenkinson, N. (1981), "Investment, Profitability, and the Valuation Ratio," Bank of England Discussion Paper.

- Malinvaud, E. (1977), Theory of Unemployment Reconsidered, Basil Blackwell, Oxford, 1977.
- Malinvaud, E. (1980), Profitability and Unemployment, Cambridge University Press.
- Martin, W. E. and M. O'Connor (1981), "Profitability: A Background Paper," in Martin, W. E. (ed.), The Economics of the Profits Crisis, London: Department of Industry.
- Morley, R. (1979), "Profit, Relative Prices, and Unemployment," The Economic Journal, Vol. 89, September, 582-600.
- Oulton, N. (1978), "Explaining Aggregate Investment in Britain: the Importance of Tobin's Q," Economics Letters, Vol 1.
- Oulton, N. (1979), "Aggregate Investment and Tobin's q: Evidence from Britain," University of Lancaster Discussion Paper 5.
- Sachs, J. D. (1979), "Wages, Profits and Macroeconomic Adjustment: A Comparative Study," Brookings Papers on Economic Activity, No. 2, 269-332.
- Sachs, J. (1980), "Energy and Growth under Flexible Exchange Rates," NBER Working Paper No. 582, November 1980, also forthcoming in Bhandard and Putnam (eds.), The International Transmission of Economic Disturbances under Flexible Exchange Rates, forthcoming, MIT Press, 1982.
- Sargent, J. R., "Productivity and Profits in UK Manufacturing," Midland Bank Review, Autumn.
- Sargent, T. (1978), "Estimation of Dynamic Labor Demand Schedules under Rational Expectations," Journal of Political Economy, Vol. 86, No. 6.
- Summers, L. H. (1981), "Taxation and Corporate Investment: a q-Theory Approach," Brookings Paper on Economic Activity no. 1, 67-140.
- Summers, L. H. and J. Poterba (1982), "Dividend Taxes, Corporate Investment, and 'Q'," NBER, mimeo.
- Symons, J. S. V. (1982), "The Demand for Labour in British Manufacturing," in Review of Economic Studies, forthcoming.
- Tobin, James (1981), "Comment on Bruno and Sachs, 'Supply Versus Demand Approaches to the Problem of Stagflation'," Conference on Macroeconomic Policies for Growth and Stability -- The European Perspective, Kiel, July 1979, (appeared in volume, op. cit.).