THE ROLE OF REAL AND NOMINAL RIGIDITIES IN MACROECONOMIC ADJUSTMENT: A COMPARATIVE STUDY OF THE G3 ECONOMIES

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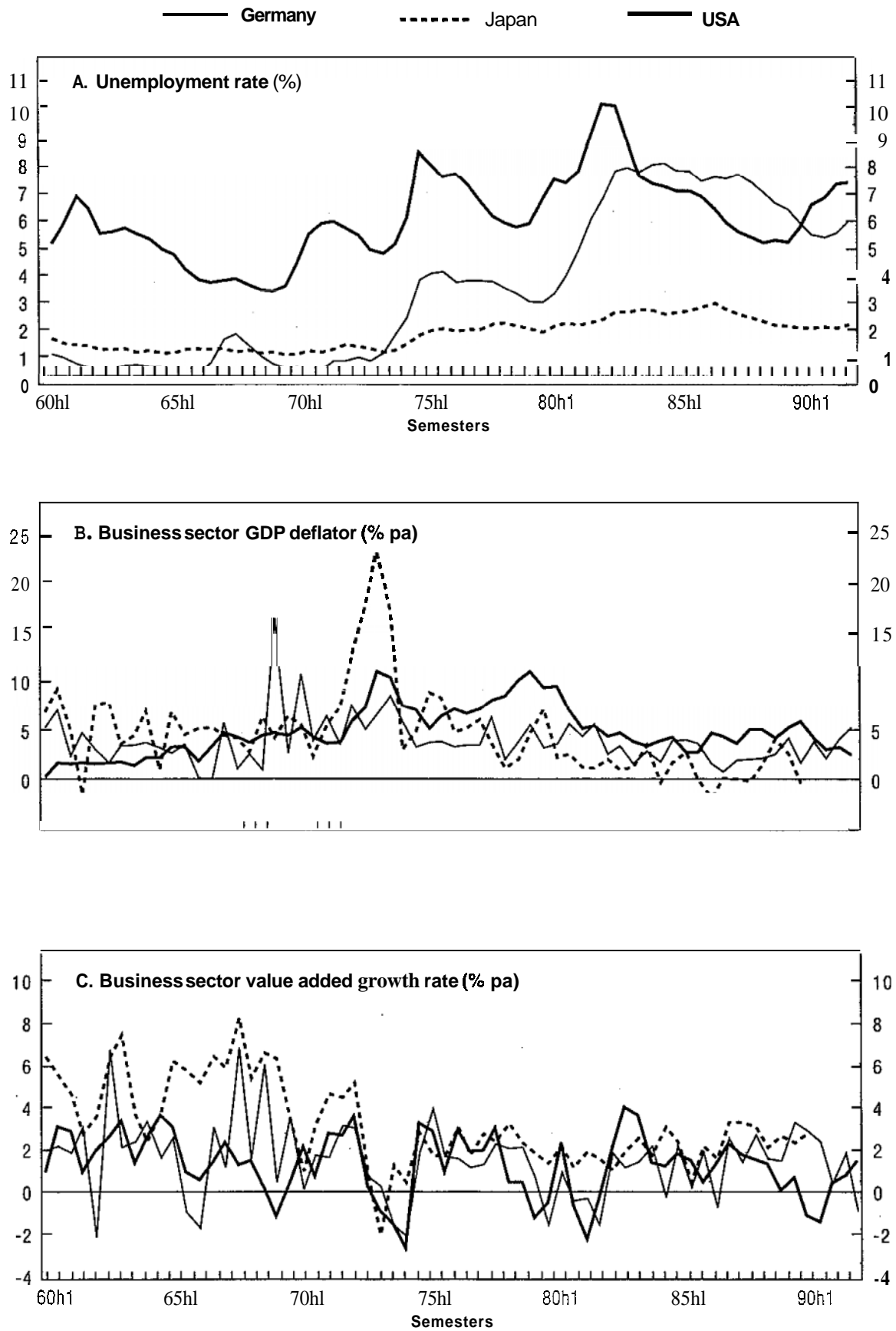
CONTENTS

INTRODUCTION

The continued upward trend in unemployment in the OECD area raises important questions about what policies can do to improve the overall employment situation and the prospects for growth and inflation, both in the short run and on a more durable basis. Although spurred by the sharp area-wide rise in unemployment associated with the current recession, such a question also has to be seen in the light of the events and empirical evidence that have emerged during recent decades. It is with a medium-term perspective that the problems of unemployment, inflation and slow growth in many OECD countries have come *to* be closely identified with structural features of the economy, particularly within labour markets and the supply sector, rather than trend or cyclical developments in the macroeconomy. In this context, various attempts have been made to explain the marked contrast between the different underlying levels of economic growth and unemployment in Japan, North America and Western Europe in terms of structural factors and corresponding degrees of supply and labour market flexibility.'

The extent of the divergence in trend and cyclical volatility in the three largest OECD economies (hereafter the G3) is well illustrated in Figures 1A to 1C, showing the respective movements in total unemployment, inflation and business sector output over the last three decades. Although unemployment has risen in all three countries, in many other respects, the experience has been very different. Increases in the unemployment rate have been smallest in Japan, with the average unemployment rate rising from 1.2 percentage points in the 1960s to 2.5 percentage points in the 1980s, with little cyclical component apparent.[2] By contrast, in Germany the average unemployment rate has risen from below 1 percentage point in the 1960s to around 7 percentage points in the 1980s, with a marked cycle superimposed on the rising underlying trend.[3] In the United States the cyclical component of unemployment is even more pronounced, although the trend rise is less dramatic with unemployment having risen from an average of 4.8 percentage points in the 1960s to 7.3 percentage points in the 1980s.

Against this background, this study attempts to shed light on a number of key factors contributing to these different developments by analysing the structural characteristics and simulation properties of three small macroeconometric models representing key elements of each of the G3 economies. As such it extends previous empirical work on the wage, price and supply adjustment in the OECD area, contributing in particular to the OECD INTERLINK model.[4]

Following the earlier approach of Helliwell and others, a common supply-side framework is adopted for the estimation and analysis of models of the process of

Figure 1. Unemployment, inflation and growth in the G3 economies
1960-1992

—— Germany   ------- Japan   —— USA

A. Unemployment rate (%)

B. Business sector GDP deflator (% pa)

C. Business sector value added growth rate (% pa)

Semesters

macroeconomic adjustment; one which is consistent with an underlying aggregate production function and which permits the identification of a unique equilibrium unemployment rate consistent with stable inflation.5 Although broadly neo-classical in terms of structural specification and equilibrium properties, the dynamic adjustment of output, employment and inflation to long-run equilibrium in this framework can be characterised as being essentially "New Keynesian" because of the presence of real and nominal rigidities in wage- and price-setting. In particular, such rigidities mean that following a shock to the economy there will be a potentially protracted period of adjustment before equilibrium is restored and hence persistence in output and employment disequilibria.6

Specific questions of policy importance are as follows:

- **Are there identifiable differences in rigidities in wage and price setting in the G3 countries?**
- **To what extent might these explain different degrees of responsiveness to demand and supply shocks, different patterns of cyclical adjustment and differing degrees of unemployment persistence?**
- **What is the extent and influence of real wage resistance in the G3 economies?**
- **Is there evidence of a systematic connection between poor productivity performance and trend developments in unemployment?**
- **What role is played by real interest rates in supply side adjustment and is there evidence of a systematic link between recent trends in the real cost of capital and unemployment?**

The rest of the paper is organised as follows. Section II describes the broad analytical framework and the structure of the empirical models considered. Section III then presents and discusses the evidence on the extent and influence of real and nominal rigidities in wage and price setting in each of the G3 economies. A set of recent empirical estimates are presented and compared with those from other studies. Model simulations are then used to illustrate how observed differences in these separate factors for the G3 countries may affect the dynamic response of their macroeconomies to demand and supply shocks. In Section IV the connection and possible influence of two further supply-related factors are explored – differences in trend growth of factor productivity and trend developments in the cost of capital. Section V provides a general summary of the analysis and key findings. Specific details of the econometric estimates of the key equations used in the analysis and the relevant technical derivations of model properties are given in Annexes 1 and 2 respectively.

I. THE ANALYTICAL FRAMEWORK

This section provides an overview of the basic model specification used in the analysis; one which is largely common to each of the G3 country models considered. It focuses particularly on the supply-side specification and its influence on

long-run model properties.[7] The specific econometric estimates referred to in the text are summarised in Annex 1.

A. The supply specification

The general model considered is one in which the production technology for the business sector is expressed in terms of a generalised two-factor (labour and capital) constant returns-to-scale CES production function. However, to the extent that the assumption of a unit elasticity of substitution cannot be rejected in estimating the model, then a further simplification is possible to a constant returns Cobb-Douglas specification. For the empirical estimates obtained in this study, this proves to be the case for both the United States and Germany and the supply-side specification outlined below is for the Cobb-Douglas case, since this considerably simplifies the exposition. For Japan a Cobb-Douglas restriction appears not to be statistically acceptable and so a CES technology with an elasticity of substitution of 0.40 is employed. However, none of the main results outlined here is affected by this difference.

Assuming business sector output (value added) is determined by a Cobb-Douglas technology then:

Output (value added)

$$q = \alpha (e + n + h) + (1 - \alpha) k \qquad [1]$$

where lower case letters denote logs and
q = output
n = employment
k = capital stock
e = labour efficiency
h = average hours worked
α = labour share parameter.

This form of production function divides total labour input into three distinct elements; the number of employees, average hours worked and "labour efficiency". The latter variable represents the degree of labour-augmenting, *i.e.* Harrod neutral, technical progress defined in terms of residual output growth over and above that explained by changes in the two primary factor inputs. In effect, the primary labour efficiency variable, e, is calculated as the set of residuals which ensure that equation [1] holds exactly.

"Normal" output, q^*, is then defined by the same production function expression, but substituting a smoothed value of labour efficiency, e^*, for e and a trend value of average hours, h^*, for h. On this basis a corresponding measure of capacity utilisation, CU, is defined by:

Capacity utilisation

$$CU = (q - q^*) \qquad [2]$$

Consistent with this production technology and assuming profit maximisation, the corresponding labour and capital demand equations can be defined to have long-run static solutions which, ignoring intercept and dynamic terms (which is done throughout the following analysis), are as follows:

Long-run demand for labour

$$(n + h) = q - wp \tag{3}$$

Long-run demand for capital

$$k = q - rp \tag{4}$$

where w = hourly wage costs
p = value added prices
wp = (w − p) = real wage costs
r = user-cost of capital
rp = (r − p) = real user-cost of capital

and the real user-cost of capital is defined in terms of the real price of investment goods adjusted for expected real interest rates (see Annex 1 for further details).

In analysing hours worked, empirical results suggest that hours are largely determined by non-economic factors in the long-run which can be readily proxied by time trends, although in the short-run they clearly also respond significantly to fluctuations in output and real wage costs.

Cost minimisation, subject to the constraints of the production technology, then gives an expression for average unit costs which, given constant returns to scale, are equal to marginal unit costs as follows:

$$cost = a\ (w - e^*) + (1 - a)r \tag{5}$$

In the long run, value-added prices are determined by unit costs subject to a mark-up which is assumed to be sensitive to demand pressure, as represented by a capacity utilisation term, CU.

Long-run value-added prices

$$p = cost + b_1\ CU \tag{6}$$

Real wages are assumed to be determined in a bargaining framework and, in the long run, depend on the level of trend labour productivity, pr^*, the unemployment rate, U, and a vector, x, of "exogenous" supply factors.[8]

Long-run real wages

$$(w - p) = pr^* - \gamma_1\ U + \delta x \tag{7}$$

By combining the long-run solutions to the wage, price and cost relationships given by equations [5] to [7], an expression for the long-run equilibrium unemployment rate, U^* is given by:

$$\gamma_1 U^* = (pr^* - e^*) + [(1 - \alpha)/\alpha]\ rp + (b_1/\alpha)\ CU + \delta x \tag{8}$$

However, as shown in Annex 2, the long run adjustment of factor demands also ensures that output coincides with normal output in the long run, so that CU = 0, and with a Cobb-Douglas technology the difference between trend labour efficiency and trend labour productivity is exactly $[(1 - \alpha)/\alpha]$ rp. Combined with equation [8], these conditions confirm the existence of a unique equilibrium unemployment rate in the long run, defined in terms of coefficients γ_1 and δ, and x, the vector of "exogenous" supply factors (together with various "omitted" constant terms).

The supply-side of the model is completed by labour force participation rate equations which incorporate time trends, taken as a proxy for social factors, with

additional effects coming from changes in employment and unemployment to capture so-called "discouraged worker" effects.

B. The demand specification

The models are completed with a set of relatively conventional equations for each of the main components of aggregate demand, as represented in the corresponding sectors and country blocks of the OECD INTERLINK model.[9]

Key elements of this part of the model include:

- consumption equations, relating the levels of real consumers' expenditure to real disposable income, real interest rates and the rate of inflation through a dynamic error-correction equation;
- housing investment, modelled as a function of real disposable income, real interest rates and real house prices;
- stockbuilding, modelled as functions of sales and real interest rates;
- aggregate goods and services import volumes, modelled as functions of total final expenditure and price competitiveness;
- aggregate goods and services export volumes, modelled as functions of world demand and export price competitiveness.

The form and role of the consumers expenditure equations are of particular importance in ensuring consistency of aggregate demand with the long-run supply-side equilibrium. A well-determined negative effect from inflation and real interest rates is found in each of the estimated equations, which ensures that if aggregate demand is high relative to supply (with unemployment below its equilibrium rate and/or output above its normal level) then the resulting upwards pressure on inflation and real interest rates leads to the crowding-out of consumption and convergence towards the supply-side equilibrium.

The model is closed through a series of equations linking real disposable income to GDP, consumer prices to a weighted average of import prices and the business sector value added deflator. Government expenditures are assumed to be exogenous in real terms.

II. DYNAMIC ADJUSTMENT AND THE ROLE OF REAL AND NOMINAL RIGIDITIES

A. Quantifying rigidities within the model structure

The long-run equilibrium properties of the model described in the previous section can in many respects be regarded as being broadly neo-classical. Nevertheless, following shocks to the economy, the presence of real and nominal rigidities in wage- and price-setting can be shown to lead to a potentially protracted period of adjustment before equilibrium is restored.

A high degree of real rigidity describes a situation where real wages and the mark-up of prices over costs respond little to changes in demand pressure.

Nominal rigidities arise when nominal wages and prices respond relatively slowly to changes in their determinants, and in particular respond slowly to each other. This section begins by setting out the dynamic form of the wage and price relationships and shows how estimated parameters (those described in Annex 1) can be used to provide comparable measures of real and nominal rigidities, specifically for the G3 economies. It is then shown that the cumulative disturbance to unemployment following various simulated shocks is a function of these parameters. Full derivations of these results are given in Annex 2.

For the purpose of simplifying the exposition, the analysis excludes all constant terms and assumes that the real user-cost of capital is constant throughout; the consequences of changes in this variable are considered explicitly in section IV **B.** On this assumption, the dynamic form of the price equation [6] can be represented as:[10]

$$p = (w - e^*) + \beta_1 \, CU - \beta_2 \, M \, w + \varepsilon_p \qquad\qquad [9]$$

where A denotes the first difference operator and the terms in minimised costs in [5] have been replaced by unit labour costs, $(w - e^*)$.

In equation [9], the $-\beta_2 \, M \, w$ term allows for nominal rigidities in the adjustment of prices to changes in wages, while also maintaining dynamic homogeneity of prices with respect to wage costs.[11] The larger the value of β_2 the more sluggish will be the adjustment of prices to wage costs. The parameter on the term in capacity utilisation, β_1, provides a measure of the responsiveness of prices to demand conditions. The smaller β_1, the greater will be the extent of real rigidity in price-setting. The final term, ε_p, represents an exogenous disturbance term.

Similarly, the dynamic form of the wage equation [7] can represented as:

$$(w - p) = pr^* - \gamma_1 \, U - \gamma_2 \, \Delta\Delta p + \gamma_3 \, Awedge + \varepsilon_w \qquad\qquad [10]$$

In equation [10], the $-\gamma_2 \, M \, p$ term allows for nominal rigidities in the adjustment of wages to a change in prices while maintaining dynamic homogeneity. The larger is γ_2, the greater the extent of nominal inertia in wage-setting. The unemployment rate parameter, γ_1, provides a measure of the responsiveness of wages to labour market conditions. The smaller is γ_1, the greater will be the extent of real rigidity in wage determination.

The term γ_3 A wedge is included as one of a number of possible supply-side variables represented by the vector "x" in equation [7].[12] Such a term allows for the possibility that real wages respond to changes in so called "wedge" factors. These are typically factors associated with "real wage resistance", measured in terms of those variables which intervene between real wage costs and the real consumption wage, such as taxes and real import prices.[13] The term, ε_w, is a disturbance term similar to ε_p in the price equation.

Given the estimated wage and price equations for the G3 economies summarised in Annex 1, Table 1 below provides a corresponding set of estimates of real and nominal rigidities.

The most important features of these results are as follows:[14]

– real rigidities are very low in Japan because of the high responsiveness of wages to unemployment;

Table 1. Real and nominal rigidities implied by the estimated wage and price equations

	Unemployment effect on wages γ_1	Capacity utilisation effect on prices β_1	Nominal rigidities		
			Prices β_2	Wages γ_2	Total $\gamma_2 + \beta_2$
United States	1.09	7.24	5.02	0.98	6.00
Japan	13.10	–	1.08	0.52	1.60
Germany	3.73	–	3.26	1.23	4.49

Notes: The above parameters are based on the equations reported in Tables A4 and A5 in Annex I, with long-run values calculated by dividing the relevant coefficients by the corresponding error-correction coefficients.

γ_1 is calculated from the unemployment rate coefficient in the wage equation (Table A5). For Japan, the unemployment rate variable is in log form and a further adjustment is made, dividing by the average unemployment rate over the estimation sample period.

β_1 is calculated from the capacity utilisation coefficient in the price equations (Table A4). An adjustment is made for the weight of labour in total costs (dividing by 0.68, 0.80 and 0.69 for the United States, Japan and Germany respectively – see Appendix I for explanation).

γ_2 is calculated from the sum of the M p variable coefficients in the wage equation (Table A5). This figure is also divided by four to convert from a semi-annual to an annual basis.

β_2 is calculated in a similar way to γ_2, but using the M w coefficients in the price equation (Table A4). A similar adjustment is made for the share of labour costs in total costs, as for β_1.

- conversely the responsiveness of wages to unemployment is low in the United States, although price-setting is more responsive to demand conditions;
- the responsiveness of wages to unemployment in Germany, lies somewhere between those of Japan and the United States;
- nominal rigidities are relatively high for the United States and Germany, but comparatively low in Japan;
- in all cases, nominal inertia is greater in price-setting than wage-setting.

B. Adjustment to demand disturbances

To illustrate the role of these factors in the processes of adjustment to demand shocks, Figures 2A to 2C report the effects on unemployment, inflation and GDP for each of the G3 countries obtained for a simulated increase in an exogenous component of demand equivalent to 1 per cent of **real** GDP. In each of these simulations the initial increase in GDP and fall in unemployment are eventually entirely eliminated as higher inflation "crowds-out" aggregate demand. For simplicity, these simulations assume constant real interest rates and a constant real exchange rate so that in equilibrium inflation eventually stabilises at a new higher rate; one which is sufficient to provide the required reduction in aggregate demand and full crowding-out. The comparison of the adjustment process as between the individual G3 economies is however of more concern here than the long-run response itself, since the latter is largely a consequence of the monetary policy assumptions imposed on the model.[15]

Figure 2. The effect of a one per cent increase in real demand
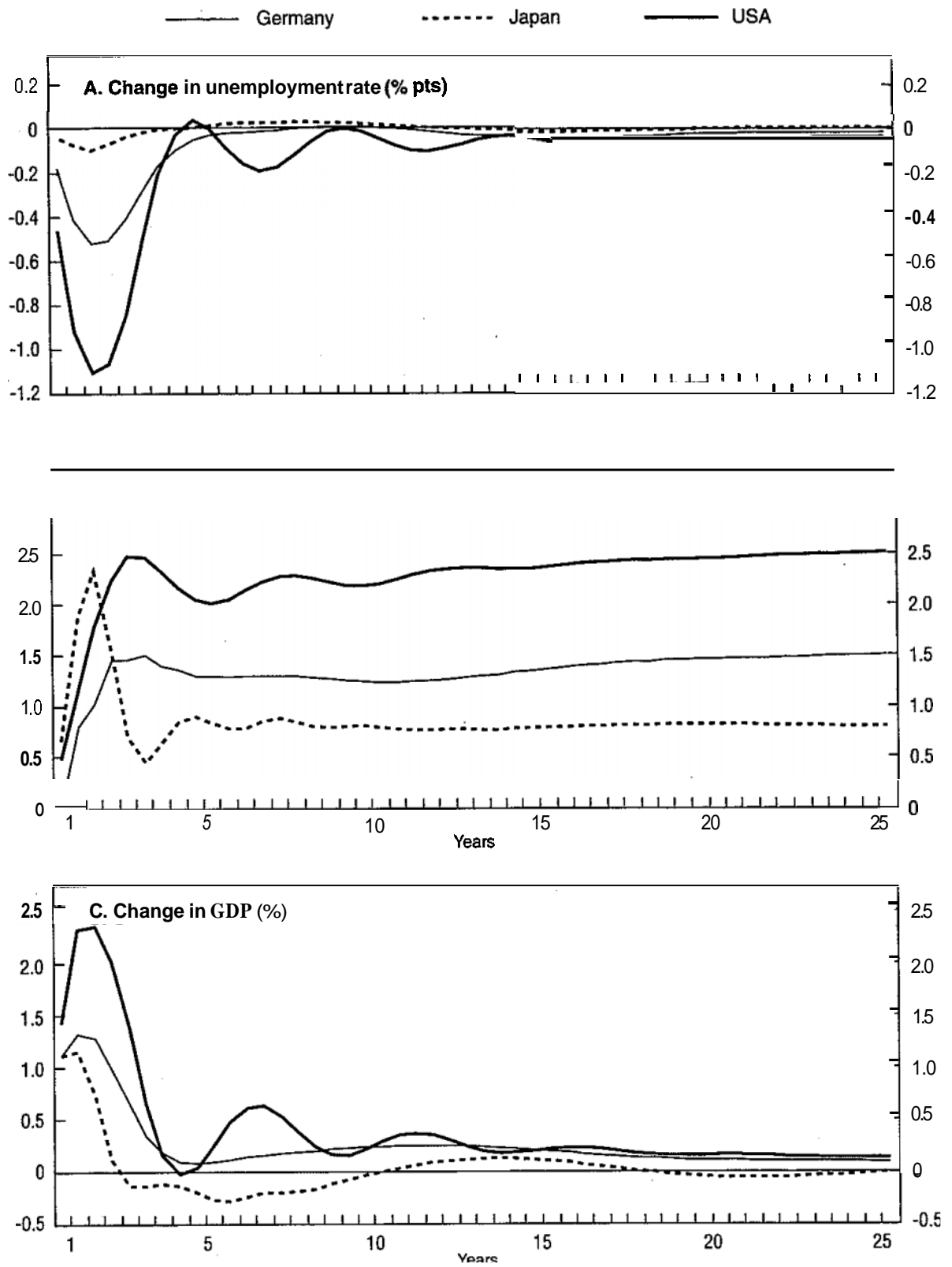
Germany ⸻ Japan ······ USA ⸻

A. Change in unemployment rate (% pts)

C. Change in GDP (%)

Note: All results are semi-annual observations expressed as differences from the baseline.

In understanding the different dynamic simulation responses shown for each of these models, a useful starting point is to consider an expression for the "sacrifice ratio", which measures the cumulative percentage point increase (decrease) in the unemployment rate, $\Sigma\, U$, required to bring about a one percentage point fall (increase) in the annual inflation rate, π, following a demand shock.[16] Given the above framework, an expression for the cumulative deviation of unemployment as the result of a demand shock can be obtained in terms of the final change in the steady state rate of inflation, π, and the parameters which represent the degrees of real and nominal rigidities in the wage and price equations as follows (see Annex 2 for the relevant derivation):

$$- \Sigma\, U = \left(\gamma_2 + \frac{\beta_2}{1 + \beta_1 \alpha} \right) \frac{\pi}{\gamma_1} \qquad [11]$$

so that the corresponding measure of the sacrifice ratio, $-\Sigma\, U/\pi$ is given by:

$$\frac{- \Sigma\, U}{\pi} = \left(\gamma_2 + \frac{\beta_2}{1 + \beta_1 \alpha} \right) \frac{1}{\gamma_1} \qquad [12]$$

Thus the greater the extent of both nominal rigidities (*i.e.* the larger γ_2 and β_2 are) and real rigidities (*i.e.* the larger $1/\beta_1$ and $1/\gamma_1$ are) the greater the sacrifice ratio.

Using the parameter estimates in Table 1, the corresponding estimates of the sacrifice ratio for Japan, Germany and the United States are given in the final column as 0.12, 1.20 and 1.68 respectively. Table 2 compares the estimates of the sacrifice ratio fom the present study with those derived from other studies. Although the form of the wage and price equations from which they are taken differs between studies, the interpretation of the sacrifice ratio remains the same. From these there appears to be broad agreement across studies with respect to the ranking of the sacrifice ratio across the G3 economies, *i.e.* from Japan as the lowest to the United States, the highest. There is also some agreement that the

Table 2. **A comparison of alternative sacrifice ratios estimates**

	This study	Layard *et al.* (1991)	OECD (1989)	Grubb *et al.* (1983)
United States	1.68	0.80	1.23	3.14
Japan	0.12	0.05	0.05	0.18
Germany	1.20	0.49	0.57	0.36
OECD Major 7		0.53	0.73	0.87

Notes: The sacrifice ratio corresponds to the cumulative disturbance to the unemployment rate (in percentage point years) following a shock to demand associated with a one percentage point per annum long-run change in the inflation rate. The estimates shown in the first column are calculated from the real and nominal rigidity parameter estimates reported in Table 1, using the following formula (see main text and Annex 2 for derivation):

Sacrifice Ratio = $\left(\gamma_2 + \dfrac{\beta_2}{1 + \beta_1 \alpha} \right) \dfrac{1}{\gamma_1}$

The estimates of Layard *et al.* (1991) are based on a similar form of analysis drawing on estimates of wage and price equations which also have long-run error correction formulations, whereas the estimates in the final two columns are based on coefficient estimates from Phillips curve type wage equations. The broad interpretation is nonetheless the same.

sacrifice ratio is very low for Japan *i.e.* below 0.2. The absolute value of the sacrifice ratio for the United States and Germany shows greater variation across the studies with the estimates from the present study being at the higher end of the range.

For a given final change in inflation the cumulative disturbance to unemployment is directly proportional to the sacrifice ratio. Thus in the demand shock simulations, the greater disturbance to unemployment shown in Figure 2 for the United States compared with Germany and, more notably, with Japan, is a reflection of the ranking of the estimates of real and nominal rigidities for each of these economies.

While the extent of nominal and real rigidities explain the cumulative size of the disturbance to unemployment before equilibrium is re-established, there are other factors concerning the short-term responsiveness of the labour market which also help to explain the differences in the amplitude of short-term changes in unemployment across the G3 country simulations.[17] The relatively high responsiveness of both the labour force to increased employment opportunities and average hours to output and the relatively low responsiveness of employment to output, are additional reasons why there is so little short-run variation in unemployment to the demand shock in Japan (see Table 3). Conversely the high responsiveness of employment to output helps to explain why the magnitude of the initial change in unemployment **is** comparatively large and volatile in the United States.

Additional reasons for the bigger short-term fall in unemployment in the United States relative to Germany concern the larger short-run output response. This is partly due to the smaller effect which any given percentage change in imports has in damping down the multiplier response in the United States, where imports are a much smaller proportion of total expenditure, relative to Germany. There are also

Table **3.** **Short-term labour market responsiveness to real demand shocks**

	Percentage increase in first year				Change in unemployment rate (percentage points)
	(1) output	(2) Hours	(3) Employment	(4) Labour force	
United States	2.32	0.55	1.44	0.32	-0.92
Japan	1.16	0.32	0.38	0.27	-0.08
Germany	1.32	0.20	0.59	0.10	-0.42

	Responsiveness of hours (2)/(1)	Responsiveness of employment (3)/(1)	Responsiveness of labour force (4)/(3)
United States	0.24	0.62	0.22
Japan	0.28	0.33	0.71
Germany	0.15	0.45	0.17

Note: This table reports the short-term responses of key labour market variables and output to an exogenous demand shock equivalent to a one per cent ex-ante increase in real GDP. The reported responses in the top half of the table are all expressed as percentage deviations from baseline, except for the unemployment rate, which are reported as changes in the percentage unemployment rate. The figures in the lower half of the table are calculated as various ratios of figures in the top half of the table.

Figure 3. The effect of a one per cent increase in nominal demand
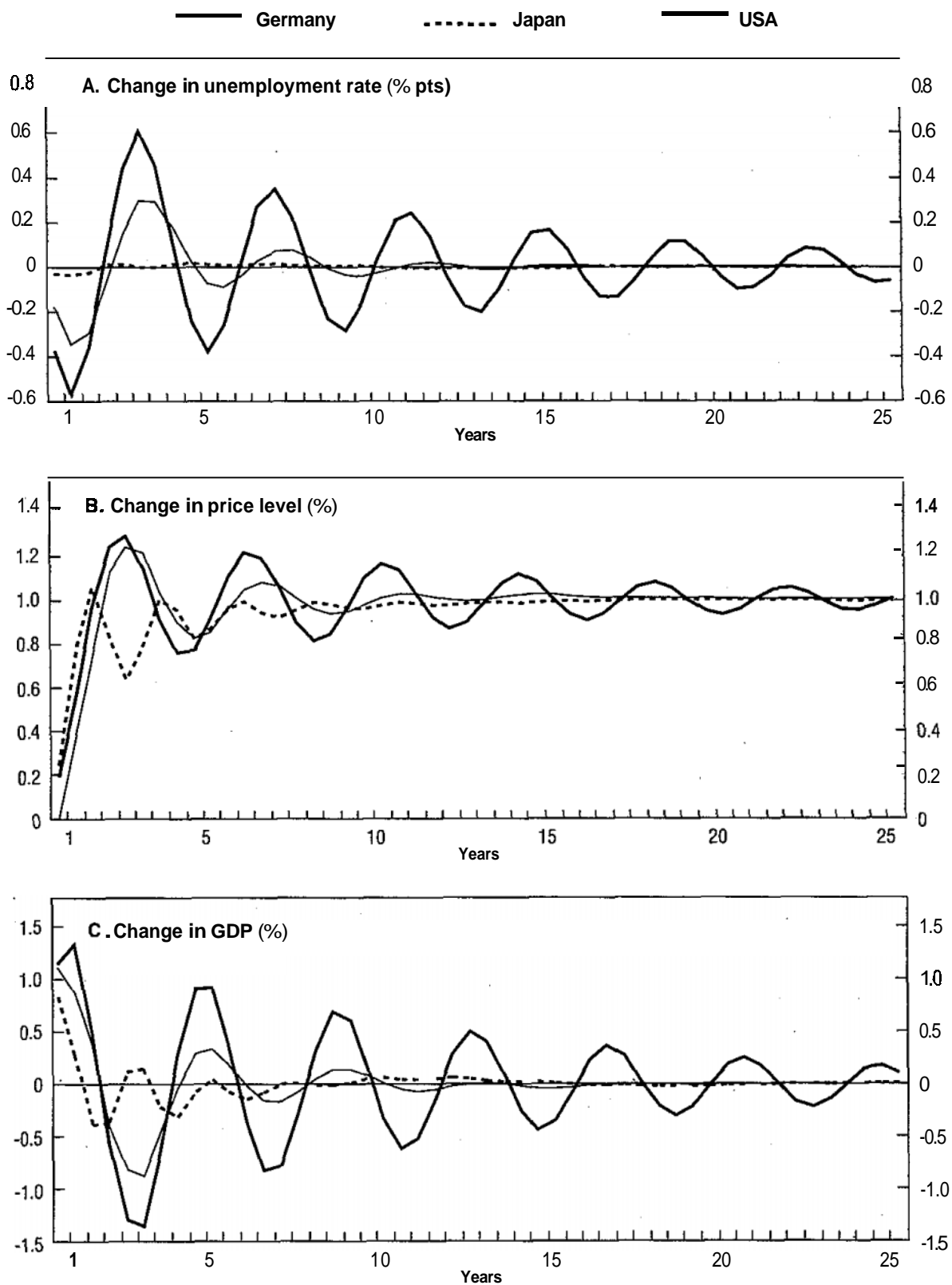
——— Germany   ······· Japan   ━━━ USA

A. Change in unemployment rate (% pts)

B. Change in price level (%)

C. Change in GDP (%)

Note: All results are semi-annual observations expressed as differences from the baseline.

larger contributions from stockbuilding and housing investment in the U.S. model. Variant simulations in which the standard U.S. consumption equation is replaced by once which includes the first difference term in the unemployment rate, reflecting possible consumer confidence effects, leads to even more pronounced cycles.

In Figures 3A to 3C an alternative form of demand shock is considered, namely an increase in an exogenous component of demand equivalent to 1 per cent of **nominal** GDP. In this case, as prices rise the magnitude of the shock to real demand is accordingly diminished. In the long-run there should be an increase in the price level by exactly 1 per cent with the real economy unchanged.[18]

The speed with which this new equilibrium is achieved is seen to be inversely related to the extent of nominal and real rigidities in wage- and price-setting. Thus in the case of Japan, equilibrium is achieved relatively quickly with very little disturbance to unemployment, whereas for both the United States and Germany the economy follows a series of damped cycles around the long-run equilibrium and full convergence is still not achieved even after twenty-five years in the case of the United States.

C. Adjustment to supply disturbances

The effects of supply disturbances can also be analysed in the same framework. In this context, the supply-shock is assumed to take the form of a disturbance to real wages or the price mark-up which is not caused by a change in demand conditions. Suppose for example there is an increase in "wage-push" pressure represented by the disturbance ε_w in the wage equation [10]. If the disturbance is permanent then the increased inflationary pressure will need to be offset by a rise in the unemployment rate which is given by combining the long-run solutions to the wage and price equations [9] and [10] thus:

$$U = \frac{\varepsilon_w}{}$$

[13]

Hence, the increase in the unemployment rate necessary to restore equilibrium is directly proportional to the degree of real wage rigidity $(1/\gamma_1)$ and the magnitude of the supply shock.

More generally, the inflationary effect of temporary supply shocks, represented by temporary changes in ε_w or ε_p, has to be counter-balanced by a period of higher unemployment and under-utilisation of capacity before equilibrium is restored, so that:

$$\Sigma \, \varepsilon_w + \Sigma \, \varepsilon_p = \gamma_1 \, \Sigma \, U - \beta_1 \, \Sigma \, CU$$

[14]

The cumulative disturbance to capacity utilisation, $\Sigma \, CU$, can be eliminated from [14] (see Annex 2), to give an expression for the cumulative disturbance to unemployment following a temporary supply shock as follows:

$$\Sigma \, U = \frac{1}{\gamma_1} \left(\Sigma \, \varepsilon_w + \frac{\Sigma \, \varepsilon_p}{1 + \alpha \, \beta_1} \right)$$

[15]

Thus the disturbance to unemployment following a supply shock increases with the degree of real rigidity $(1/\gamma_1$ and $1/\beta_1)$ in both wage- and price-setting.

102

Figures 4A to 4C illustrate further the effect of a temporary supply shock which raises **ex-ante** real wage costs by 1 per cent for a single period (one semester) for each of the G3 countries. In each case there is a temporary increase in inflation and unemployment, but both variables return to their base values by the end of the simulation period with the cumulative disturbance to unemployment before equilibrium is re-established again being proportional to the measure of real wage rigidity $(1/\gamma_1)$. Thus Japan, Germany and United States endure temporary increases in the unemployment rate equivalent to 0.04, 0.15 and 0.46 per cent point years respectively. Unlike the demand shock, however, the fluctuations in output for Japan are of similar magnitudes to those for Germany and the United States.

Wedge effects

A further form of supply shock allowed for in equation [10] is a change in the "wedge" between employers' real wage costs and employees' consumption wages. Here, the cumulative increase in unemployment before equilibrium is re-established due to a change in the wedge variable is given by:

$$\Sigma U = \frac{\gamma_3 \, \Delta wedge}{\gamma_1} \tag{16}$$
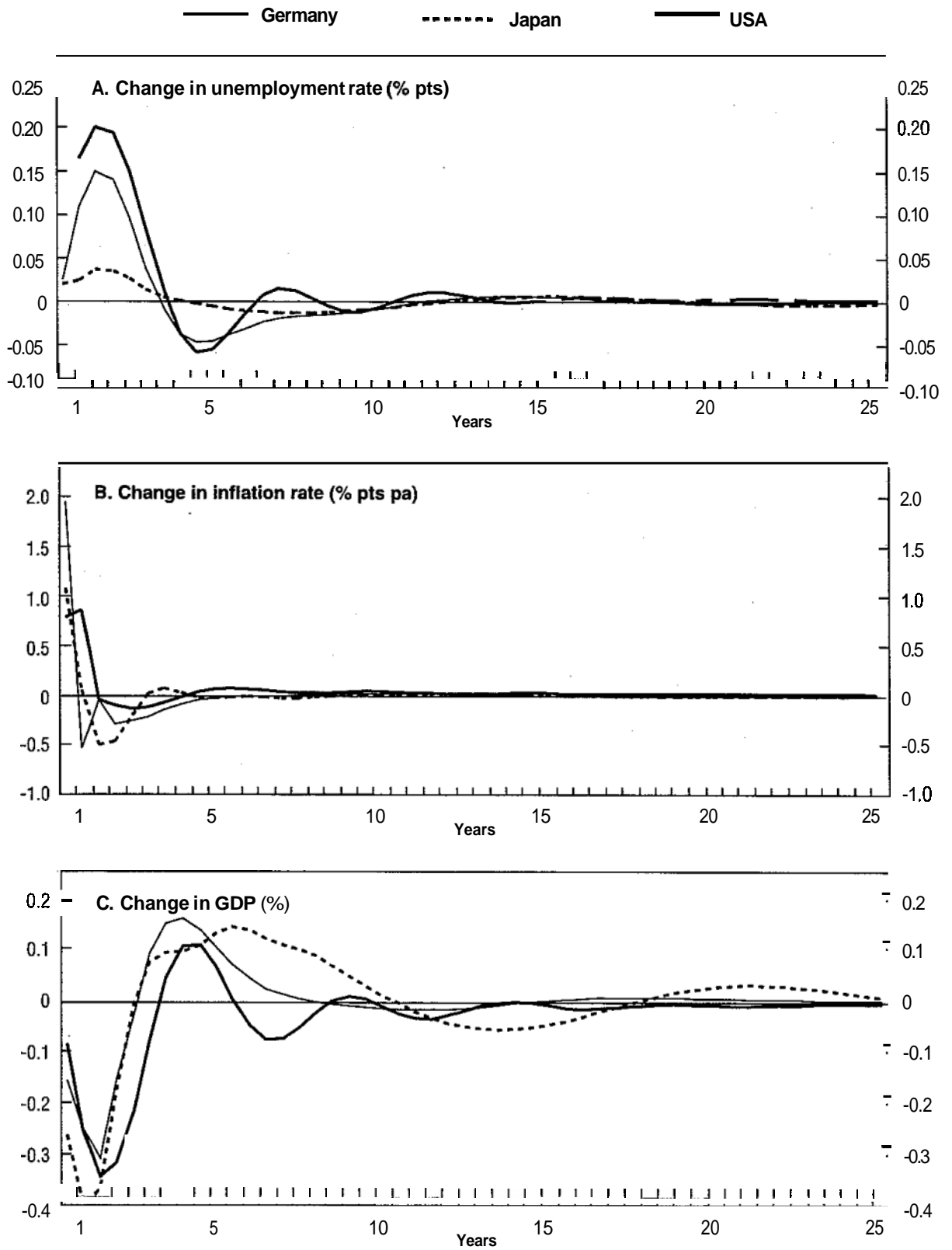
and is directly proportional to the measure of "real wage resistance", γ_3, the size of the change in the wedge variable and the measure of real wage rigidity, $(1/\gamma_1)$.

In the current study, the presence of such wedge effects has been tested for in each of the G3 wage equations by examining the significance of the inclusion of separate components of the "wedge" in both levels and first difference form. These include employers' taxes, indirect taxes and income taxes, import prices and in some cases the ratio of consumer prices to the value added deflator as a composite measure. Key movements in these variables for the G3 countries are illustrated in Figures 5A to 5C.

The estimation results reported in Annex 1 indicate no well determined and correctly signed effects from any of the wedge variables in **levels** form, suggesting that the wedge does not have any permanent effect on the equilibrium unemployment rate. The results obtained by including wedge variables in first difference form, are summarised in Table 4 below, and suggest that for both Japan and Germany such effects are small and not well determined.

For the United States a relatively strong and well determined effect from taxes on employers' wage costs and a weaker effect from consumer prices are found. Thus, although a one percentage point increase in the employers' tax rate may have no permanent effect on the equilibrium unemployment rate, the estimates imply that it will lead to a temporary rise equivalent to an additional 3.2 percentage point years of unemployment (see Table 4 for the basis of this calculation). This result and the relevant adjustment dynamics are illustrated by Figures 6A to 6C. Calculations of this sort suggest that the steady increase in employers' tax rate in the United States from the mid-1980s could account for a rise in the average U.S. unemployment rate of the order of 1½ percentage point.[19] The weaker effect from the wedge between consumer prices and the business sector value added deflator found in the U.S. wage equation, suggests that every one percentage point

Figure 4. The effect of a temporary supply shock
(ex-ante real wages raised by one per cent for one semester)

———— Germany   ------- Japan   ━━━━ USA

A. Change in unemployment rate (% pts)

B. Change in inflation rate (% pts pa)

C. Change in GDP (%)

Note: All results are semi-annual observations expressed as differences from the baseline

104

Figure 5. Wedge variables

A. Employers tax rate (%)[1]

B. Import price wedge (1970 S1 = 1.0)[2]

C. Consumer price wedge (1970 S1 = 1.0)[3]

Legend: Germany ———, Japan ------, USA ——
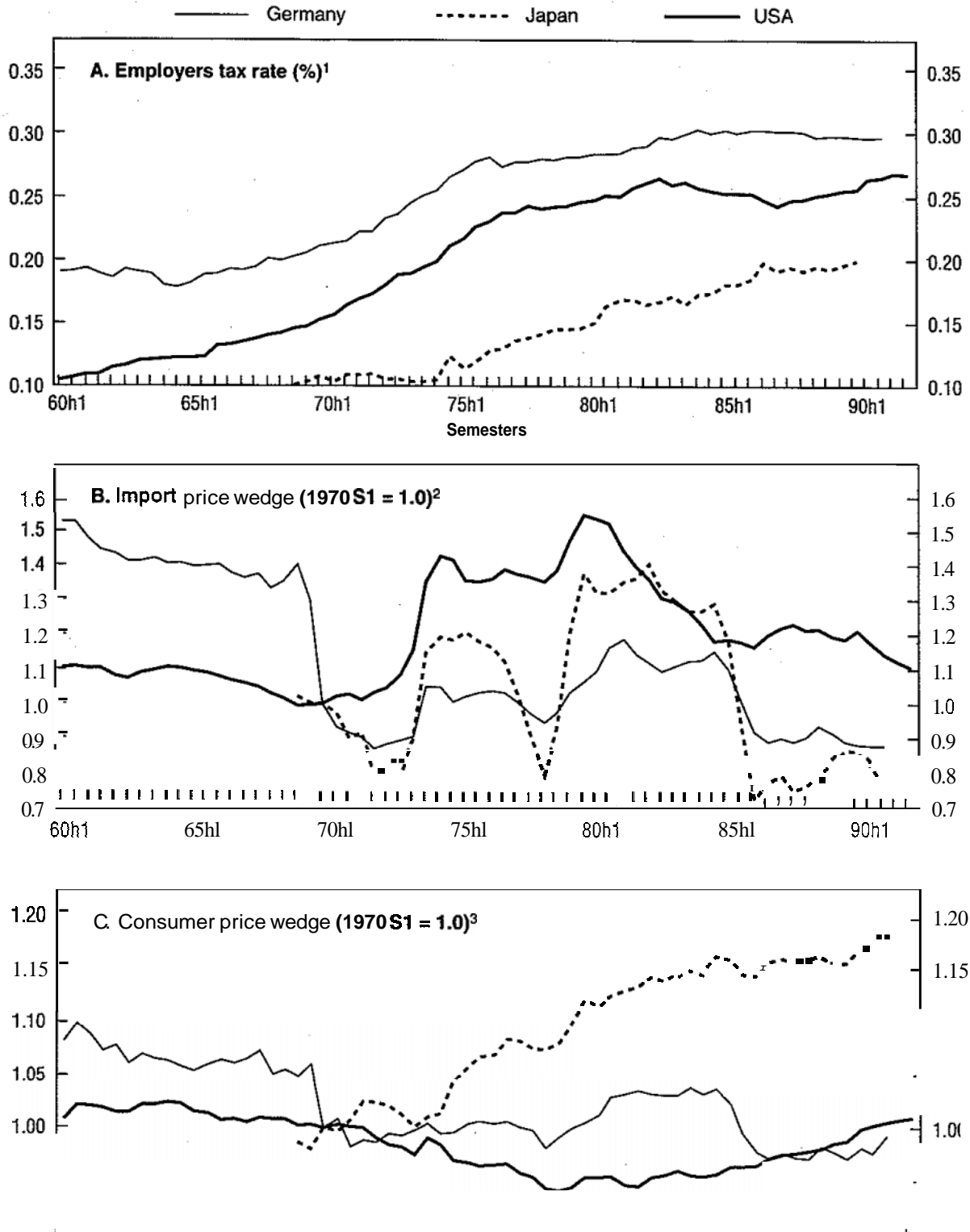
1. The employers tax wedge is the private sector compensation rate divided by the wage rate, minus one.
2. The import price wedge is the log of the real import price of goods and services, weighted by the share of imports in total final expenditures.
3. The consumer price wedge is the log of the ratio of the consumer price deflator *to* the business sector value added deflator.

105

**Figure 6.   The effect of an increase in the US tax rate
on employers wage cost by one percentage point**
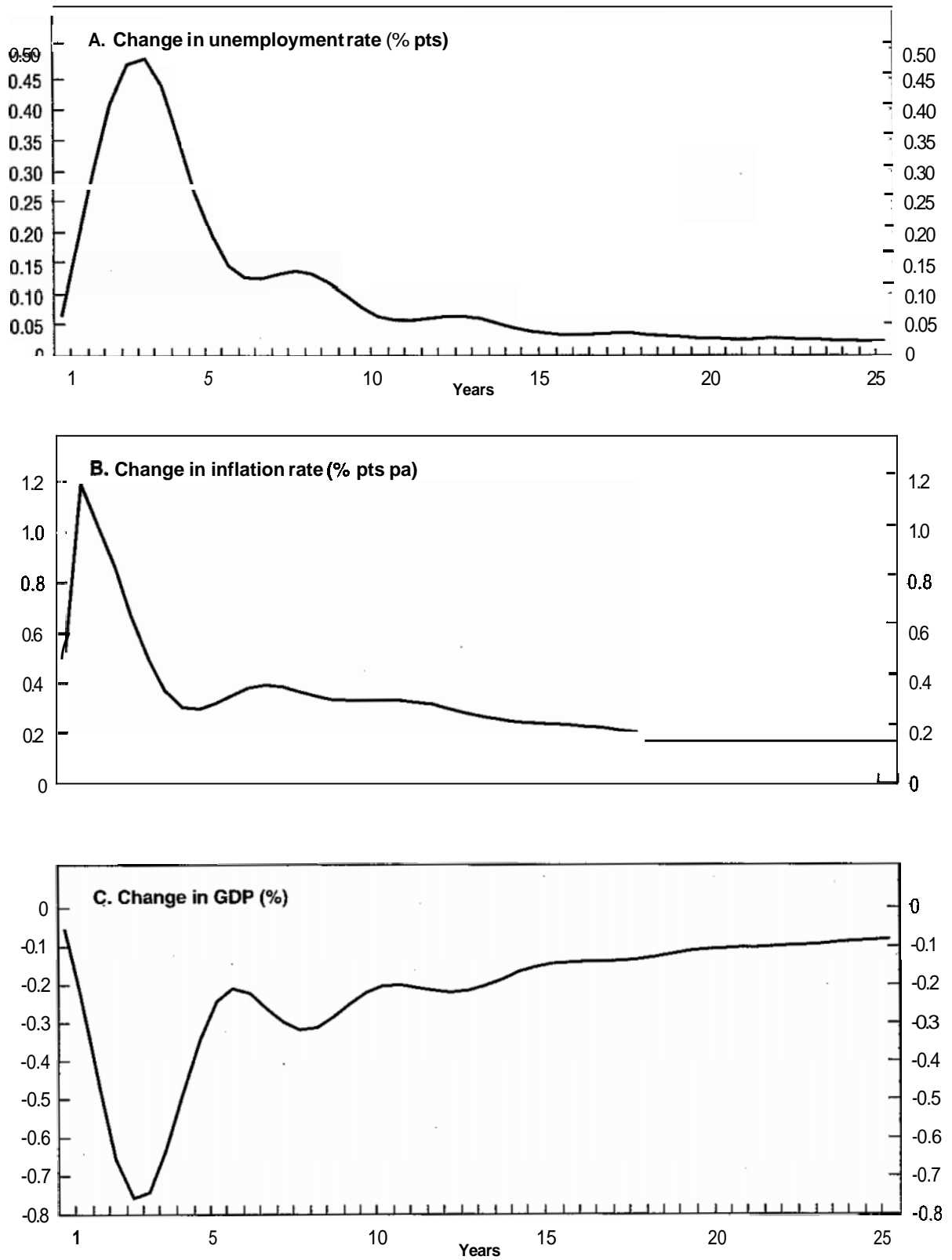
A. Change in unemployment rate (% pts)

B. **Change in inflation rate (% pts pa)**

C. Change in GDP (%)

Note: All results are semi-annual observations expressed as differences from the baseline.

Table 4. Real wage resistance effects in the G3 wage equations

	Wedge variable	Short-run coefficient	Long-run coefficient	Unemployment effect
United States	Employers' taxes	0.70 (3.4)	3.54 (2.0)	3.24
	Consumer prices	0.38 (2.5)	1.89 (1.3)	1.73
Japan	import prices	0.19 (1.5)	0.69 (1.3)	0.05*wt
	Employers' taxes	0.17 (0.6)	0.61 (0.6)	0.05
	Indirect taxes	0.30 (1.2)	1.08 (1.0)	0.08
Germany	Import prices	0.08 (0.6)	0.43 (0.6)	0.12*wt
	Employers' taxes	0.28 (0.8)	1.53 (0.8)	0.41
	Income taxes	0.25 (0.9)	1.39 (0.8)	0.37

Notes: T-ratios are reported in brackets.
Consumer and import price wedge effects are measured relative to the business sector GDP deflator. The import wedge effects are weighted by the volume of imports in total expenditure.
Short-run wedge coefficients relate to the estimated wedge effects in first difference form, see Table A5 in Annex 1.
Long-run coefficients are reported as the short-run coefficient divided by the error-correction coefficient, scaled also by two to convert from a semi-annual to an annual basis.
The "unemployment effect" corresponds to the temporary effect on unemployment of increasing the relevant wedge variable by one percentage point, measured in terms of the number of percentage point years. This is calculated as the long-run wedge effect multiplied by the real wage rigidity parameter $(1/\gamma_i)$ from Table 1. For the import price wedge this needs to be further multiplied by the weight (wt) of imports in total expenditure.

rise in consumer prices relative to the value added deflator temporarily raises unemployment by about 1.7 percentage point years.

The absence of any strong wedge effects for Germany should not, however, be regarded as being typical of other European economies. Preliminary estimation work not reported here as well as research by others, for example Layard *et a/. (op.cit.)*, suggest that for some other European economies, such as the United Kingdom and France, wedge effects are much stronger. The absence of any strong effects in Japan and Germany confirms the findings of Layard *et a/. (op. cit.,* see Table A2, Chapter 9). They also find only weak effects for the United Stales, but the difference with the present results may be accounted for by the fact that they do not attempt to distinguish between the effect of individual components of the wedge.

III. THE INFLUENCE OF OTHER SUPPLY FACTORS

A. Trend productivity and equilibrium unemployment

In most OECD economies, including those of the G3, there was a slowdown in productivity growth in the 1970s, occurring around the time of the first oil price shock (see Maddison, 1987) and the possible failure of wage aspirations to simultaneously moderate may be identified as a potential cause of rising unemployment over the period.[20] Such a mechanism was identified as being an impor-

tant explanation of the rise in OECD unemployment in work by Grubb, Jackman and Layard (1982, 1983). However, Bean (1993) in a more recent survey paper is critical of this work and argues that the overall conclusion from the existing literature must be that the productivity slowdown "has only a modest role to play in explaining the rise in unemployment".

To explore this issue within the present framework, the wage equation estimates have also been modified to allow for the possibility that wages adjust only sluggishly to changes in the level of trend productivity. Thus although the same long-run relationships are assumed to hold, equation [7] is amended to include an additional term in the rate of growth of trend productivity, $- \gamma_4 \Delta pr^*$, as follows:

$$(w - p) = pr^* - \gamma_1 U - \gamma_4 \Delta pr^*, \qquad 0 < \gamma_4 < 1 \qquad [17]$$

Assuming that prices are determined according to the cost minimisation rules described in equations [5] and [6], it can be shown that the equilibrium unemployment rate is dependent on the **growth rate** of trend productivity as follows:

$$U^* = \frac{- \gamma_4 \Delta pr^*}{\gamma_1} \qquad [18]$$

It should be emphasised that equation [18] does not predict any change in the equilibrium unemployment rate following a one-off change in the level of productivity, but only in respect of a **permanent** change in the **growth rate** of productivity. As noted recently by Manning (1992), "there is nothing theoretically absurd about claiming a link between the equilibrium unemployment rate and the rate of productivity growth as both these variables are probably bounded".[21]

In practice because the estimated wage equations take the more general dynamic form:

$$\Delta (w - p) = -\theta_1 (w - p - pr^*)_{-1} + \theta_2 \Delta pr^* + \dots \text{ other terms} \qquad [19]$$

the test for the neutrality of the equilibrium unemployment with respect to trend productivity growth is equivalent to testing the restriction $\theta_2 = 1$ (which is similar to a test of $\gamma_4 = 0$ in [17]) against the alternative that $0 < \theta_2 < 1$.[22]

The broad results of these tests can be summarised as follows.

For the United States the relevant coefficient is slightly greater, but insignificantly different from unity at the 10 per cent level, suggesting that productivity growth does not have a permanent effect on the equilibrium unemployment rate. For Japan, the coefficient θ_2 is about 0.5, although it is poorly determined (with a t-ratio of just over 1). The point estimate implies that every 1 percentage point slowdown in trend productivity growth rate raises the equilibrium unemployment rate by only about 0.1 percentage point. The reason that this effect is so small is that wages are very sensitive to unemployment (i.e. γ_1 is large in [18]).

However, for Germany the relevant coefficient is close to zero (which is imposed in the final equation) and significantly different from one at the 5 percent level. The preferred wage equation for Germany, therefore, suggests that the equilibrium unemployment rate is sensitive to the growth rate of trend productivity, such that each 1 percentage point per annum increase in trend productivity growth leads to a fall in the equilibrium unemployment rate of about 1.4 percentage point.

Figure 7. The effect of a one per cent fall in trend productivity
growth in Germany
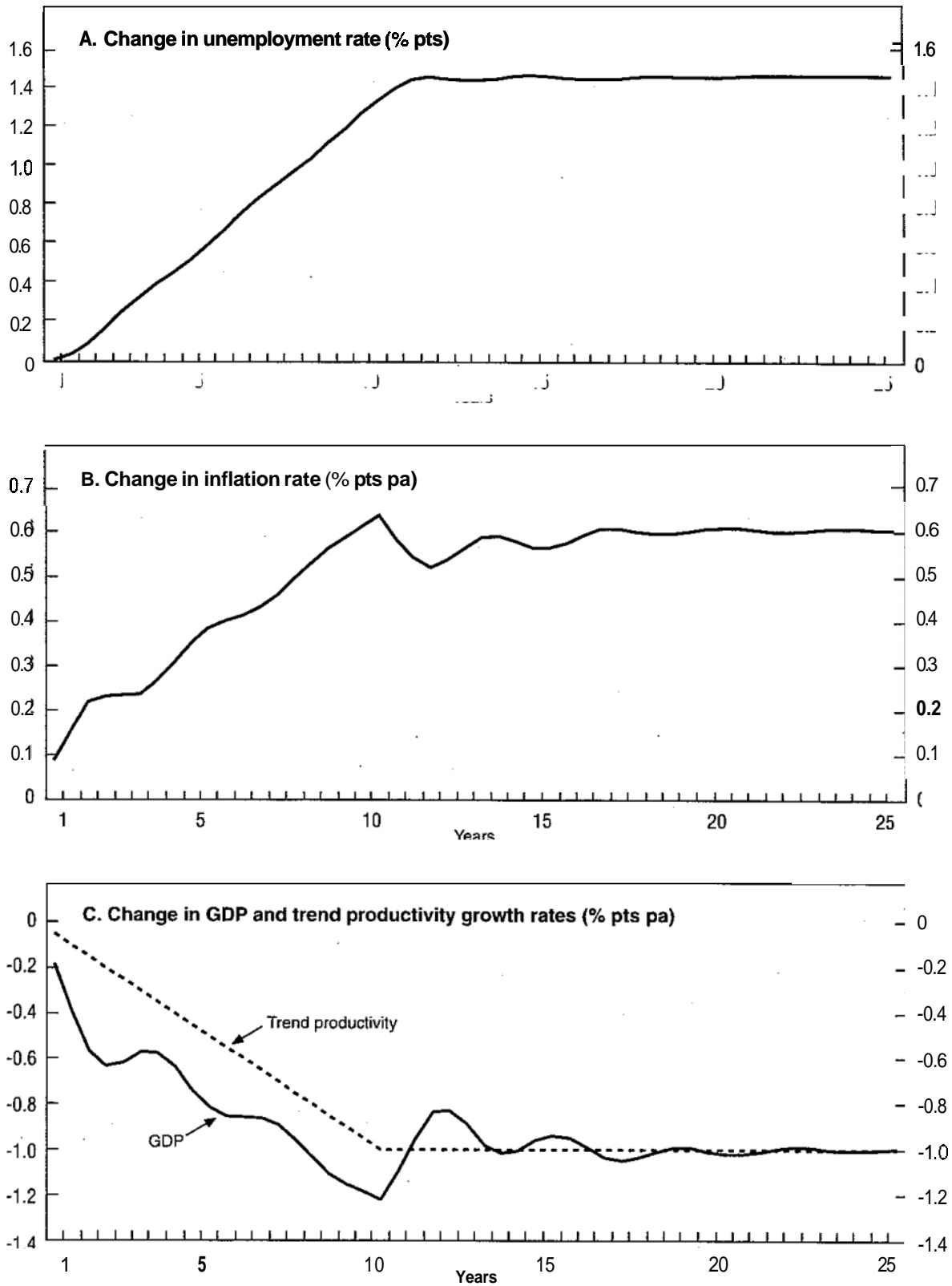
Note: All results are semi-annual observations expressed as differences from the baseline

109

The implications of this result are confirmed in simulations of a rise in trend labour productivity growth on the German model, as shown in Figures 7A to 7C. Here a permanent fall in the trend productivity growth rate of 1 percentage point per annum, phased in over a period of ten years leads to a rise in the unemployment rate by 1.4 percentage point with stable inflation and the GDP growth rate also permanently reduced by one percentage point.

Although the slowdown in trend productivity cannot easily be viewed as a wholly exogenous event, such estimates suggest that it may be an important factor in explaining recent trends in unemployment in Germany.[23]

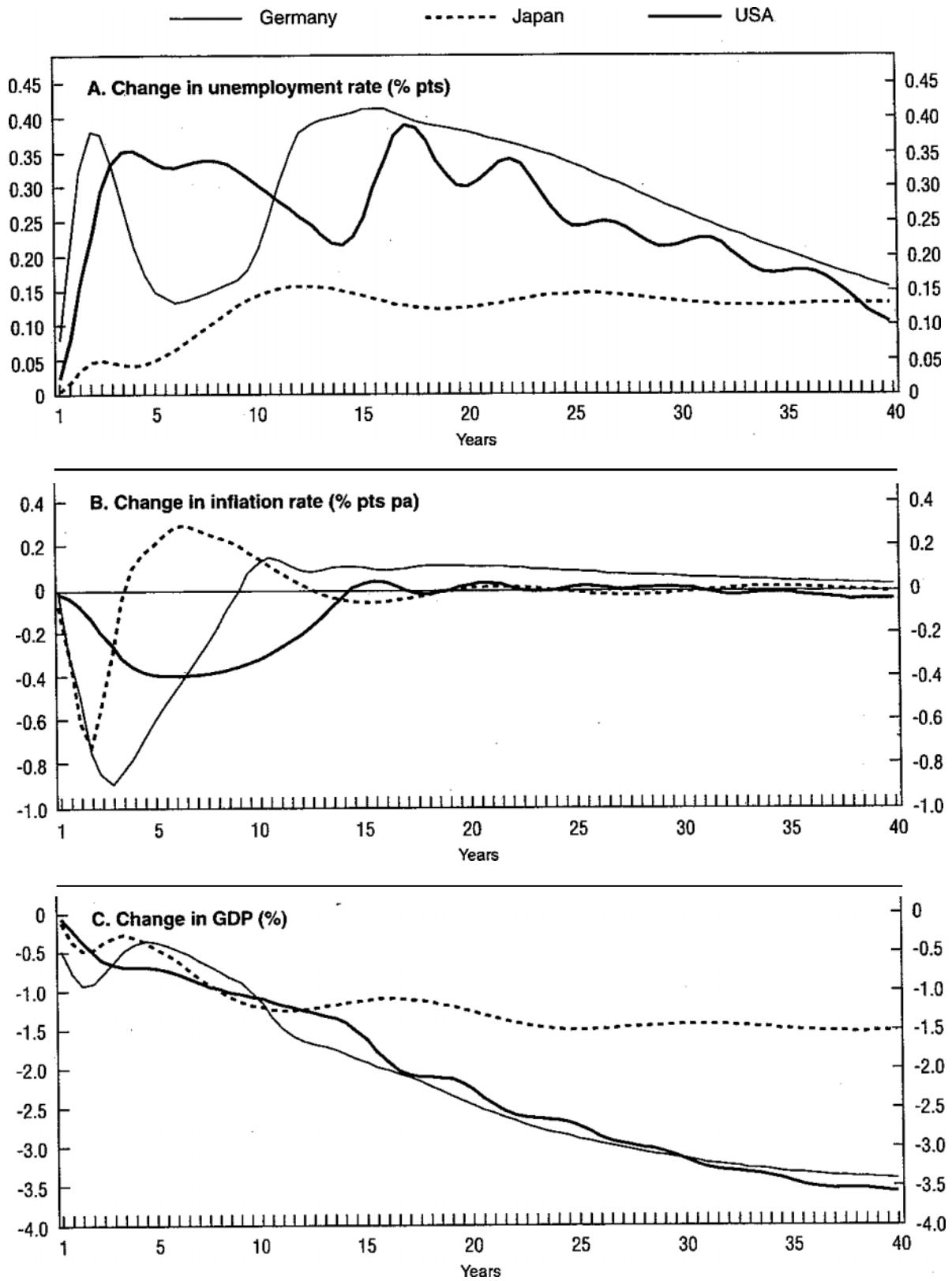## B. The effects of changes in the user-cost of capital

The coincidence of trend increases in unemployment with high and rising real interest rates in many European economies during the 1980s has led a number of researchers to suggest a possible connection. Although there are likely to be temporary effects from interest rates on unemployment acting via interest-sensitive components of demand, the empirical support for a transmission mechanism linking real interest rates and equilibrium unemployment is less clear and depends critically on the assumed forms of production technology and wage and price-setting.

Darby *et al.* (1992) examine the implications of a sustained rise in real interest rates for a vintage production technology. In this model the mark-up of prices over wages is related to marginal productivity, whereas real wages are dependent on average labour productivity. An increase in real interest rates thus temporarily increases marginal costs relative to average costs, through lower investment and the use of older vintages, and thereby raises the unemployment equilibrium. Prior restrictions within this model ensure that there is no long-run effect on equilibrium unemployment, but an empirical version of the same framework based on data for the United Kingdom suggests that the rise in real interest rates that occurred in the 1980s could have had temporary but prolonged effects. They further argue that such an effect is consistent with the observation that many European economies during the 1980s have experienced a combination of high unemployment and high capacity utilisation.

In a recent review of unemployment in Europe and the interaction between capital accumulation and unemployment [Dreze and Bean (1990)], the role of interest rates is not particularly highlighted. Rather, the possibility is considered that demand contraction in the earlier 1980s may have contributed to a large relative decline in capital accumulation, which, in turn, may have caused persistence in unemployment. Part of the problem here is finding robust empirical support for some of the crucial transmission mechanisms through which interest rates might influence equilibrium unemployment. For example, in the studies surveyed, no significant role could be found for interest rates in the measures of the user-cost of capital variable used to determine relative factor productivity. Similarly, the effects of high capacity utilisation on prices were typically found to be weak or non-existent.

However, a more direct route for real interest rates to influence long-run equilibrium unemployment, one explicitly incorporated in the models under con-

Figure 8.   The effect of a one per cent increase in
real interest rates

———— Germany   ------- Japan   ———— USA

A. Change in unemployment rate (% pts)

B. Change in inflation rate (% pts pa)

C. Change in GDP (%)

Note: All results are semi-annual observations expressed as differences from the baseline.

111

sideration here, is where the cost of capital enters directly into the determination of prices.[24] In such a model, an increase in the real user-cost of capital will tend to increase the mark-up of prices over wage costs and the implied deterioration in the real consumption wage may only be accepted by the workforce following a rise in the equilibrium level of unemployment. In the present framework, higher capital costs will lead to adverse supply-side responses on unemployment in the medium-term. But the deterioration in trend labour productivity, as the capital-labour ratio falls, also leads to a moderation in real wage aspirations ensuring that there is no permanent increase in unemployment in the long run.

To illustrate this point for the G3 countries, the effects of an increase in real interest rates are shown in Figures 8A to 8C. Here the simulation is for a 1 percentage point step increase in real interest rates, which gradually feeds through to increase the real user-cost of capital over time, with government expenditure being used as an instrument to ensure that inflation is unchanged in the long-run.[25]

Two features of these simulation results should be noted. Firstly, there is a cumulative increase in unemployment experienced by each economy despite the fact that there is no long term change in inflation. This should be contrasted with what would happen following a simple demand shock. Following a demand shock, if the inflation rate is unchanged in the long-run, any increase in unemployment would need to be counter-balanced by a corresponding period of lower unemployment, so that unemployment would also be unchanged on a cumulative basis. Secondly, the adjustment to long-run equilibrium is extremely protracted. This sluggishness is partly due to the long lag before the real user-cost of capital responds to real interest rates, but also reflects the slow speed of adjustment of both the capital stock and prices to changes in capital costs which emerge from the estimation results.[26] Thus the median lag between prices and capital costs varies between two years, for Japan, and five years, for the United States, compared with median lags between prices and wage costs of no more than one or two semesters.

Comparing results for individual countries, the model for Japan shows a smaller increase in unemployment than that of either the United States or Germany. This is because of lower real wage rigidity, which implies that a much smaller increase in unemployment is required to offset the inflationary pressure from higher capital costs. However, the increase in unemployment for Germany is quite similar to that for the United States, despite a higher real wage rigidity parameter. This feature is partly explained by the fact that wages in Germany are slower to adjust to the downturn in trend productivity than is the case for the United States, as highlighted in the previous section.

IV. SUMMARY CONCLUSIONS

The broad aim of this paper has been to examine to what extent the divergent behaviour of output, inflation and unemployment in the G3 countries can be explained by differences in real and nominal rigidities in wage and price formation

and more generally the different supply-side characteristics of these economies. The specific analysis shows that even in models which embody relatively standard neo-classical long-term equilibrium properties, dynamic adjustment may be a lengthy process and the presence of rigidities are likely to have important effects on the duration and size of disequilibria, notably so for labour markets and unemployment.

In this respect it is important to distinguish between the long-run effects of once-and-for-all changes in the *levels* of productivity, wedge variables and the real cost of capital and *dynamic* shocks to the growth rates of these variables. The model estimates presented here suggest that it is only the latter which may have a permanent effect on long-run unemployment, although for shocks in either form there may be a protracted period of adjustment.

Specific results of note are summarised in the following points:

- Real and nominal rigidities in wage and price setting appear to be much higher in the United States and Germany than Japan, reflected in correspondingly larger disturbances to the real economy following shocks to demand. In this respect, the United States seems most vulnerable to demand shocks, with the response of both output and unemployment following a more pronounced cyclical adjustment than for either Japan or Germany. This result is partly explained by the greater sensitivity of employment to demand in the United States, which may be contrasted with Japan, where a greater responsiveness of both average hours and the labour force to changes in labour demand dampens disturbances to unemployment. By the same token, the greater vulnerability of the U.S. economy to demand shocks may also imply a more effective role for conventional demand management policies.
- There are particularly marked differences in real rigidities in wage determination across the G3 countries, with wages being most sensitive to unemployment in Japan and least sensitive in the United States. Following a temporary supply shock which raises wages independently of demand conditions, the disturbance *to* unemployment is shown to be directly related to such measures of real rigidity in the labour market.
- The extent of "real wage resistance" following changes in the "wedge" between firms' real wage costs and the employees' real consumption wage is investigated as a possible source of supply shocks. Little evidence is found of any large real wage resistance effects for any of the G3 economies, with the exception of an effect from taxes on employers' wage costs in the United States. The estimates obtained, however, suggest that, although a one-off change in the tax rate on employers' wage costs does not have any permanent effect on the equilibrium unemployment rate, the continued rise in this tax rate since the mid-1960's, could account for as much as 1½ percentage point of the rise in the average unemployment rate over the period.
- There is evidence that the equilibrium unemployment rate may be sensitive to the rate of the trend productivity growth in Germany, but negligibly so for either Japan or the United States.
- There is also evidence of an adverse effect of the real cost of capital on unemployment. Although within the present model framework, there **is** no evidence of a permanent effect on the equilibrium rate of unemployment,

the estimation results suggest extremely long adjustment periods and hence the scope for temporary, but sustained effects. These results depend however on estimated speeds of capital stock adjustment which are notoriously difficult to identify empirically. As in the case of other supply-side shocks, the presence of greater real rigidities for the United States and Germany imply much larger disturbances to output and employment than for Japan.

Given these estimated relationships, significant structural differences are apparent in wage and price setting which are both consistent with the statistical facts and replicate, in simulation, the "stylised" characteristics of macroeconomic adjustment in the three economies. Although in some respects the results for western Germany are perhaps now less relevant given the major and ongoing upheaval of the economy since unification, many of the characteristics which are structurally different from those of either the United States and Japan appear also to be ones shared with the other European economies.[27] Whether these results can be generalised further for other OECD countries will, however, depend on further empirical work in this area.

NOTES

1. A general outline of this debate is given by Barbone and Poret (1989), Lawrence and Schultze (1987) and Dreze and Wyplosz (1988).

2. A detailed analysis and review of the trend and cyclical components of unemployment are given by Elmeskov and Pichelman (1993) – in this issue – and also Elmeskov (1993).

3. The period of analysis is primarily to the end of 1990 and the data set considered here is, therefore, that for western Germany.

4. Key references to the OECD INTERLINK model and related supply sector analyses include Richardson (1988), Helliwell *et al.* (1986) and Jarrett and Torres (1987).

5. In this respect, this study extends the empirical work previously reported in Turner (1992).

6. A central theme of New Keynesian economics is that the interaction of real and nominal rigidities are essential to understanding how an economy adjusts to shocks, see for example Mankiw and Romer (1991) and the survey of New Keynesian economics by Gordon (1990).

7. As Nickell (1988) observes: "It seems always worthwhile writing down the set of long-run solutions to all the supply-side equations in a model. Inconsistencies will thereby often be revealed and how levels of key variables are determined in the long-run will be quickly indicated. With many empirical macroeconometric models, the results of the exercise are often quite surprising."

8. A coefficient of unity on pr* in equation [7] is required to ensure that following a permanent shift in productivity growth, the wage-price system does not lead to indefinite increases or decreases in unemployment.

9. To simplify the analysis and computational task of simulating shocks over the very long run, each of the estimated G3 models is programmed in the form of a small linearised simulation model or "maquette". Each of these consists of the supply-side equations discussed earlier together with the main demand-side relationships for the G3 countries taken from the full INTERLINK system. Previous experience with maquettes of this form suggest that the simulation results provide a reasonably good approximation to the full system results for single countries. The maquettes do not, however, include the international linkage mechanisms of the full system.

10. In practice, more complex dynamic forms of price and wage relationships are likely to exist, but the specific forms adopted in equations [9] and [10] are sufficient to summarise the relevant features of the dynamic adjustment process without adding undue complexity.

11. Here, as in most macroeconometric models, the dynamic homogeneity of prices with respect to wages (and vice versa) is required to ensure neutrality of unemployment with respect to inflation.

12. The estimated wage relationships described in later sections also allow for the further possibility of sluggish adjustment to trend productivity. The influence of such a factor is discussed explicitly in Section IV.A.

13. In the literature on wage "bargaining" models such effects typically occur where firms are concerned with real wage costs whilst employees are concerned with real consumption wages (see for example Layard et *al.* (1991).

14. These estimates have many features in common with those calculated by Layard *et al.* (*op. cit.,* Table 2, Chapter 9) who find that Japan has the highest responsiveness of wages to unemployment of all the nineteen OECD countries analysed. The responsiveness of prices to demand conditions in the United States is found to be one of the highest amongst the OECD countries examined. In general nominal inertia is found to be greater in price-setting than in wage-setting.

15. The final increase in inflation in this case is proportional to the inverse of the semi-elasticity of aggregate demand to inflation. Alternatively if, for example, the simulations had been conducted with a fixed money rule rather than fixed real interest rates then the inflation rate would be unchanged in the long run. Use of such a policy assumption would also imply somewhat different short-term dynamics, although the ranking of unemployment disturbances between countries would essentially be unchanged.

16. In the following analysis, the notation Σ y is used to denote the cumulative deviation of variable y from its base values from the time of the impact of the shock to the time when the new equilibrium is established. Cumulative disturbances in unemployment are measured in "percentage point years", where one "percentage point year" would, for example, correspond to an increase in unemployment of one percentage point for the duration of one year, or an increase of one-half a percentage point for two years.

17. See Elmeskov and Pichelman (*op. cit.*) for conceptually similar measures of labour-market responsiveness relating to the G3 and other OECD economies.

18. The effects of such a nominal demand shock can be thought of as being comparable with those of a shift in money demand, which impacts fully on the price level whilst leaving real output unchanged in the long term.

19. The increase in the average unemployment rate is calculated as (14 x 3.2)/28, since there has been a rise in the employers' tax rate by about 14 percentage points from the beginning of 1965 to 1992 (28 years) and as shown in Table 4 each percentage point rise results in 3.2 percentage point years.of unemployment.

20. Such a view contrasts with the phenomena where **higher** productivity may be associated with short-term reductions in employment and thereby **higher** unemployment in the short-run, as workers are temporarily displaced.

21. Manning (1992) using a different framework finds evidence for the slowdown in productivity growth being an important explanation of the rise in unemployment in many OECD countries. The mechanism postulated is ihat when productivity growth is high, workers tend to moderate wage demands in order to increase the likelihood of being employed in the future, so as to earn higher future wages. The possibility of trend productivity entering directly into the wage relationship is also considered in previous OECD studies, see for example Chan Lee *et al.* (1987).

22. A similar dynamic homogeneity restriction has also been tested in the price equation. Thus having estimated the dynamic price equation represented by:

$$A\ (p - w + e^*) = -\lambda_1\ (p - cost)_{-1} + \lambda_2\ Ae^* + ...\ other\ tems \qquad [20]$$

the restriction that $\lambda_2 = 0$, which gives neutrality of the price-cost mark-up with respect to trend labour productivity/efficiency growth, is tested against the alternative that $0 < \lambda_2 < 1$. In the case of both Germany and the United States this coefficient is found to be small, wrongly signed and statistically insignificant. In the case of Japan the

coefficient, although correctly signed is statistically insignificant at the 5 per cent level and, therefore, excluded from the final preferred equation.

23. Since the 1960s there has been a slowdown in the trend productivity growth in Germany from about 5.6 per cent per annum to about 2.3 per cent per annum. On this basis, the present model estimates suggest a rise in the equilibrium unemployment rate of the order of $4\frac{1}{2}$ percentage points.

24. This is also a feature of previous OECD studies of the supply sector, as described by Helliwell *et al.* ($op.\,cit.$) and Jarrett and Torres ($op.\,cit.$).

25. These particular simulation results should only be regarded as illustrative, since they assume constant real exchange rates in spite of a change in real interest rates.

26. Extremely slow adjustment speeds for the capital stock are also noted in previous comparable studies, by Helliwell *et al.* ($op.\,cit.$) and Jarrett and Torres *(op.\,cit.)*. It is important to note that, even so, the levels of business investment are relatively responsive in the short run to changes in output and factor costs.

27. They may also be of significance for performance of the now unified German economy. To the extent that unification involves an adverse shock to the level of productivity and aggregate wages fail to adjust in the short-term, a more protracted period of adjustment during which unemployment increases, with little or no gains from lower inflation, may be experienced.

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Annex 1

ESTIMATION PROCEDURES AND RESULTS

This annex describes the empirical estimates of the various supply and wage/price equation components of the models described in section II of the main text and the parameters underpinning the various calculations and simulation results reported in sections III and IV. It includes descriptions of the modelling methods used in identifying the production function, factor demand, wage and price relationships, the relevant data definitions and sources and the relevant equation estimates and test statistics.

Labour demand and the production technology (Table A I)

In order to determine the underlying business sector production technology, an estimate of the elasticity of substitution is derived from estimates of the labour demand equation. Initially a series for labour efficiency is derived, assuming an underlying Cobb-Douglas production technology, and then smoothed using a Hodrick-Prescott filter to give a measure of trend labour efficiency. A dynamic version of the labour demand equation described by equation [3] in the main text is then estimated and the Cobb-Douglas restriction that the elasticity with respect to real wage costs is (minus) unity is tested. The resulting preferred equations are listed in Table A I.

On this basis, the Cobb-Douglas restriction was accepted for both the United States and Germany. For Japan, however, it was not and a grid search was conducted to find the elasticity of substitution consistent with the more general CES production function specification. Thus for a range of values of the elasticity of substitution, consistent measures of labour efficiency were derived individually and the labour demand equation re-estimated. The criteria for choice was based on the best-fitting labour demand equation and on this basis the preferred production technology was a CES form with an elasticity of substitution of 0.4. Though the likelihood surface is relatively flat in the range of plus or minus .05, a parameter value of 0.4 was clearly preferred to either **0.3** or 0.5.

Capital (investment) demand (Table A3)

Having determined the form of the production technology the long-run solution to the capital stock equation is imposed with the same elasticity of substitution within a more dynamic error correction functional form. The long-run error correction parameters in these equations, with the possible exception of the equation for the United States are typically not very well determined statistically, although the overall dynamic equations are relatively robust (see Table **A3).**

121

Average hours (Table A2)

For both Japan and the United States, average hours worked were first regressed in log form on a constant, time trend, logged time trend and the reciprocal of a time trend and the fitted values taken as measures of trend hours. Dynamic equations were then estimated in which the change in hours is explained by the change in output and real wage costs with the deviation of actual from trend hours specified as the error-correction term (see Table A2). For Germany the trend in average hours is simply captured by the inclusion of a single unlogged time trend in the dynamic equation.

Prices (Table A4)

The long run solution to the business sector price equations is imposed such that value-added prices are a mark-up on average unit costs measured to include capital costs, consistent with the form of the production technology i.e. the variable "cost". It is more common to consider prices as a mark-up on unit labour costs only, although testing of the final preferred equations, listed in Table A4, suggested that in all cases the total unit costs specification did at least as well as one which was soley a mark-up on unit labour costs. Only the price equation for the United States includes a mark-up effect from the *level* of capacity utilisation, although both the equations for Japan and Germany include dynamic effects from changes in capacity utilisation. The equation for Japan also includes a variable which measures the change in oil price inflation up until 1976 and is zero therafter. The significance of this variable suggests that there was a strong effect on prices in Japan from the first oil price shock, but that subsequent oil price shocks had much less impact. The price equation for the United States also includes a highly significant dummy variable for the first oil price shock.

Wages (Table A5)

The long-run error-correction solution to the wage equation is imposed so that real wages, defined in terms of employers' wage costs deflated by value added prices, rise in line with the level of trend productivity, see Table A5. A significant effect from the rate of unemployment is found in all equations. For Japan this enters in log form whereas in the equations for the United States and Germany it is unlogged. No correctly signed significant effects from the level of any wedge variable were found, although dynamic effects from various components of the wedge are included in each equation. For the United States, a specific dummy variable is included for the period 1989 H1 to account for a large outlier in the wage data derived from national accounts data, as used here, compared with conceptually similar measures of wages derived from survey data.

Labour force participation (Tables **A6** and A7)

Separate participation rate equations are estimated for male and females, with participation rates being explained by a combination of time trends, as proxies for demographic and social trends, and employment or unemployment variables to capture encouraged worker effects (see Tables A6 and A7). For all three countries the latter effects are found to be stronger in the case of females than for males.

Test statistics

All the reported equations were estimated by OLS methods.' The following test statistics were used to evaluate the properties, form and stability of estimated equations:

Serial correlation: A Lagrange multiplier test for up to second order serial correlation.

Functional form: Ramsey's RESET test using squared fitted values.

Normality: Jarque-Bera test of residual skewness and kurtosis

Heteroscedasticity: Based on the regression of squared residuals on squared fitted values.

Structural stability: A Chow test for structural stability, dividing the estimation period in half.

Predictive failure: Chow's second test test, estimating the equation over the full sample and a sample in which the last five observations are ommitted.

All these statistics have a Chi-square distribution with degrees of freedom given in brackets after the statistic. Failure of the test at the 10 per cent, 5 per cent and 1 per cent levels of significance is shown by "*", "**" and "***" respectively.

Variable definitions and sources

In the following variable definitions, lower case letters are used to denote logs, subscripts to denote lags and "A" the first difference operator. All data is semi-annual seasonally adjusted form and, with the exception of hours, taken from the OECD Analytical Data Base as used in conjunction with the INTERLINK model. The primary sources are in the main those of the relevant national authorities.

l = Business sector employment

q = Business sector value added output

k = Business sector capital stock

h = Index of average hours per regular employee, based on national sources as follows:

- Japan   : EPA index of average hours per regular employee, all industries;
- United States : index of aggregate weekly hours of production of non-supervisory workers on private non-farm payrolls by (total) industry;
- Germany   : product of DIW series of number of working days per person and DIW series of number of hours worked per person.

h^* = Trend hours. The fitted values from a regression of h on a constant, time trend, logged time trend and a reciprocal time trend.

e = Labour efficiency, constructed as residual output growth, i.e. that unexplained by the growth in person hours and the capital stock given the assumed form of production technology (see section II).

e' = Trend labour efficiency, is obtained by smoothing the labour efficiency index using a Hodrick-Prescott filter.

q^* = Normal output (see section II).

pr^* = Trend labour productivity, a smoothed version of actual labour productivity. For Germany and Japan $pr^* = (q^* - n - h^*)$. For the United States a Hodrick-Prescott filter of $(q^* - n - h^*)$ is used to eliminate the underlying cyclical pattern.

CU = Capacity utilisation index as measured by $q - q^*$.

123

w   = Nominal wage costs per hour.

P   = Business sector value added prices.

r   = Nominal user-cost of capital $p_i (\theta + i)$.

i   = A distributed lag of real long-term interest rates.

θ = A constant chosen to reflect the average rate of physical depreciation.

IRLR   = Real long-term interest rates (long-term interest rates less a moving average of current and past inflation).

wp   = Real wage costs per hour.

rp   = Real user-cost of capital.

p_i = Business sector investment price deflator.

cost   = Average unit costs, measured as:

$[a(w - e^*) + (1 - a)r]$, for the United States and Germany, where a is the wage share.

$\log [a^\sigma (W/E^*)^{(1 - \sigma)} + b^\sigma R^{(1 - \sigma)}]^{(1/1 - \sigma)}$, for Japan, where $\sigma = 0.4$ is the substitution elasticity, and a and b are production function scale parameters.

pc   = Consumer prices.

pm   = Import price of goods and services.

pme   = Imported price of energy.

UNR   = Unemployment rate.

PRM   = Male labour force participation rate.

PRF   = Female labour force participation rate.

TE   = Employers' tax rate.

TI   = Indirect tax rate.

TY   = Income tax rate.

TIME   = Time trend, increased by 1 each semester.

TIME84   = Time trend, increased by 1 each semester up to 1984 H2 and 0 thereafter.

DxxHy   = Denotes a dummy variable equal to 1 in the year 19xx semester y and zero elsewhere.

OPEC1   = Dummy equal to –1 in 1974 H1 and +1 in 1974 H2 and zero elsewhere.

S1   = Seasonal dummy equal to 1 in the first semester of each year.

NOTE

1. Re-estimation of the wage and price equations, which may be subject to simultaneity bias, using instrumental variable methods resulted in equations estimates which do not differ substantially from the equations reported here.

Table A1. Business sector employment equations

Dependant variable:	ΔI	ΔI	$\Delta(I + h)$
Countries:	Germany	Japan	United States
Estimation period:	61H1-91H2	70H1-91H2	65H1-92H2
Constant	-0.0244 (-2.88)	-0.3663 (-4.09)	-0.0331 (-2.17)
ΔI_{-1}	0.3231 (4.10)	–	–
$\Delta(I + h)_{-1}$	–	–	0.2419 (5.32)
	0.2291 (7.70)	0.2221 (4.56)	0.7090 (13.7)
Δq_{-1}	0.1252 (3.45)	0.0861 (1.86)	–
Δq_{-2}	–	0.1276 (2.85)	–
Δwp	–	-0.0812 (-2.19)	-0.3113 (-2.93)
Δe^*	-0.4636 (-4.72)	-0.6548 (-1.67)	–
ecm_{-1}	0.0738 (3.30)	0.0827 (4.07)	0.0820 (2.52)
D75H1	–	–	-0.0233 (-4.25)
SE of regression	0.00383	0.00335	0.00498
R–sqd	0.8215	0.6488	0.9128
Autocorrelation	0.82 (2)	2.71 (2)	1.31 (2)
Functional form	1.26 (1)	0.58 (1)	2.03 (1)
Normality	1.45 (2)	1.09 (2)	0.38 (2)
Heteroscedasticity	2.54 (1)	0.06 (1)	0.87 (1)
Predictive failure	4.75 (5)	1.15 (5)	2.06 (5)
Structural Stability	1.25 (6)	7.29 (7)	4.61 (5)

Note: The ecm variable is defined as $ecm = (q - I - h) - \sigma.wp - (1 - \sigma).e^*$, where the elasticity of substitution, σ, is **0.4** for Japan and is 1.0 for Germany and the United States.

125

Table **A2.** **Hours equations**

Dependant variable:	**Ah**		
Countries:	Germany	Japan	United States
Estimation period:	62H2-91H2	70H1-91H2	65H1-92H2
Constant	1.4662 (2.79)	−0.0037 (−2.01)	−0.0029 (−3.92)
Δh_{-1}	−0.5270 (−3.69)		0.1713 (2.44)
	0.1313 (2.25)	0.3133 (5.01)	0.2250 (6.80)
Δq_{-1}	0.1341 (1.80)	−	−
Δwp	−	−0.1742 (−3.77)	−0.2220 (−3.75)
Δwp_{-1}	−0.2816 (−2.04)	−0.1009 (−2.28)	−
h_{-1}	−0.3040 (−2.79)	−	−
TIME/100	−0.1414 (−2.92)	−	−
$(h - h^*)_{-1}$		−0.1463 (−2.77)	−0.2085 (−3.57)
$OPEC1_{-2}$	−	−	0.0082 (2.74)
SE of regression	0.00807	0.00528	0.00278
R-sqd	0.4199	0.5702	0.8266
Autocorrelation	5.20 (2)$'$	2.28 (2)	3.65 (2)
Functional form	0.01 (1)	0.65 (1)	3.80 (1)$'$
Normality	1.14 (2)	0.68 (2)	1.70 (2)
Heteroscedasticity	2.12 (1)	4.05 (1)$''$	0.94 (1)
Predictive failure	8.06 (5)	10.60 (5)$'$	12.30 (5)$''$
Structural Stability	11.90 (7)	5.00 (5)	6.87 (5)

126

Table A3.   Capital stock equations

Dependant variable:	Ak		
Countries:	Germany	Japan	United States
Estimation period:	62H1–91H2	70H1–91H2	65H1–92H2
Constant	-0.0025 (−1.02)	0.0019 (2.13)	-0.0020 (−2.00)
Δk_{-1}	1.0500 (19.9)	1.2291 (11.8)	1.5536 (11.2)
$A k_2$	–	-0.6720 (-4.13)	-0.6227 (−2.93)
Δk_{-3}	-0.1605 (−3.67)	0.6160 (3.74)	−0.1908 (−1.15)
Δk_{-4}	–	−0.3318 (−3.62)	0.1709 (2.03)
	0.0601 (10.1)	0.0984 (7.01)	0.0569 (8.76)
Δq_{-1}	-0.0182 (−1.82)	–	–
DIRLR/100	-0.0653 (−3.85)	-0.0249 (−2.03)	–
$(q - k_{-1} - \sigma rp)_{-1}$	0.0032 (1.21)	0.0052 (1.22)	0.0026 (2.15)
D73H2	–	0.0036 (3.20)	–
SE of regression	0.00077	0.00100	0.000596
R–sqd	0.9885	0.9921	0.9781
Autocorrelation	1.16 (2)	0.51 (2)	0.55 (2)
Functional form	2.23 (1)	2.45 (1)	0.09 (1)
Normality	4.55 (2)	0.85 (2)	1.82 (2)
Heteroscedasticity	2.40 (1)	3.05 (1)'	0.19 (1)
Predictive failure	3.26 (5)	6.65 (5)	4.15 *(5)*
Structural Stability	3.26 (5)	12.70 (8)	9.27 (8)

Table A4. Business sector value-added prices equations

Dependant variable:	$\Delta[p - (w - e^*)]$		
Countries:	Germany	Japan	United States
Estimation period:	61H2-91H2	70H2-91H2	66H2-92H2
Constant	0.0449 (1.70)	-0.0082 (-2.99)	0.0290 (1.83)
$\Delta[p - (w - e^*)]_{-1}$	–	0.4756 (3.15)	0.3435 (3.33)
$\Delta[p - (w - e^*)]_{-2}$	0.2616 (2.44)	–	–
$\Delta\Delta w$	-0.4462 (-5.13)	-0.5714 (-4.54)	-0.6779 (-7.26)
$\Delta\Delta w_{-1}$	-0.2260 (-2.67)	–	–
$(p - cost)_{-1}$	-0.0747 (-1.74)	-0.1655 (-3.03)	-0.0496 (-1.94)
$\Delta\Delta pme^*$	–	0.0427 (3.41)	
$\Delta\Delta pme^*_{-1}$	–	0.0364 (2.40)	–
ACU	–	0.0021 (1.26)	0.2065 (3.41)
ΔCU_{-1}	0.1195 (1.46)	0.0043 (2.45)	–
ΔCU_{-2}	–	0.0026 (1.47)	–
cu-1	–	–	0.2444 (5.70)
D74H2	–	–	0.0178 (4.15)
SE of regression	0.00825	0.00993	0.00405
R-sqd	0.4170	0.7842	0.7094
Autocorrelation	0.11 (2)	2.36 (2)	1.86 (2)
Functional form	0.38 (1)	0.52 (1)	0.00 (1)
Normality	4.05 (2)	1.17 (2)	1.62 (2)
Heteroscedasticity	6.54 (1)"	2.31 (1)	1.64 (1)
Predictive failure	0.89 (5)	4.26 (5)	1.79 (5)
Structural Stability	2.85 (6)	2.76 (7)	9.89 (6)

Table A5. **Wage equations**

Dependant variable:	$\Delta(w - p)$		
Countries:	**Germany**	**Japan**	**United States**
Estimation period:	61H2-91H2	70H2-91H2	65H1-92H2
Constant	-0.0032 (-0.20)	0.0046 (0.33)	-0.0337 (-1.75)
Δpr^*	0.0000	0.5564 (1.19)	1.0000
$\Delta(w - p - pr^*)_{-1}$	–	–	0.1863 (1.76)
$\Delta\Delta p$	-0.2173 (-2.22)	-0.2882 (-2.88)	-0.3920 (-3.15)
$\Delta\Delta p_{-1}$	-0.2306 (-2.37)	–	–
$(w - p - pr^*)_{-1}$	-0.0912 (-2.07)	-0.1392 (-2.81)	-0.0996 (-2.01)
u	–	-0.0383 (-3.47)	–
$U_{-1}/100$	-0.3402 (-6.77)	–	-0.1082 (-2.53)
$\Delta U_{-1}/100$	-0.7992 (-2.28)	.	–
ATE	0.2795 (0.85)	0.1700 (0.60)	0.7041 (3.39)
ΔTI	–	0.3012 (1.16)	–
ATY	0.2530 (0.92)	–	–
$wt\Delta(pm - p)$		0.1907 (1.51)	–
$wt\Delta(pm - p)_{-1}$	0.0789 (0.63)	–	–
$\Delta(pc - p)$		.	0.3763 (2.46)
OPEC1	–	0.0375 (5.84)	–
D89H1	–	–	-0.1884 (-3.75)
SE of regression	0.00919	0.00786	0.00492
R-sqd	0.5800	0.8732	0.5852
Autocorrelation	1.39 (2)	2.05 (2)	1.52 (2)
Functional form	0.25 (1)	0.85 (1)	0.33 (1)
Normality	1.87 (2)	0.05 (2)	0.25 (2)
Heteroscedasticity	2.67 (1)	0.94 (1)	0.69 (1)
Predictive failure	1.83 (5)	2.99 (5)	1.91 (5)
Structural Stability	2.12 (9)	7.61 (8)	13.40 (7)'

Table A6. Male labour force participation rate equations

Dependant variable:	APRM		
Countries:	Germany	Japan	United States
Estimation period:	64H1-90H2	70H1-91H2	70H1-91H2
Constant	0.0033 (1.12)	0.1103 (2.55)	0.2019 (3.18)
ΔPRM_{-1}	1.1164 (7.48)	–	
ΔPRM_{-2}	−0.8077 (−4.39)	–	–
ΔPRM_{-3}	0.3374 (2.42)	–	–
AI	0.0167 (1.04)	0.3448 (4.27)	–
DU/100	–	–	−0.1647 (−3.32)
PRM_{-1}	−0.0042 (−1.24)	−0.1161 (−2.45)	−0.2368 (−3.11)
TIME84/100	−0.0028 (−1.79)	–	–
$U_{-1}/100$	–	−0.3692 (−4.62)	−0.0915 (−3.45)
SE of regression	0.00134	0.00197	0.00210
R-sqd	0.7354	0.5005	0.3668
Autocorrelation	6.98 (2)″	3.28{2)	1.03 (2)
Functional form	0.81 (1)	0.01 (1)	0.03 (1)
Normality	1.81 (2)	0.05 (2)	12.20(2)···
Heteroscedasticity	2.72(1)·	4.18(1)··	0.76 (1)
Predictive failure	6.03 (5)	3.06 (5)	1.06 (5)
Structural Stability	11.80 (7)	3.67 (4)	1.04{4)

130

Table A7. Female labour force participation rate equations

Dependant variable:	APRF		
Countries:	Germany	Japan	United States
Estimation period:	63H2-90H2	70H1-90H2	62H1-91H2
Constant	0.0674 (3.17)	0.0413 (3.39)	−1.4183 (-4.87)
ΔPRF_{-2}	0.6080 (5.87)	–	–
ΔU	-0.0030 (−2.45)	–	–
ΔI	–	0.9028 (11.0)	0.1913 (5.68)
PRF_{-1}	−0.1450 (−3.00)	-0.0791 (−3.39)	-0.1724 (-4.70)
I_{-1}	–	–	0.0828 (4.87)
TIME/100	0.0339 (3.15)	0.0154 (3.39)	–
S1	-0.0067 (−2.65)	–	
SE of regression	0.00367	0.00201	0.00218
R-sqd	0.9173	0.8320	0.5193
Autocorrelation	4.14 (2)	0.34 (2)	1.25 (2)
Functional form	1.44 (1)	1.25 (1)	0.09 (1)
Normality	0.22 (2)	0.55 (2)	0.36 (2)
Heteroscedasticity	0.04 (1)	3.40 (1)'	2.70 (1)
Predictive failure	8.13 (5)	2.97 (5)	3.42 (5)
Structural Stability	5.33 (6)	4.65 (4)	1.68 (4)

131

Annex 2

MODEL STRUCTURE AND THE RELATIONSHIP BETWEEN UNEMPLOYMENT RESPONSES AND REAL AND NOMINAL RIGIDITIES

This annex provides a more detailed exposition of the underlying structure of the model outlined in section II and the derivation of the corresponding simulation properties related to unemployment equilibrium and adjustment described in section III. It also draws on the work of Layard *et al.* **(1991)**.

Since the analysis here is primarily concerned with the partial response of variables to exogenous shocks, those variables which are exogenous or are assumed to be unchanged are generally ignored, unless otherwise stated.

Model properties and unemployment equilibrium

Given the assumption of a Cobb-Douglas production technology, the long-run solutions to the factor demand equations for capital and labour are as follows (average hours worked are ignored here because in the long-run they are modelled as a trend):

$$n = q - wp \qquad [A.1]$$
$$k = q - rp \qquad [A.2]$$

where all lower case letters denote logs and

q = output
n = employment
k = capital stock
p = value added prices
w = hourly wage costs
r = user-cost of capital
$rp = r - p$, the real user cost of capital
$wp = w - p$, the real hourly wage cost

Normal output, q^*, is then defined as:

$$q^* = a (n + e') + (1 - a)k \qquad [A.3]$$

where

e^* = trend labour efficiency
a = labour share parameter

Capacity utilisation, CU, is then defined as the deviation of actual output from normal output:

$$CU = q - q^* \qquad [A.4]$$

In the long-run prices are assumed to be determined by unit costs subject to a mark-up which may be sensitive to changes in capacity utilisation, so that:

$$p = [a(w - e^*) + (1 - \alpha)r] + b_1 \, CU \qquad \text{[A.5]}$$

Real wages are assumed to be determined in a bargaining framework and, in the long run, depend on the level of trend labour productivity, pr^*, the unemployment rate, U, and a vector x of "exogenous" influences:

$$(w - p) = pr^* - \gamma_1 \, U + \delta \, x \qquad \text{[A.6]}$$

The wage and price equations given by [A.5] and [A.6], can then be combined to derive an expression for the equilibrium unemployment rate, U^*, of the following form:

$$\gamma_1 \, U^* = (pr^* - e^*) + [(1 - \alpha)/\alpha] \, rp + (b_1/\alpha) \, CU + \delta \, x \qquad \text{[A.7]}$$

At the same time however, the adjustment of factor demands and the form of the production technology ensures that two other important condition hold in the longer run.

Firstly, equations [A.1] – [A.4] can be combined to give:

$$CU = a \, wp - a \, e^* + (1 - \alpha) \, rp \qquad \text{[A.8]}$$

and the price equation [A.5] can also be rearranged as:

$$-b_1 \, CU = a \, wp - a \, e^* + (1 - a) \, rp \qquad \text{[A.9]}$$

Equating the right hand sides of [A.8] and [A.9] then shows that for any value of b_1 normal and actual output coincide so that capacity utilisation must be unchanged in the long-run, *i.e.* CU = 0.

Secondly, from the labour demand equation, [A.1], trend productivity, pr^*, is given by $pr^* = (y - n) = wp$. Substituting for wp in the right hand side of [A.8] and setting this equal to 0 (given that CU = 0 in the long run) gives, after rearranging:

$$(pr^* - e^*) = - [(1 - \alpha)/\alpha] \, rp \qquad \text{[A.10]}$$

i.e. the difference between trend labour efficiency and trend labour productivity is exactly $[(1 - \alpha)/\alpha] \, rp$.

Substituting these two conditions into [A.8] confirms that in the long run there is a unique equilibrium unemployment rate, *i.e.* such that U^* returns to a baseline value which can be defined in terms of the vector x of "exogenous" influences and coefficients γ_1 and δ (plus other intercept terms not included in this analysis), *i.e.*

$$U^* = \delta \, x/\gamma_1 \qquad \text{[A.11]}$$

Adjustment dynamics

Since the analysis below is primarily concerned with the partial responses to exogenous shocks, all variables are assumed to be expressed in terms of deviations from "baseline". The relevant intercept terms and those variables which are exogenous or are assumed to be unchanged are also ignored.

To analyse dynamic adjustment to the long run within the given framework, it is useful to consider more dynamic versions of the wage and price equations. Thus for prices, a convenient dynamic form of equation is:

$$p = [a(w - e) + (1 - a) \, r] + b_1 \, CU - b_2 \, \Delta\Delta w - b_3 \, \Delta\Delta r \qquad \text{[A.12]}$$

Here the addition of the terms $-b_2 \, \Delta\Delta w$ and $-b_3 \, \Delta\Delta r$ terms allow for nominal rigidities in the adjustment of prices to changes in wage and capital costs, while maintaining dynamic homogeneity. The larger b_2 and b_3 are, the more sluggish the adjustment of prices to costs.

Equation [A.12] can be further simplified to [A.13] if it is assumed that following the shocks considered below, the real user-cost of capital, $rp = (r - p)$, remains unchanged. Thus:

$$p = (w - e^*) + \beta_1 \, CU - \beta_2 \, \Delta w + \varepsilon_p \qquad [A.13]$$

where $\beta_1 = (b_1/\alpha)$ and $\beta_2 = (b_2/\alpha)$, where α represents the labour share in costs. The term, ε_p, is included to represent a supply shock which raises prices independently of any effect from demand conditions.

A dynamic form of the wage equation can similarly be represented as:

$$(w - p) = pr^* - \gamma_1 \, U - \gamma_2 \, \Delta\Delta p + \varepsilon_w \qquad [A.14]$$

where the $-\gamma_2 \, \Delta p$ term allows for nominal rigidities in the adjustment of wages to a change in prices while maintaining dynamic homogeneity. The final term, ε_w, is similar to ε_p in the price equation and is used below to represent the effect of a supply shock which raises wages independently of any effect from demand conditions. In practice there could be further lagged adjustment terms in both the wage and price equations which are ignored for simplicity of exposition.

The effects of a demand shock

Following a demand shock, in which wedge, e^*, pr^*, ε_w and ε_p are all assumed to be unchanged, the wage and price equations, [A.13] and [A.14], can be simplified and combined to give:

$$\beta_1 \, CU - \gamma_1 \, U = \beta_2 \, \Delta\Delta w + \gamma_2 \, \Delta\Delta p \qquad [A.15]$$

But, in long-run equilibrium price and wage inflation must be stable, *i.e.* Δw and Δp are unchanged, and as outlined above, the constraints on the factor demand equations ensure that CU is also unchanged. This implies that unemployment is also unchanged in long-run equilibrium.

Nevertheless, the demand shock will lead to a temporary reduction in unemployment and a permanent change in the steady state rate of inflation. From [A.15]:

$$\beta_1 \, \Sigma \, CU - \gamma_1 \, \Sigma \, U = \beta_2 \, \Sigma \, \Delta\Delta w + \gamma_2 \, \Sigma \, \Delta\Delta p \qquad [A.16]$$

where "$\Sigma \, y$" denotes the sum all deviations of variable y from its base values from the time of the impact of the shock to the time the new equilibrium is established. The sum of deviations of the change in wage and price inflation must be equal to the final change in the equilibrium inflation rate, π, which will be common to both wages and prices, thus:

$$\beta_1 \, \Sigma \, CU - \gamma_1 \, \Sigma \, U = (\gamma_2 + \beta_2) \, \pi \qquad [A.17]$$

The Sacrifice Ratio – indicating the cumulative percentage point increase (decrease) in the unemployment rate, $\Sigma \, U$, required to bring about a one percentage point fall (increase) in the annual inflation rate, π, following a demand shock – is derived analytically by substituting out $\Sigma \, CU$ from Equation [A.17] in terms of $\Sigma \, U$, π and the rigidity parameters in the wage and price equations.

To do this it is necessary to note that the dynamic versions of the factor demand equations can be represented as:

$$n = \theta_1(L) \, q - \theta_2(L) \, wp \qquad [A.18]$$

$$k = \theta_3(L) \, q - \theta_4(L) \, rp \qquad [A.19]$$

where $\theta_i(L)$ are polynomials in the lag operator L, such that $\theta_i(1) = 1$ for $i = 1$ to 4. Substituting for n and k from [A.18] and [A.19] into [A.4] and [A.5] and summing all deviations from the impact of the shock to the time of the new equilibrium gives:

$$\Sigma \, CU = [1 - a \, \theta_1(L) - (1 - a) \, \theta_3(L)] \, \Sigma \, q + a \, \theta_2(L) \, \Sigma \, wp + (1 - a) \, \theta_4(L) \, \Sigma \, rp \qquad [A.20]$$

135

However, noting that the real user-cost of capital is assumed unchanged and that the level of real wages eventually returns to its baseline value in the long run, this simplifies (setting $L = 1$) to:

$$\Sigma \, CU = \alpha \, \Sigma \, wp \qquad\qquad [A.21]$$

Performing the same operation of summing all deviations from the time of the shock to the time of the new equilibrium on the wage equation [A.13], gives:

$$\Sigma \, wp = - \gamma_1 \, \Sigma \, U - \gamma_2 \, \pi \qquad\qquad [A.22]$$

Then, eliminating $\Sigma \, wp$ from [A.21] and [A.22] and substituting for $\Sigma \, CU$ in [A.17], and re-arranging, gives the following expression for the sacrifice ratio:

$$\text{Sacrifice Ratio} = \frac{- \Sigma \, U}{\pi} = \left(\gamma_2 + \frac{\beta_2}{1 + \beta_1 \, \alpha} \right) \cdot \frac{1}{\gamma_1} \qquad\qquad [A.23]$$

If there is no long-run effect from capacity utilisation on pricing behaviours, *i.e.* $\beta_1 = 0$, then this expression simplifies to:

$$\text{Sacrifice Ratio} = \frac{- \Sigma \, U}{\pi} = \left(\frac{\gamma_2 + \beta_2}{\gamma_1} \right) \qquad\qquad [A.24]$$

Hence from equations [A.23] and [A.24] the cumulative disturbance to unemployment following a shock to demand for a given long-run change in the inflation rate, π, is shown to be a function of the nominal and real rigidity parameters in the wage and price equations.

The effect of a supply shock

The effect of a supply-shock is examined in terms of a disturbance to real-wages or the price mark-up which is not caused by a change in demand conditions.

Suppose for example there is an increase in "wage-push" pressure represented by a shock ε_w in the wage equation. If the disturbance is permanent then the increased "wage-push" pressure will need to be offset by a rise in the unemployment rate, which is given by combining the wage and price equations [A.13] and [A.14], (where wedge, e, and ε_p are all unchanged by assumption):

$$- \beta_1 \, CU + \gamma_1 \, U = - \beta_2 \, \Delta\Delta w - \gamma_2 \, \Delta\Delta p + \varepsilon_w \qquad\qquad [A.24]$$

However, in long-run equilibrium price and wage inflation must be stable (*i.e.* M w and M p are unchanged) and the constraints on the factor demand equations ensure that CU is also unchanged. Hence expression [A.24] implies that in long-run equilibrium the unemployment rate changes by an amount:

$$U = \frac{\varepsilon_w}{\gamma_1} \qquad\qquad [A.25]$$

Thus the increase in the unemployment rate necessary to restore equilibrium is directly propottional to the degree of real wage rigidity as represented by $(1/\gamma_1)$.

Similarly, if there is a temporary disturbance to wages, ε_w, or prices, ε_p, then there will be a temporary increase in unemployment, but with a total cumulative increase in unemployment before equilibrium is re-established. Thus from [A.24]:

$$- \beta_1 \, \Sigma \, CU + \gamma_1 \, \Sigma \, U = - \beta_2 \, \Sigma \, \Delta\Delta w - \gamma_2 \, \Sigma \, \Delta\Delta p + \Sigma \, \varepsilon_w + \Sigma \, \varepsilon_p \qquad\qquad [A.26]$$

But, if the shocks are temporary, then there will be no permanent change in the inflation rate and hence $\Sigma \, M \, w$ and $\Sigma \, M \, p$ will both be zero, hence:

$$- \beta_1 \, ZCU + \gamma_1 \, \Sigma \, U = \Sigma \, \varepsilon_w + \Sigma \, \varepsilon_p \qquad\qquad [A.27]$$

Taking the Σ operator through [A.13] and using [A.21] to eliminate Σ (p – w) gives the result:

$$\Sigma\ \text{CU} = -\frac{a.\ \Sigma\ \varepsilon_p}{1 + \beta_1\ \alpha} \qquad\qquad\qquad [\text{A.28}]$$

Then eliminating Σ CU from [A.27] using [A.28] gives, after rearranging, an expression for the cumulative disturbance to unemployment as follows:

$$\Sigma\ \text{U} = \frac{1}{\gamma_1}\left(\Sigma\ \varepsilon_w + \frac{\Sigma\ \varepsilon_p}{1 + \alpha\ \beta_1}\right) \qquad\qquad [\text{A,29}]$$

Thus the cumulative increase in the unemployment rate necessary to restore equilibrium increases with the degree of real rigidity as represented by $(1/\gamma_1)$ and $(1/\beta_1)$.