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MODELLING THE SUPPLY SIDE OF THE SEVEN MAJOR OECD ECONOMIES

by
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MODELLING THE SUPPLY SIDE OF THE SEVEN MAJOR OECD ECONOMIES

If a macroeconometric model is to be useful for policy analyses which go beyond short-term forecasting requirements, particular attention must be paid to the form and consistency of its various components with respect to longer-term equilibria. In particular, long-run properties and ultimate stability of such models with respect to output, employment and inflation depend crucially on the consistency and form of the supply-side specification.

This paper presents recent work by the OECD contributing to its INTERLINK world model. It focuses on the specification and estimation of the supply-side aspects of the sub-models for the seven major OECD Member countries. It presents a general analytical framework for the specification of a consistent model of business sector behaviour within a dynamic form which meets both short-term forecasting and longer-term theoretical requirements. Comparative estimation results are reported for individual economies along with simulation results for a number of demand and supply shocks which illustrate comparative properties. A number of key features and differences in short- to medium-term model properties are shown to be closely related to specific structural characteristics of the estimated supply-side relationships.

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Pour qu'un modèle macroéconométrique soit utile aux analyses de politique économique qui vont au delà des besoins des prévisions à court terme, on doit porter une attention particulière à la conformation et à la cohérence de ses différentes composantes eu égard aux équilibres de plus long terme. En particulier, les propriétés à long terme et la stabilité finale de tels modèles en ce qui concerne la production, l'emploi et l'inflation dépendent de façon cruciale de la cohérence et de la conformation des spécifications du secteur de l'offre.

Cet article présente les travaux récents menés par l'OCDE sur son modèle mondial INTERLINK. On y met l'accent sur les spécifications et les estimations concernant le secteur de l'offre des sous modèles pour les sept principaux pays Membres de l'OCDE. Il présente un cadre analytique général pour la spécification d'un modèle cohérent du comportement du secteur des entreprises sous un aspect dynamique, qui répond à la fois aux nécessités de la prévision à court terme et aux exigences théoriques à plus long terme. Les résultats d'estimations comparatives sont présentés pour les économies individuelles ainsi que les résultats d'un certain nombre de chocs de demande ou d'offre, qui illustrent les propriétés comparatives du modèle. On montre qu'un certain nombre de points clés et de différences dans les propriétés du modèle entre le court et le moyen terme, sont étroitement liés aux caractéristiques structurelles spécifiques des relations estimées pour le bloc de l'offre.

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MODELLING THE SUPPLY SIDE OF THE SEVEN MAJOR OECD ECONOMIES

Dave Turner, Pete Richardson and Sylvie Rauffet[1]

I. Introduction and Summary

This paper presents recent work by the OECD contributing to its INTERLINK world model. In particular it focuses on the specification and estimation of the supply-side aspects of the sub-models for the seven major OECD Member countries. It presents a general analytical framework for the specification of a consistent model of business sector behaviour within a dynamic form which meets both short-term forecasting and longer-term theoretical requirements. Comparative estimation results are reported for individual economies along with simulation results for a number of demand and supply shocks which illustrate comparative properties. A number of key features and differences in short- to medium-term model properties are shown to be closely related to specific structural characteristics of the estimated supply-side relationships

The background to the present study and the OECD INTERLINK model in general is given by Richardson (1988). Overall this model provides a representation of the world macro economy combining a set of small- to medium-sized semi-annual models -- one for each OECD Member country -- with reduced-form trade and balance-of-payments relationships for six non-OECD regional groups of economies. A key feature of the model is the treatment of the world economy as a coherent and integrated whole, with developments in individual domestic economies, international trade, exchange rates and financial flows determined on a globally-consistent basis. Considerable emphasis is therefore given to international economic linkages, through trade and financial conditions.

In the context of the OECD's regular macroeconomic analysis and projections exercises the model performs a variety of functions including: an aid to the construction and co-ordination of individual country projections, the production of globally-consistent trade projections and, increasingly, the preparation of alternative projections and scenarios through model-based simulation exercises. With the main focus of discussion of macroeconomic and structural policies shifting towards medium-term considerations, the model is used frequently in the production of medium-term scenarios, which extend the OECD's short-term projections published in the OECD *Economic Outlook* over a five- to six-year period,

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1. A preliminary version of this paper was presented at the 50th International Conference of the Applied Econometrics Association "The State of Art in Applied Econometrics", Paris 10-12 January 1996. The authors are all former members of the Macroeconomic Analysis and Systems Management Division of the OECD Department of Economics, where the work described was carried out. They are grateful to a large number of colleagues for comments and suggestions, to Timo Tyrvainen and Helen Yeches who also participated in the project, and to Claude Giorno who implemented the final version of the estimated relationships in the current version of the OECD INTERLINK model. Special thanks go to Lyn Louichaoui, Jan Davies-Montel and Erin Weiser for their assistance in preparing this and earlier versions of the paper.

and a wide variety of alternative scenarios, exploring the broad consequences of alternative economic conditions and policy assumptions.

Given the range and nature of uses which the model serves, the criteria for its form and development have evolved in fairly specific ways. In general, it has been necessary to recognise an important balance between statistical goodness-of-fit, structural simplicity and theoretically plausible behaviour. For a macroeconometric model to be useful for policy analyses which go beyond short-term forecasting requirements, particular attention must be paid to its long-run equilibrium properties and stability with respect to output, employment and inflation. These in turn depend crucially on the consistency and form of its supply-side specification[2]. At the same time, appropriate econometric methods are needed to ensure that short-term dynamic properties and underlying estimated properties are data consistent and well determined.

Against this background, the present study extends previous OECD empirical work on wage, price and supply determination in the major OECD economies, in particular those of Helliwell *et al.* (1986) and Jarrett and Torres (1987). In common with these studies a consistent supply-side framework is adopted for the estimation and analysis of macroeconomic adjustment; one which embodies an underlying production function for the aggregate business sector and corresponding factor demand, wage and price relationships. The combination of these permit the identification of a unique equilibrium unemployment rate consistent with stable inflation for each country[3]. At the same time the estimated production functions are useful in providing a broad class of measures of productive potential and thereby indicators of cyclical output gaps, as for example described in Giorno *et al.* (1995*a*), for use in related medium-term and fiscal policy analyses.

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 classified 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[4].

The rest of the paper is organised as follows. Section II describes the broad analytical framework and the structure of the empirical models considered. Specific emphasis is given to the long-run supply-side specification and dynamic adjustment to shocks. Section III then presents comparative empirical results for each of the seven major OECD economies, reviewing a number of influential factors such as model structure, the speeds of adjustment of factor demand and the evidence of real and nominal rigidities in wage and price relationships. The final Section IV reports a range of comparative simulation results for demand and supply shocks applied to each of the G7 country models. A particular focus is on how differences in structural characteristics embodied in the estimated supply-side specifications account for differences in overall model properties.

2. A detailed discussion of the role of supply-side equations and structural factors in determining long-term properties is given by Nickell (1988).
3. Preliminary work in the present study, concentrating on the G3 economies, was reported in Turner et al. (1993) and Turner and Rauffet (1994).
4. Specific examples of the importance of differences in structural characteristics across countries to the adjustment process within INTERLINK are also given by the recent OECD simulation studies reported in Richardson et al. (1994) and Giorno *et al*. (1995*b*).

II. The analytical framework

This section provides an overview of the supply-side specification which is common to each of the major seven country models considered. It focuses particularly on how this influences long-run model properties and the dynamic adjustment to equilibrium.

A. The long-run supply-side specification

The general model considered here 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, if 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 all the major seven countries with the sole exception of Japan. For this reason, 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)

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

where lower case letters denote logs and

q	=	output (measured at factor cost)
n	=	employment
k	=	capital stock
e	=	labour efficiency index
h	=	average hours worked
α	=	labour share parameter.

Thus, the production function divides total labour input into two or three elements; the number of employed persons, average hours worked (for the U.S., Japan, Germany and France only[5]) 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.

Given the above production function framework, it is possible to define a number of measures of market disequilibria, both for goods and factors of production. In the present analysis, one measure of particular relevance to short-term price setting behaviour is the difference between actual output and its "normal" level, where the latter is defined as the level which could be produced with the currently

5. Because of problems of data availability, the average hours variable has only been included for these countries.

employed quantities of factor inputs, operating at a "normal" or trend rate of utilisation[6]. Thus, "normal" output, q^*, is defined by the same production function expression, but substituting a smoothed value of labour efficiency, e^*, for e and, where appropriate, a trend value of average hours, h^*, for h. On this basis a corresponding measure of the intensity of factor utilisation, IFU, is defined by:

Intensity of factor utilisation

[2] $IFU = (q - q^*)$.

Consistent with this production technology and assuming competitive markets, 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

[3] $(n + h) = q - wp$,

Long-run demand for capital

[4] $k = q - rp$,

where:
- w = 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 I for further details). In those country models where hours are separately identified the wage cost variable, w, is the hourly wage cost whereas for the other country models it is the wage cost per employee.

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:

[5] $cost = \alpha (w - e^*) + (1 - \alpha)r$.

6. A distinction can be drawn between such a measure and those used more generally to represent "potential" output, which may also correct for short-term disequilibrium in labour markets (see for example Giorno *et al.* (1995*a*)).

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 an intensity of factor utilisation term, IFU, so that:

Long-run value-added prices

[6] $p = cost + b_1\ IFU.$

Nevertheless, given the specification of the supply block, following any shock, factor demands will adjust to ensure that in the long run actual and normal output coincide, so that in the long run steady-state IFU, as defined in equation [2], is zero.

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.

Long-run real wages

[7] $(w - p) = \gamma_0 + pr^* - \gamma_1\ U + \delta\ x.$

However, for an economy consistent with a Cobb-Douglas technology, in steady state equilibrium "warranted" real wage costs are given by(see Annex II)

[8] $(w - p)^* = pr^* + a,$

where a is the log of the labour share parameter. Assuming that in the long run, the real wage is equal to this warranted real wage, then combining this expression with the wage equation [7] shows that there is a unique equilibrium rate of unemployment, U*, given by:

[9] $U^* = \{(\gamma_0 - a) + \delta\ x\}/\gamma_1.$

B. Dynamic adjustment to shocks

The long-run equilibrium properties of the model described above can in many respects be regarded as being neo-classical. Nevertheless, following shocks to the economy, the presence of real and nominal rigidities in wage- and price-setting can lead to a potentially protracted period of adjustment before equilibrium is restored. This section shows how the scale of any disturbance to the real economy following a demand or supply shock is related to these rigidities. The section which follows then reports the extent of these rigidities according to the parameters of the equations estimated for each of the major seven countries, and a subsequent section then demonstrates how these relate to the model simulation properties.

A high degree of real rigidity is defined as a situation where real wages and the mark-up of prices over costs respond little to changes in demand pressure. Nominal rigidities are present 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 I) can be used to provide comparable measures of real and nominal rigidities, specifically for the G7 economies. It is subsequently shown how the cumulative disturbance to the real economy, especially unemployment, following various shocks is directly related to these parameters. Full derivations of these results are given in Annex II.

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 later. On this assumption, a simplified dynamic form of the price equation [6], allowing for nominal inertia, can be represented as[7]:

[10] $p = (w - e^*) + \beta_1 \, IFU - \beta_2 \Delta\Delta w + \varepsilon_p$,

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

In equation [10], the $-\beta_2\Delta\Delta w$ 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. The larger the value of β_2 the more sluggish will be the adjustment of prices to wage costs. The parameter on the IFU term, β_1, provides a measure of the responsiveness of prices to demand conditions. The final term, ε_p, represents an exogenous disturbance term.

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

[11] $(w - p) = \gamma_0 + pr^* - \gamma_1 U + \delta x - \gamma_2 \Delta\Delta p + \gamma_3 \Delta \, wedge + \varepsilon_w$,

where the $-\gamma_2\Delta\Delta p$ term allows for nominal rigidities in the adjustment of wages to a change in prices while maintaining dynamic homogeneity. The larger is $\gamma_2\Delta\Delta p$, 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 $\gamma_3\Delta$ wedge is included as one of a number of possible supply-side variables represented by the vector "x" in equation [7]. 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 cause real wage costs to diverge from the real consumption wage, such as taxes and real import prices. The term ε_w is a disturbance term similar to ε_p in the price equation.

Adjustment to demand shocks

Given the framework described above, the cumulative deviation[8], ΣU, of unemployment from its equilibrium rate as the result of a demand shock can be derived in terms of the final change in the steady

7. In estimation, more complex dynamic forms are identified for the price and wage equations, but for purposes of exposition equation [10] captures the key aspects of dynamic adjustment relevant to inertia within the system.
8. In this analysis the notation Σy 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 1 percentage point year could, for example, correspond either to an increase in the unemployment rate of 1 percentage point for the duration of one year, or an increase of one-half a percentage point for two years. Such measures do not take into

state rate of inflation, π, and the parameters which measure the extent of real and nominal rigidity in the wage and price equations as follows (see Annex II for a formal derivation):

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

Alternatively, this expression can be re-arranged to provide a measure of the "sacrifice ratio", corresponding to the cumulative percentage point increase (decrease) in the unemployment rate, required to bring about a 1 percentage point fall (increase) in the annual inflation rate following a demand shock, thus:

$$[13] \qquad \frac{-\Sigma U}{\pi} = \left[\gamma_2 + \frac{\beta_2}{(1+\alpha\beta_1)} \right] . \frac{1}{\gamma_1}.$$

From this expression it can be seen directly that the greater the extent of both nominal rigidities (i.e. the larger $1/\gamma_1$ and $1/\beta_1$) the greater the sacrifice ratio, and also the greater the disturbance to the real economy following a demand shock (for any given change in inflation).

Adjustment to supply shocks

For the present purposes, a supply shock is defined as a disturbance to real wages or the price mark-up which is not caused by demand conditions. Suppose for example there is an increase in "wage-push" pressure represented by the term ε_w in the wage equation [11]. Unlike a demand shock, an adverse supply shock will result in both higher inflation and higher unemployment, at least initially. If the disturbance is permanent then the increased inflationary pressure needs 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 [10] and [11], thus[9]:

$$[14] \qquad U = \frac{\varepsilon_w}{\gamma_1}.$$

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

The inflationary effect of temporary supply shocks, represented by temporary changes in ε_p or ε_w, has to be counter-balanced by a period of higher unemployment and under-utilisation of productive factors before equilibrium is re-established if any rise in inflation is to be avoided, so that (see Annex II for proof):

$$[15] \qquad \Sigma\, \varepsilon_p + \Sigma\, \varepsilon_w = \gamma_1\, \Sigma\, U - \beta_1\, \Sigma\, IFU.$$

account time preference rates, which might be relevant to any welfare evaluation of the size and duration of unemployment effects.

9. This again assumes an unchanged real cost of capital, which ensures that trend labour productivity and labour efficiency do not change.

The cumulative disturbance to the intensity of factor utilisation can be eliminated from this expression (see Annex II) to give an expression for the cumulative disturbance to unemployment following a temporary supply shock as follows:

$$[16] \qquad \Sigma\, U = \left[\Sigma\, \varepsilon_w + \frac{\Sigma\, \varepsilon_p}{(1+\alpha\beta_1)} \right] \frac{1}{\gamma_1}.$$

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

A specific form of supply shock which is considered in the wage equation [11] is a change in the "wedge" between employers' real wage costs and employees' consumption wages. In this case the cumulative increase in unemployment required if a permanent rise in inflation is to be avoided is given by:

$$[17] \qquad \Sigma\, U = \frac{\gamma_3 \Sigma \Delta\, \text{wedge}}{\gamma_1}$$

and is directly proportional to the measure of real wage resistance γ_3, the size of the change(s) in the wedge variable and the measure of real wage rigidity ($1/\gamma_1$).

III. Comparative Empirical Results

Modelling the supply blocks for the major seven OECD economies, involves the translation of the broad theoretical framework defined in the previous section into a set of four or five estimated equations corresponding to the factor demand (capital, labour and hours), wage and price equations and implicitly the production function. These typically take the form of dynamic equations, estimated on the basis of semi-annual data, with individual long-term properties tied down by error correction terms defined by the corresponding long-run considerations. Full details of these, with individual coefficient estimates and statistical tests are reported in Tables A1 to A5 of Annex II. On this basis, this section provides some general insights into cross-country estimation results and their implications for the overall structural characteristics of the models.

In order to determine the underlying business sector production technology, an estimate of the elasticity of substitution between labour and capital is derived from estimates of the labour demand equation. Initially a series for labour efficiency is derived, assuming an underlying Cobb-Douglas production technology. This series is 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] is then estimated and the Cobb-Douglas restriction that the elasticity of employment with respect to real wage costs is (minus) unity is tested. This test was easily accepted for all of the major seven countries, with the exception of Japan. For the majority of countries the Cobb-Douglas specification was then imposed on the remaining supply block equations.

For Japan, however, the Cobb-Douglas restriction was strongly rejected at conventional levels of statistical significance (even over shortened sample periods). Thus a grid search was conducted to find the elasticity of substitution consistent with a more general CES production function. For a range of values of the elasticity of substitution, consistent measures of labour efficiency were derived individually and the labour demand equation. On this basis the preferred production technology was a CES from with an elasticity of substitution of 0.40. In practice, there was little difference in the goodness-of-fit in the range of plus or minus 0.05, although a parameter of 0.40 was clearly preferred to 0.30 or 0.50.

Adjustment of Factor Demand Equations

Although the long-run specification imposed on the factor demand equations is, with the exception of Japan, basically the same across all countries, the estimated parameters reveal wide cross-country differences in the speed of adjustment. In this section the single equation properties of the factor demand equations are contrasted, highlighting those features which have a major influence on overall model simulation properties.

Table 1 summarises the single equation response of the labour demand equations to a permanent increase in output. The short-term adjustment of employment is quickest for the U.S. and Canada with nearly 50 per cent of the adjustment to the long-run equilibrium completed in the first semester. However, in addition to the North American countries, both Germany and the United Kingdom have completed 75 per cent of the long-run adjustment within two years. Conversely the employment equations for Italy, Japan and France adjust relatively slowly, taking over five years, just under, and just over ten years, respectively, to complete 75 per cent of the adjustment.

However, if allowance is also made for the adjustment of average hours (in those countries where this variable is distinguished) these rankings change somewhat (in Table 1 the response of total man hours is shown in brackets). It remains the case that labour demand in the U.S. adjusts the quickest. However, because of the rapid response of average hours in the case of Japan the increase in total man hours is about 60 per cent in the first semester, with a similar speed of adjustment for Germany. The negligible response from average hours in France implies that that the overall adjustment of labour demand remains sluggish.

The response of the capital stock to a change in output, reported in Table 2, has a major influence on the model simulation properties. On the one hand, the adjustment of the capital stock to a change in output is very slow. Thus, on average across all the G7 countries the median lag of the capital stock with respect to a change in output is about 20 years, compared to less than 2 years for the labour demand equations. This sluggish adjustment of the capital stock means that it often takes more than ten years before a new equilibrium is reached in the full model simulations discussed in the next section. On the other hand, the implied adjustment of investment following a shock to output is distinctly "lively", so that the peak (percentage) response of investment (typically in the first in or second year) lies between 1½ and 2½ times the (percentage) change in output. This strong accelerator response from investment is a feature of all the demand for capital equations and leads to pronounced, although damped, cyclical responses in most full model simulations.

Real and Nominal Rigidities in the Wage and Price equations

In this framework the magnitude, duration and dynamic pattern of disturbances to the economy following a shock, as shown by the analysis in Section II, depends on the degree of real and nominal rigidities. The extent of these rigidities according to the estimated wage and price equations for the G7 countries are summarised in Table 3.

A number of features stand out in an examination of these estimates. Firstly, the extent of nominal inertia is generally greater in prices than it is in wages, i.e. $\beta_2 > \gamma_2$, (with sole exception of Japan, where they are similar). This result is also broadly true of the estimates of nominal inertia reported in

Table 1. The estimated speed of adjustment of labour demand to a permanent increase in output

	Impact effect in the first semester (% of full adjustment)	Number of semseters taken for 50% adjustment	Number of semesters taken for 75% adjustment
USA	0.50 [0.79]	1 [1]	2 [1]
Canada	0.50	1	3-4
Japan	0.20 [0.60]	6-7 [1]	18-19 [3-4]
Germany	0.42 [0.61]	2-3 [1]	2-3 [1-2]
France	0.24 [0.24]	2-3 [2-3]	22-23 [22-23]
Italy	0.14	5-6	10-11
United Kingdom	0.29	1-2	3-4

Table 2. The estimated speed of adjustment of capital with respect to a permanent increase in output

	Number of semesters taken for 50% adjustment	Number of semesters taken for 75% adjustment	Peak accelerator response of investment
USA	8	14	2.5 (3)
Canada	17	42	1.5 (4)
Japan	26	55	2.1 (1)
Germany	16	40	2.1 (1)
France	80	100+	2.6 (2)
Italy	48	100+	1.8 (1)
United Kingdom	57	100+	3.0 (1)

Note: Calculations are single equation impulse responses based on the estimated equations reported in Tables A1, A2 and A3 of Annex I. In order to evaluate the accelerator response the ratio between investment and the capital stock is assumed to be the same as that over the sample estimation period. The figure in brackets in the final column is the semester in which the peak accelerator response occurs.

Table 3. The extent of real and nominal rigidities in the estimates wage and price equations

	Wage equation response		Price equation response		Sacrifice ratio[1]
	Unemployment effect	Nominal inertia	IFU effect	Nominal inertia	
	γ_1	γ_2	β_1	β_2	
USA	2.5	1.6	4.8	3.4	1.0
Canada	1.8	0.9	0.9	2.3	1.3
Japan[2]	21.6	1.0	0.0	0.9	0.1
Germany	2.5	0.9	0.0	2.0	1.1
France	4.2	1.4	1.4	2.9	1.0
Italy[2]	1.2	0.0	0.0	4.3	8.6
UK[2]	0.5	0.0	0.0	6.7	5.7

1. The sacrifice ratio is calculated according to expression [13].
2. The unemployment effect in the wage equations for Japan, Italy and the UK is captured by the logarithm of the unemployment rate. The coefficient γ_2 is therefore calculated at the average unemployment rate over the sample period.
3. Estimates of β_1, β_2, γ_1 and γ_2 are derived from the estimated equations reported in Tables A4 and A5 in Annex I.

Layard *et al*. (1991). Secondly, the effects of unemployment on wages are generally greater than the effect coming from the intensity of factor utilisation on prices, i.e. $\beta_1 < \gamma_1$, with the sole exception of the U.S. where pressure of demand effects on prices are the largest across any of the G7 countries. This is one reason why there is a reasonably close correlation between rankings of the estimates of real wage rigidity and the overall sacrifice ratio.

The estimates of the sacrifice ratio (see the final column of Table 3), derived by combining the estimates of nominal and real rigidities, divide the countries into three broad groups: Japan, where the estimate of the sacrifice ratio, at 0.1 is very low, Italy and the U.K. where the estimates are very high, at about 6 or above, and the remaining countries where the estimates range from about 1 to 1½. In the case, of Japan the low estimate of the sacrifice ratio reflects the historically low variation in unemployment over the estimation period, which in turn is partly explained by the high responsiveness of labour supply to demand pressures.

There are reasons for interpreting the result that the U.K. has the highest sacrifice ratio with particular caution. This is because the estimate of the unemployment effect on wages (which as noted above is critical to the overall estimate of the sacrifice ratio) is based on an equation estimated over the period 1967 to 1991, but the coefficient measuring this effect in the wage equation has shown a tendency to increase during the 1980s, reflecting ongoing structural reforms in the U.K. labour market. This would imply a progressively lower sacrifice ratio over the period.

IV. Model Properties

In this section, the full model properties of the G7 country models are analysed and compared, with attention focused on how differences in the supply-side specification of the country models (discussed in Section III) account for differences in simulation properties. Two different sets of simulations are examined: a shock to demand and a supply shock to wages[10]. In all of these cases the simulations are carried out under the monetary policy assumption of unchanged real interest rates and floating exchange rates[11]. The sensitivity of the simulation results to this monetary policy assumption are considered at the end of the section.

A. A Demand Shock

The demand shock simulation, reported in Table 4, takes the form of a permanent increase in government consumption expenditure equivalent to 1 per cent of baseline GDP.

Certain broad characteristics of the simulation results are the same across all countries. There is an initial increase in GDP, which peaks in the first or second year when the accelerator response from investment (described in Section III) is strongest. As unemployment falls below the equilibrium rate and the intensity of factor utilisation increases, inflation picks up, although the peak in inflation typically lags behind the peak output response. The increase in inflation leads to the elimination of the initial output gains through two principle transmission mechanisms: an initial worsening of competitiveness leads to a worsening in net exports in the short-term and higher inflation has a direct negative effect on consumption (proxying a wealth effect operating on net financial assets). The long-run equilibrium is identical across all country models: initial GDP and unemployment gains are fully eliminated, returning to their baseline values, and inflation stabilises at a permanently higher rate[12]. In other words, there is complete “crowding-out” of private expenditures by public expenditures. For most of the countries the nature of this long-run equilibrium is clearly discernible, within the ten-year simulation horizon which is reported here, although given the long adjustment lags in the capital stock (discussed in Section III), none of the simulations correspond with it precisely.

To understand cross-country differences in the simulation results, two essential features need to be distinguished: firstly, on the supply side, the magnitude of the sacrifice ratio implied by the wage and price equations; secondly, on the demand side, the marginal import propensity. The size of the sacrifice ratio derived from the wage-price block (as discussed in the previous section) is important because, following a demand shock it shows what the cumulative change in unemployment will be before equilibrium is re-established, for any given final change in inflation. Thus, other things being equal, a large sacrifice ratio will tend to lead to a large cumulative disturbance to unemployment (and, by implication, GDP) following a demand shock. The magnitude of the marginal import propensity is important because of its effect on the impact multiplier. On the basis of these two characteristics the G7 countries can be divided into three groups for the purposes of analysing the simulation results of a demand shock.

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10. In all of these simulations the country models are run as separate entities, rather than being linked together as part of a world model.
11. Within INTERLINK exchange rates are determined endogenously, primarily as functions of international interest rate and price differentials. In conjunction with the above interest rate assumption, the floating rate option tends to maintain a broadly unchanged real exchange rate over the simulation period.
12. It should be noted that this permanent increase in inflation is a reflection of the monetary policy assumption used in the simulation. A different monetary policy rule (e.g. assuming an unchanged money stock) would imply a different result (a return to the baseline rate of inflation).

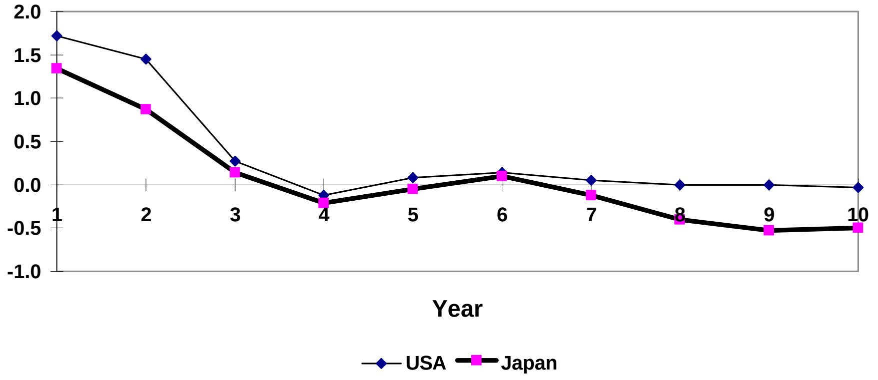
Table 4. Simulated demand shock
Percentage deviations from baseline

Year	1	2	3	4	5	6	7	8	9	10
United States										
Real GDP level	1.7	1.4	0.3	-0.1	0.1	0.1	0.1	0.0	0.0	0.0
Inflation rate	0.3	1.0	1.8	1.6	1.4	1.3	1.2	1.2	1.1	1.1
Unemployment rate	-0.7	-0.9	-0.5	-0.1	0.0	0.0	0.0	0.1	0.1	0.1
Japan										
Real GDP level	1.3	0.9	0.1	-0.2	-0.1	-0.1	-0.1	-0.4	-0.5	-0.5
Inflation rate	0.7	1.8	1.7	1.2	1.3	1.8	1.9	1.6	1.3	0.9
Unemployment rate	-0.1	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Germany										
Real GDP level	1.1	0.9	0.7	0.4	0.3	0.3	0.2	0.1	0.0	0.0
Inflation rate	0.2	0.8	0.9	1.1	1.1	1.2	1.2	1.1	1.1	1.1
Unemployment rate	-0.2	-0.3	-0.2	-0.2	-0.1	-0.1	0.0	0.0	0.0	0.0
France										
Real GDP level	0.8	0.7	0.5	0.4	0.2	0.1	0.0	0.0	-0.1	-0.1
Inflation rate	0.2	0.6	0.8	0.9	1.0	1.0	1.1	1.0	0.9	0.9
Unemployment rate	-0.2	-0.3	-0.3	-0.2	-0.2	-0.1	0.0	0.0	0.1	0.1
Italy										
Real GDP level	0.9	0.7	0.5	0.6	0.4	0.4	0.4	0.4	0.4	0.4
Inflation rate	0.2	0.7	0.6	0.7	0.9	1.0	1.2	1.3	1.3	1.4
Unemployment rate	-0.1	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
United Kingdom										
Real GDP level	0.7	0.7	0.5	0.5	0.4	0.4	0.3	0.3	0.2	0.2
Inflation rate	0.1	0.7	0.8	0.8	0.8	0.8	0.9	0.8	0.8	0.8
Unemployment rate	-0.1	-0.3	-0.4	-0.3	-0.3	-0.3	-0.2	-0.2	-0.2	-0.2
Canada										
Real GDP level	0.7	0.8	0.7	0.4	0.2	0.0	-0.2	-0.3	-0.4	-0.3
Inflation rate	0.2	0.5	0.9	1.1	1.2	1.2	1.1	1.0	0.9	0.7
Unemployment rate	-0.3	-0.3	-0.3	-0.2	-0.1	0.0	0.1	0.1	0.1	0.1

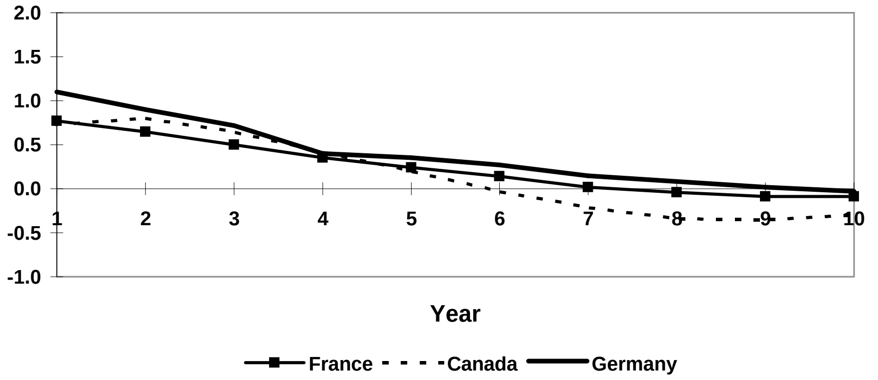
Simulation: A sustained increase in government consumption expenditure equivalent to 1 per cent of baseline GDP, with unchanged real interest rates and floating exchange rates.

Figure 1 :
G7 Fiscal Multipliers

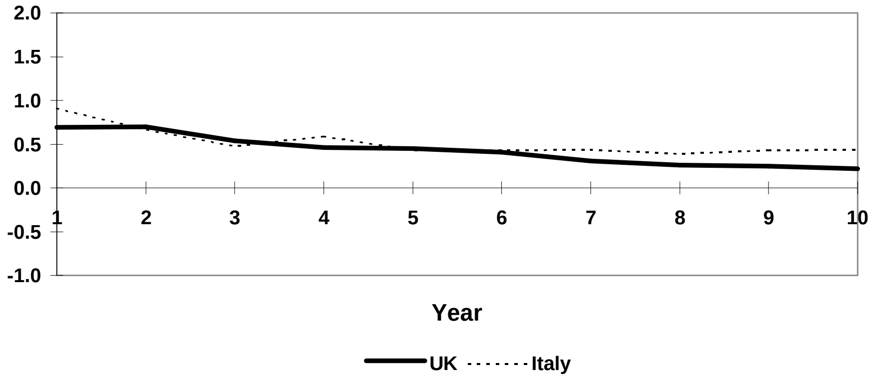
1(a) GDP Multipliers for USA and Japan



1(b) GDP Multipliers for France, Germany and Canada



1(c) GDP Multipliers for UK and Italy



Japan and the U.S. are distinguished by the fact that they both have a comparatively low marginal import propensity, which means that the impact multiplier is relatively large (see Figure 1(a)). Consequently, the increase in inflation is also relatively large (see Figure 2(a)), and hence crowding-out is much quicker. Thus, within four years GDP is below baseline -- more quickly than for any of the other G7 countries. An important difference between the U.S. and Japan models is that the sacrifice ratio (measured in terms of unemployment) for the latter is very low. However, this in part reflects the high responsiveness of the labour force to changes in labour market conditions for Japan, so that the difference in sacrifice ratio between the two countries is much smaller when measured in terms of output rather than unemployment. Nevertheless, an important consequence is that the disturbance to the unemployment rate is very much smaller for Japan than for any of the other countries.

France, Germany and Canada all have a similar sacrifice ratio (between 1.0 and 1.3) and a relatively high marginal import propensity, which means that the impact multipliers are more modest (unity or less) than for either the U.S. or Japan (see Figure 1(b)). This in turn means that the pick-up in inflation is smaller and the speed of crowding-out is less rapid (see Figure 2(b)). Nevertheless, given the magnitude of the sacrifice ratios, GDP and unemployment return to baseline within the ten-year simulation horizon for all of these countries (after six years in the case of Canada).

Italy and the U.K. have in common both a relatively high sacrifice ratio and a high marginal import propensity. The latter feature means that, as for the previous group of countries, the impact multiplier is below unity. However, the high sacrifice ratios mean that, unlike the previous group of countries, the speed of crowding-out is so slow that unemployment and GDP are not even close to falling below their baseline values by the end of the ten-year simulation horizon. Indeed, whereas the implied sacrifice ratios calculated from the simulation results (namely, the cumulative fall in unemployment over each of the ten years divided by the inflation rate in the tenth year) are quite close to the figure derived from the parameters in the wage and price equations for all of the other countries, this is not the case for the U.K. and Italy. This provides a further confirmation that the results for Italy and the U.K. after ten years are further away from their eventual long-run equilibrium than is the case for the other countries.

B. A Supply Shock

The supply shock simulation, reported in Table 5, takes the form of a positive shock to wages, equivalent to a temporary *ex ante* increase of 1 per cent in nominal wages for one semester only, relative to the baseline[13]. The monetary assumption is the same as for the earlier demand but in addition government expenditures are assumed to be unchanged in real terms.

According to the analysis discussed in the previous section the cumulative disturbance to unemployment following a supply shock to wages is proportional to the extent of real wage rigidity, i.e. inversely proportional to the sensitivity of real wages to unemployment. The model simulation results conform to this prediction as summarised in Figure 3, where the rankings of the cumulative disturbance to unemployment correspond closely with the ranking of $1/\gamma_1$ in Table 3[14].

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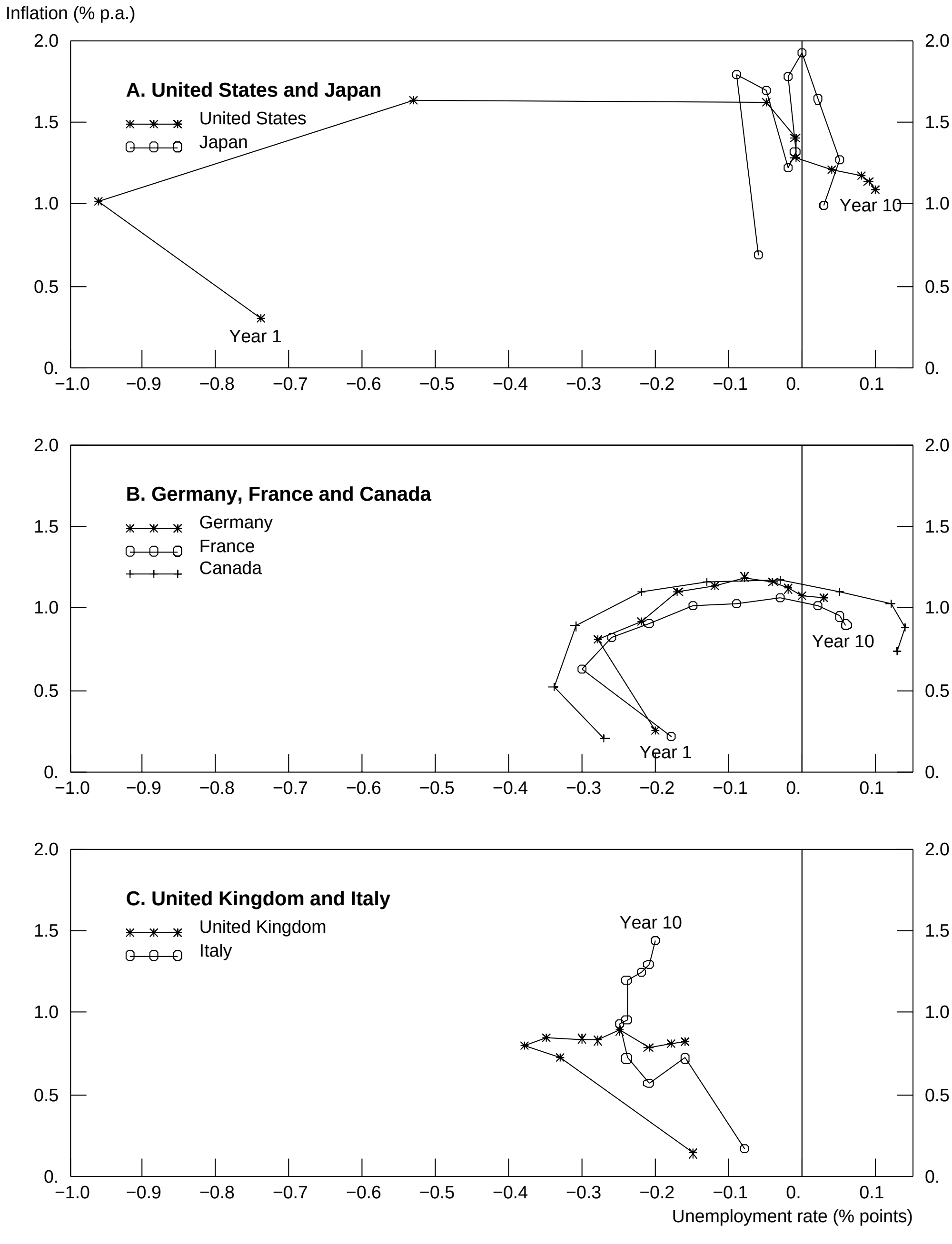
13. The shock is applied as a residual to the wage equation. The time profile of this residual will depend on the dynamic specification of the wage equation. For example, if the wage equations is specified as: $\Delta w = ...-\lambda w\text{-}1 + ...$ other terms, where w is the log of nominal wages, Δ is the first difference operator and λ is a coefficient on the error-correction term, then the residual applied to increase ex ante wages by 1 per cent is 0.01 in the first period, 0.01 x (λ-1) in the second period and zero in every period thereafter.
14. Further evidence on the importance of structural differences in supply behaviour for the unemployment response, in the case of a supply-side productivity shock, is given by Giorno *et al.* (1995*b*).

Figure 2. UNEMPLOYMENT AND INFLATION RESPONSES FOLLOWING A DEMAND SHOCK



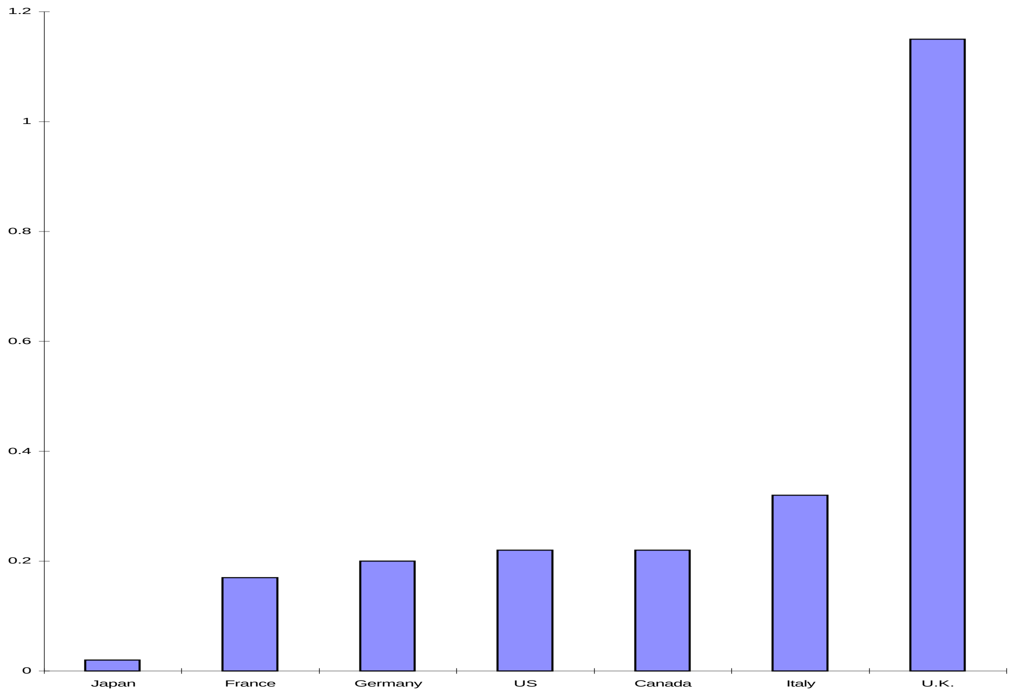
Source: See Table 4.

Table 5. Simulated supply shock
Percentage deviations from baseline

Year	1	2	3	4	5	6	7	8	9	10
United States										
Inflation rate	0.45	-0.01	-0.17	-0.07	0.02	0.02	0.00	-0.02	-0.02	-0.02
Unemployment rate	0.16	0.22	-0.01	-0.09	-0.05	0.00	0.01	0.00	-0.01	-0.01
Japan										
Inflation rate	0.66	0.02	-0.22	-0.17	-0.04	-0.08	-0.18	-0.20	-0.13	-0.06
Unemployment rate	0.01	0.01	0.02	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01
Germany										
Inflation rate	0.41	0.03	0.01	-0.01	-0.03	-0.02	-0.02	-0.01	-0.01	-0.01
Unemployment rate	0.10	0.08	0.02	-0.03	-0.01	0.02	0.02	0.01	-0.01	0.0
France										
Inflation rate	0.30	0.07	0.02	-0.01	-0.03	-0.04	-0.05	-0.05	-0.05	-0.05
Unemployment rate	0.04	0.03	0.03	0.03	0.02	0.02	0.01	0.00	0.00	-0.01
Italy										
Inflation rate	0.59	0.17	-0.02	0.00	-0.04	-0.04	-0.02	-0.02	0.00	0.02
Unemployment rate	0.05	0.07	0.07	0.06	0.04	0.03	0.01	0.00	0.00	-0.01
United Kingdom										
Inflation rate	0.80	-0.28	-0.17	-0.12	-0.10	-0.06	-0.02	0.00	-0.01	0.01
Unemployment rate	0.24	0.35	0.29	0.18	0.08	0.03	0.00	-0.01	-0.01	0.00
Canada										
Inflation rate	0.24	0.08	-0.02	-0.03	-0.04	-0.03	-0.02	-0.02	-0.01	-0.01
Unemployment rate	0.10	0.03	0.03	0.03	0.02	0.01	0.00	0.00	0.00	0.00

Simulation: A temporary (one-semester) *ex ante* increase of 1 per cent in nominal wages, with unchanged real interest rates and floating exchange rates.

Figure 3: CUMULATIVE CHANGES IN UNEMPLOYMENT RATE FOLLOWING A PERMANENT SUPPLY SHOCK

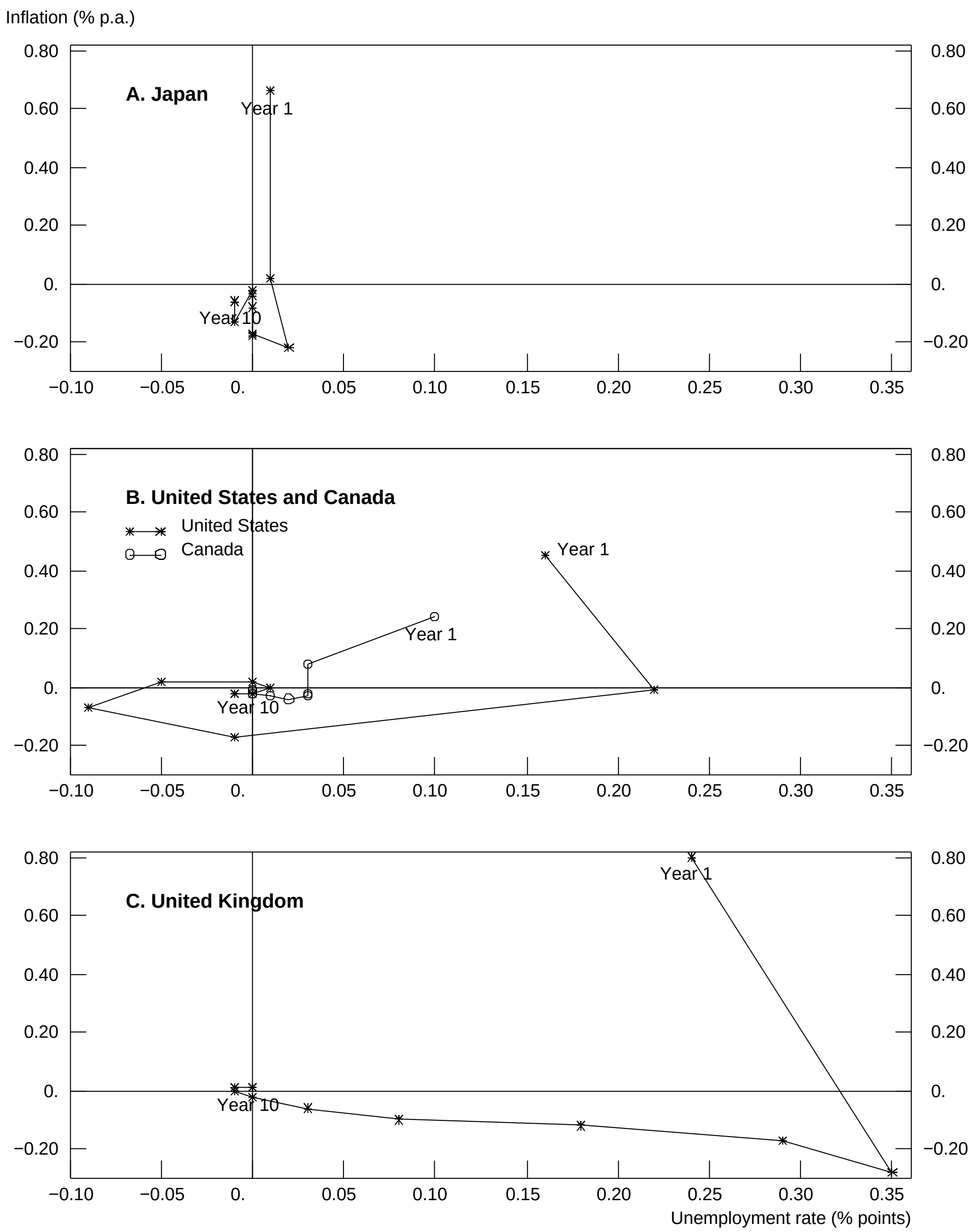


The dynamic response of unemployment and inflation is examined for a number of representative cases in Figure 4. For Japan, where the responsiveness of wages to unemployment is extremely high there is only a small disturbance to unemployment, see Figure 4(a). For Canada and the U.S., which have similar degrees of real wage rigidity, the cumulative disturbance to unemployment over the ten-year horizon is similar. Nevertheless, the pattern of dynamic response is different across the two countries with the U.S. initially exhibiting a larger initial rise in unemployment and a subsequent cyclical response pattern. This difference can largely be explained by the different multiplier properties considered in the previous set of simulations. Thus, the initial effects on output are dampened less by imports and are also reinforced more by the accelerator response of investment, in the case of the U.S. as compared to Canada. Germany, France and Italy (not shown in Figure 4), which have both a similar degree of real wage rigidity and a similar impact multiplier to Canada, consequently exhibit a similar response in terms of inflation and unemployment. Finally, the U.K. is an outlier with a very large disturbance to unemployment reflecting the insensitivity of real wages to the unemployment rate.

C. The Importance of the Monetary Policy Assumption

All of the simulations discussed above were carried out under an assumption of fixed real interest rates. In practice, what is important as regards the qualitative nature of the results is what happens to **real long-term** interest rates. Long-term interest rates are more important than short-term interest rates, because only the former enter into the cost of capital. A change in the cost of capital, because it enters

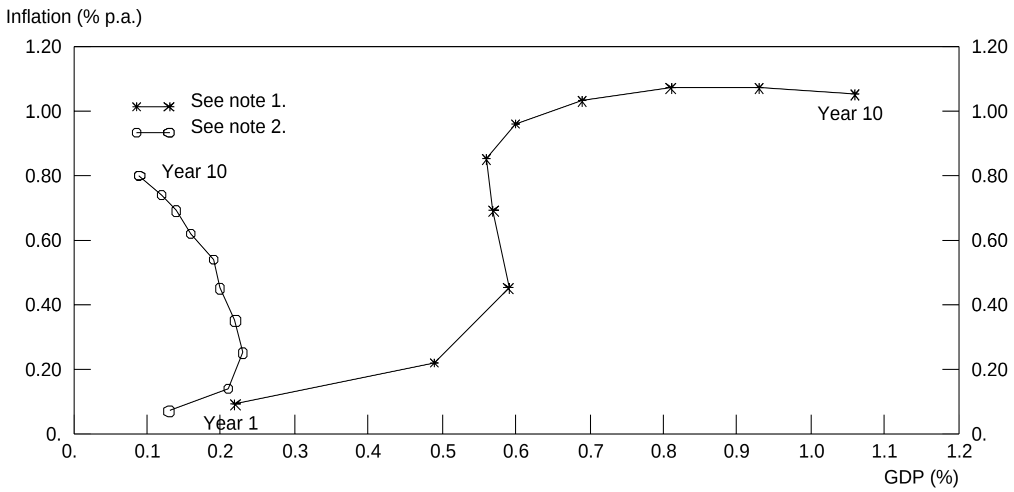
Figure 4. UNEMPLOYMENT AND INFLATION RESPONSES FOLLOWING A SUPPLY SHOCK TO WAGES



Source: See Table 5.

Figure 5. GDP AND INFLATION RESPONSES FOLLOWING A CUT IN INTEREST RATES

United States



1. Cut in short−term and long−term interest rates by 1% point.
2. Cut in short−term interest rates by 1% point with real long−term rates unchanged.
Source: See Tables 6 and 7.

directly into the price equation has a supply-side effect, whereas changes in the short-term interest rate only have effects on demand.

This is illustrated for a representative country (in this case the U.S.), in Figure 5, where the inflation and GDP responses are compared for two simulations: firstly one in which nominal short-term interest rates are reduced by 1 percentage point but real long-term interest rates remain unchanged, and secondly one in which both short- and long-term nominal interest rates are both reduced by 1 percentage point. In the former case the qualitative response is similar to that of a demand shock, with initial gains in GDP and (lower) unemployment eventually being crowded out by higher inflation. There is a similar response in the cases of Germany, Italy, the United Kingdom and Canada (see Table 6). For both Japan and France the extent of the crowding out is less marked, but this is only achieved at a cost of a continual rise in the inflation rate.

In contrast, if real long-term interest rates are allowed to fall then there are more lasting effects on unemployment and GDP, without any tendency for ever-increasing inflation, again as illustrated for the U.S. in Figure 5. A similar result is obtained for the other countries with sustained gains to GDP being achieved with either stable or falling inflation (see Table 7).

Table 6. Simulated change in short-term interest rates

Percentage deviations from baseline

Year	1	2	3	4	5	6	7	8	9	10
United States										
Real GDP level	0.13	0.21	0.23	0.22	0.20	0.19	0.16	0.14	0.12	0.09
Inflation rate	0.07	0.14	0.25	0.35	0.45	0.54	0.62	0.69	0.74	0.80
Unemployment rate	-0.05	-0.11	-0.14	-0.14	-0.13	-0.12	-0.10	-0.08	-0.06	-0.04
Japan										
Real GDP level	0.14	0.50	0.76	0.82	0.74	0.72	0.77	0.80	0.72	0.57
Inflation rate	0.09	0.50	1.14	1.68	2.10	2.45	2.99	3.68	4.40	5.03
Unemployment rate	-0.01	-0.03	-0.06	-0.08	-0.09	-0.09	-0.10	-0.11	-0.11	-0.10
Germany										
Real GDP level	0.09	0.17	0.19	0.18	0.14	0.10	0.08	0.07	0.06	0.06
Inflation rate	0.08	0.09	0.12	0.18	0.26	0.32	0.37	0.41	0.45	0.47
Unemployment rate	-0.02	-0.06	-0.09	-0.09	-0.08	-0.07	-0.06	-0.05	-0.04	-0.04
France										
Real GDP level	0.07	0.28	0.40	0.46	0.50	0.51	0.51	0.51	0.49	0.47
Inflation rate	0.12	0.25	0.45	0.66	0.91	1.15	1.40	1.66	1.90	2.13
Unemployment rate	-0.01	-0.07	-0.13	-0.17	-0.20	-0.21	-0.22	-0.21	-0.20	-0.19
Italy										
Real GDP level	0.12	0.38	0.35	0.31	0.26	0.20	0.14	0.09	0.04	0.00
Inflation rate	0.35	0.27	0.49	0.54	0.63	0.68	0.74	0.77	0.77	0.76
Unemployment rate	-0.01	-0.04	-0.08	-0.10	-0.12	-0.12	-0.12	-0.10	-0.08	-0.06
United Kingdom										
Real GDP level	0.22	0.46	0.51	0.47	0.41	0.33	0.26	0.18	0.11	0.04
Inflation rate	0.32	0.89	1.14	1.19	1.18	1.14	1.10	1.03	0.93	0.81
Unemployment rate	-0.04	-0.14	-0.23	-0.27	-0.28	-0.26	-0.23	-0.19	-0.16	-0.12
Canada										
Real GDP level	0.14	0.27	0.42	0.50	0.51	0.45	0.37	0.27	0.16	0.07
Inflation rate	0.13	0.27	0.48	0.77	1.05	1.33	1.55	1.71	1.81	1.85
Unemployment rate	-0.04	-0.09	-0.15	-0.20	-0.21	-0.20	-0.18	-0.15	-0.12	-0.09

Simulation: Cut in nominal short-term interest rates by 1 percentage point with real long-term rates unchanged.

Table 7. Simulated change in short and long-term interest rates
Percentage deviations from baseline

Year	1	2	3	4	5	6	7	8	9	10
United States										
Real GDP level	0.22	0.49	0.59	0.57	0.56	0.60	0.69	0.81	0.93	1.06
Inflation rate	0.09	0.22	0.45	0.69	0.85	0.96	1.03	1.07	1.07	1.05
Unemployment rate	-0.09	-0.25	-0.34	-0.36	-0.34	-0.33	-0.34	-0.37	-0.39	-0.41
Japan										
Real GDP level	0.12	0.41	0.62	0.70	0.72	0.80	0.93	1.06	1.16	1.25
Inflation rate	0.08	0.38	0.79	1.06	1.18	1.17	1.21	1.28	1.36	1.46
Unemployment rate	-0.01	-0.03	-0.05	-0.07	-0.08	-0.09	-0.10	-0.12	-0.13	-0.15
Germany										
Real GDP level	0.28	0.52	0.63	0.71	0.76	0.80	0.82	0.85	0.87	0.88
Inflation rate	0.11	0.15	0.23	0.35	0.47	0.55	0.59	0.57	0.48	0.32
Unemployment rate	-0.07	-0.19	-0.27	-0.33	-0.37	-0.39	-0.40	-0.40.	-0.39	-0.36
France										
Real GDP level	0.11	0.35	0.50	0.61	0.70	0.77	0.85	0.94	1.03	1.12
Inflation rate	0.12	0.28	0.47	0.64	0.82	0.95	1.04	1.08	1.07	1.02
Unemployment rate	-0.02	-0.10	-0.17	-0.22	-0.27	-0.30	-0.32	-0.34	-0.36	-0.37
Italy										
Real GDP level	0.27	0.53	0.53	0.48	0.49	0.48	0.51	0.55	0.61	0.68
Inflation rate	0.40	0.29	0.46	0.23	0.01	-0.31	-0.65	-1.00	-1.30	-1.53
Unemployment rate	-0.03	-0.07	-0.12	-0.16	-0.19	-0.20	-0.20	-0.20	-0.21	-0.22
United Kingdom										
Real GDP level	0.23	0.50	0.61	0.70	0.83	1.01	1.21	1.43	1.64	1.85
Inflation rate	0.33	0.86	0.98	0.82	0.57	0.35	0.24	0.24	0.32	0.43
Unemployment rate	-0.04	-0.15	-0.25	-0.33	-0.39	-0.45	-0.51	-0.57	-0.61	-0.65
Canada										
Real GDP level	0.18	0.37	0.56	0.71	0.79	0.80	0.81	0.82	0.86	0.92
Inflation rate	0.15	0.32	0.52	0.76	0.94	1.04	0.99	0.82	0.54	0.22
Unemployment rate	-0.05	-0.13	-0.21	-0.29	-0.35	-0.38	-0.40	-0.42	-0.44	-0.47

Simulation: Cut in nominal short-term and long-term interest rates by 1 percentage point.

V. Conclusion

This paper has outlined the supply-side framework of the OECD INTERLINK macroeconometric model. Compared to earlier versions, the long-run specification of the supply side is relatively simple, a deliberate decision which has been made in order to increase transparency in model properties. While the long-run equilibrium properties are broadly neo-classical, the framework should be more correctly described as being “New Keynesian”, since the presence of real and nominal rigidities can lead to a protracted period of adjustment following a demand or supply shock. Moreover, a number of features of the dynamic adjustment process can be related directly to key coefficients in particular equations. This has the merit of allowing standard statistical inference techniques to be used both to judge the robustness of particular simulation results and hence their reliability for policy purposes, as well as facilitating the understanding of cross-country differences in model properties.

ANNEX I. ESTIMATION PROCEDURES AND RESULTS

This Annex describes the empirical estimates of the various supply and wage/price equation components of the models for the G7 country models as described in the main text and the parameters underpinning the various calculations and simulation results reported in Sections III and IV. It includes descriptions of the relevant data definitions and sources and the relevant equation estimates and test statistics.

Variable definitions, notation and sources

In the following variable definitions, lower case letters are used throughout to denote logs, subscripts to denote lags and "Δ" the first difference operator. All data is semi-annual seasonally-adjusted form and taken from the OECD Analytical Data Base as used in conjunction with the OECD 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 (for the United States, Japan, Germany and France)
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 in the main text).
e*	=	Trend labour efficiency, is obtained by smoothing the labour efficiency index using a Hodrick-Prescott filter.
q*	=	Normal output (see Section II in the main text).
pr*	=	Trend labour productivity, a smoothed version of actual labour productivity.
CU	=	Capacity utilisation index as measured by q-q*.
w	=	Nominal wage costs per labour input (per hour for the United States, Japan, Germany and France).
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 term 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.
rp	=	Real user-cost of capital.
p_i	=	The business sector investment price deflator.

cost = Average unit costs, measured as: $\log\{a^{\sigma} (W/E^*)^{(1-\sigma)} + b^{\sigma} r^{(1-\sigma)}\}^{(1/1-\sigma)}$, for Japan, where $\sigma = 0.4$ is the substitution elasticity, and a and b are production function scale parameters; and $\{a(w-e^*) + (1-\alpha)r\}$, where α is the wage share, for the other G7 countries.

pc = Consumer prices.

pm = Import price of goods and services.

pme = Imported price of energy.

UNR = Unemployment rate.

TE = Employers' tax rate.

TI = Indirect tax rate.

TY = Income tax rate.

TIME = Time trend, increased by 1 each semester.

Test statistics

All the reported equations were estimated by OLS methods unless otherwise noted[15]. Students t statistics values are shown in brackets below their respective parameters. 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, estimating the equation over the full sample and a sample in which the last five observations are omitted.

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.

15. 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.

Equation estimates

The full set of equation estimates for the G7 economies are reported in Tables A1 to A5 as follows:

Table A1 Business sector employment
Table A2 Hours (G3 only)
Table A3 Business sector capital stock
Table A4 Business sector prices (value added deflators)
Table A5 Business sector wages (nominal wage costs)

In addition to the reported parameters, a small number of country specific dummy, variables which are not reported here, were found to be significant, most notably for the first energy price shock.

Table A1. Business sector employment equations

Dependent variable	Δ(l + h)	Δl	Δl	Δ(l + h)	Δl	Δl	Δl
Countries	**United States**	**Japan**	**Germany**	**France**	**United Kingdom**	**Italy**	**Canada**
Estimation period	65H1-92H2	70H2-91H2	61H2-92H2	64H2-92H2	63H1-92H2	61H1-91H2	67H1-93H2
Constant	-0.0331 (-2.2)	-0.3993 (-3.7)	-0.0199 (-2.4)	-0.0128 (2.7)	-0.0535 (-3.8)	-0.0249 (-2.6)	-0.0290 (-2.9)
Δl-1	--	--	0.2231 (2.2)	--	0.4569 (5.3)	0.4006 (3.9)	--
Δ(l + h)-1	0.2419 (5.3)	--	--	--	--	--	--
Δq	0.7090 (13.7)	0.1669 (3.5)	0.3588 (8.4)	0.2384 (6.0)	0.2869 (6.0)	0.1368 (3.2)	0.4973 (9.5)
Δq-1	--	0.0763 (1.6)	--	0.1925 (4.8)	--	--	0.1855 (3.4)
Δq-2	--	0.0960 (2.3)	0.1442 (2.5)	0.0931 (2.6)	--	--	--
Δwp	-0.3113 (-2.9)	-0.0812 (-3.3)	--	-0.1006 (2.5)	-0.1996 (-3.4)	-0.1105 (-2.5)	-0.2444 (-4.6)
Δwp-1	--	--	--	--	--	--	-0.0981 (-1.7)
Δe*	--	--	-0.6599 (-5.0)	-0.4019 (-3.6)	-0.4736 (-1.3)	--	--
ecm-1	0.0820 (2.1)	0.0628 (3.7)	0.0595 (2.9)	0.0282 (2.7)	0.1577 (3.8)	0.0633 (2.6)	0.0701 (3.0)
SE of regression	0.0050	0.0052	0.0087	0.0033	0.0108	0.0072	0.0138
R-squared	0.9128	0.6168	0.8119	0.7743	0.7753	0.4827	0.8728
Autocorrelation	1.3 (2)	4.6 (2)	0.5 (2)	0.1 (2)	5.8 (2)	1.4 (2)	3.6 (2)
Functional form	2.0 (1)	2.6 (1)	0.5 (1)	0.1 (1)	2.9 (1)	0.1 (1)	0.0 (1)
Normality	0.4 (2)	0.6 (2)	3.4 (2)	0.0 (2)	0.7 (2)	0.6 (2)	0.4 (2)
Heteroscedasticity	0.9 (1)	0.6 (1)	1.7 (1)	0.8 (1)	1.6 (1)	1.1 (1)	0.5 (1)
Predictive failure	2.1 (5)	0.2 (5)	2.8 (5)	2.3 (5)	14.5 (5)	3.7 (5)	3.4 (5)
Structural stability	4.6 (5)	4.6 (6)	5.9 (6)	11.3 (7)	9.4 (6)	10.7 (5)	4.1 (6)

Note: The ecm variable is defined as follows:
For the United States, Japan, Germany and France
ecm = (q - l - h) - σ.wp - (1-σ).e*, where the elasticity of substitution, σ, is 0.4 for Japan and 1.0 for other countries.
For the United Kingdom, Italy and Canada
ecm = (q - l) - σ.wp - (1-σ).e* where σ is 1.0.

Table A2. Hours equations

Dependent Variable	Δh		
Countries	United States	Japan	Germany
Estimation period	65H1-92H2	70H1-91H2	61H1-92H2
Constant	-0.0030	-0.0046	-0.0067
	(-4.0)	(-2.5)	(-2.9)
Δh-1	0.140	_	-0.3953
	(2.0)		(-3.1)
Δq	0.2290	0.3367	0.1934
	(6.8)	(5.4)	(2.6)
Δwp	-0.2289	-0.1667	_
	(3.8)	(-3.9)	
Δwp-1	_	-0.1114	-0.2004
		(-2.7)	(-2.5)
(h - h*)-1	-0.1752	-0.1460	-0.3171
	(3.3)	(-3.5)	(-2.7)
SE of regressions	0.0063	0.0077	0.0099
R-squared	0.8205	0.6071	0.3968
Autocorrelation	4.3 (2)	2.4 (2)	4.0 (2)
Functional form	3.6 (1)	0.1 (1)	0.3 (1)
Normality	2.6 (2)	0.8 (2)	1.0 (1)
Heteroscedasticity	0.7 (1)	4.5 (1)	3.0 (1)
Predictive failure	15.8 (5)	6.8 (5)	11.0 (5)
Structural stability	8.8 (5)	3.0 (5)	7.8 (5)

Table A3. Capital stock equations

Dependent variable	Δk						
Countries	**United States**	**Japan**	**Germany**	**France**	**United Kingdom**	**Italy**	**Canada**
Estimation period	80H1-92H2	72H1-91H2	75H1-92H2	64H1-92H2	63H2-92H2	75H1-91H2	68H2-93H2
Constant	-0.0064	0.0021	-0.0032	-0.0024	-0.0064	-0.0025	-0.0014
	(-1.6)	(2.3)	(-1.6)	(1.4)	(-2.3)	(-4.5)	(-0.3)
Δk-1	1.310	1.560	0.5370	0.8719	0.9657	1.1360	1.343
	(10.3)	(9.2)	(3.5)	(28.0)	(33.1)	(7.8)	(9.4)
Δk-2	-0.4355	-0.9150	0.4463	--	--	-0.2879	-0.6066
	(-3.7)	(-3.9)	(2.5)			(-2.2)	(-2.4)
Δk-3	--	0.6957	--	--	--	--	0.3988
		(3.0)					(1.7)
Δk-4	--	-0.6230	-0.1859	--	--	--	-0.2969
		(-2.7)	(-2.6)				(-2.2)
Δk-5	--	0.1729	--	--	--	--	--
		(1.3)					
Δq	0.0530	0.1021	0.0592	0.0618	0.0424	0.0388	0.0378
	(5.4)	(6.3)	(5.5)	(10.3)	(6.2)	(4.0)	(3.0)
Δq-1	--	-0.0443	--	0.0190	--	--	--
		(-1.8)		(2.9)			
Δq-2	--	-0.0156	--	--	0.0229	--	--
		(-0.9)			(3.4)		
ecm-1	0.0072	0.00247	0.00050	0.0027	0.00489	0.0040[1]	0.0041
	(1.8)	(0.8)	(2.1)	(1.5)	(1.9)		(1.1)
Δi/100	--	--	-0.0342	--	--	-0.0220	--
			(-1.8)			(-1.5)	
Δi-1/100	--	-0.0101	--	-0.0102	--	--	--
		(-0.6)		(-1.0)			
SE of regressions	0.0006	0.0090	0.0022	0.0006	0.0046	0.0024	0.0040
R-squared	0.9579	0.9936	0.9306	0.9880	0.9699	0.9186	0.9011
Autocorrelation	2.5 (2)	1.0 (2)	0.3 (2)	4.3 (2)	0.0 (2)	2.3 (2)	1.1 (2)
Functional form	1.2 (2)	1.4 (1)	1.9 (1)	2.0 (1)	0.2 (1)	0.5 (1)	0.0 (1)
Normality	0.2 (2)	0.1 (2)	36.4 (2)	0.3 (2)	0.7 (2)	1.0 (2)	3.3 (2)
Heteroscedasticity	2.7 (1)	2.8 (1)	0.4 (1)	2.0 (1)	0.0 (1)	0.3 (1)	0.0 (1)
Predictive failure	2.1 (5)	2.9 (5)	2.5 (5)	3.1 (5)	3.0 (5)	12.0 (5)	6.6 (5)
Structural stability	n.a.	13.0 (7)	2.9 (7)	9.9 (6)	9.7 (5)	7.3 (5)	12.9 (7)

Note: ecm is defined as ecm = $(q - k_{-1} - \sigma rp)$.

1. Imposed coefficient.

Table A4. Business sector value added price equations

Dependent variable	Δ[p - (w-e*)]						
Countries	United States	Japan	Germany	France	United Kingdom	Italy	Canada
Estimation period	66H2-92H2	70H1-91H2	63H2-92H2	64H2-92H2	64H1-92H2	65H1-91H2	67H1-93H2
Constant	0.0294 (1.9)	-0.0098 (-3.5)	0.0467 (2.1)	0.0577 (2.3)	0.0592 (2.0)	0.0919 (2.6)	0.0509 (2.0)
Δ[p-(w-e*)]-1	0.3529 (3.41)	0.3899 (2.41)	0.3794 (4.1)	0.2887 (3.1)	--	--	0.7066 (6.0)
Δ[p-(w-e*)]-2	--	--	--	0.3579 (3.9)	--	--	--
ΔΔw	0.6822 (-7.2)	-0.5424 (-4.3)	-0.3761 (-6.2)	-0.6292 (-7.2)	-0.2859 (-4.2)	-0.4367 (-7.2)	-0.7411 (-6.1)
ΔΔw-1	--	--	--	-0.4032 (-4.5)	-0.1318 (-1.9)	-0.3342 (-5.6)	--
ΔΔw-2	--	--	-0.1922 (-3.8)	--	--	-0.1867 (-2.8)	--
(P-cost)-1	-0.0503 (-2.0)	-0.1531 (-3.6)	-0.0709 (-2.1)	-0.0904 (-2.2)	-0.0972 (2.1)	-0.1437 (-2.5)	-0.0809 (-2.1)
ΔΔpm	--	--	--	--	--	--	0.0173 (2.3)
Δ(h-h*)	--	--	0.0988 (2.1)	--	--	--	--
CU-1	0.2390 (5.6)	--	--	0.1250 (1.2)	--	--	0.0760 (1.1)
ΔCU	0.2004 (3.3)	0.1973 (1.1)	--	--	--	--	--
ΔCU-1	--	0.4882 (2.7)	--	0.2724 (2.3)	0.1442 (1.3)	0.2848 (3.3)	0.1377 (0.9)
ΔCU-2	--	--	--	--	0.1858 (1.9)	--	--
SE of regressions	0.0071	0.0197	0.011	0.0074	0.0130	0.0147	0.0153
R-squared	0.7064	0.7635	0.6770	0.7542	0.4500	0.7165	0.5818
Autocorrelation	1.8 (2)	2.8 (2)	2.3 (2)	1.7 (2)	0.8 (2)	1.3 (2)	1.9 (2)
Functional form	0.0 (1)	1.4 (1)	0.7 (1)	0.4 (1)	1.5 (1)	1.9 (1)	4.7 (1)
Normality	1.6 (2)	2.8 (2)	1.0 (2)	0.8 (2)	4.6 (2)	1.1 (2)	0.1 (2)
Heteroscedasticity	1.8 (1)	0.1 (1)	2.8 (1)	0.1 (1)	1.2 (1)	0.2 (1)	0.1 (1)
Predictive failure	1.7 (5)	10.0 (5)	7.4 (5)	4.2 (5)	3.0 (5)	5.8 (5)	0.6 (5)
Structural stability	13.9 (6)	4.3 (6)	11.9 (6)	8.3 (8)	3.3 (6)	11.6 (6)	12.0 (6)

Table A5. Wage equations

Dependent variable	Δ(w - p)						
Countries	**United States**	**Japan**	**Germany**	**France**	**United Kingdom**	**Italy**	**Canada**
Estimation period	65H1-92H2	70H1-91H2	63H2-92H2	64H1-92H2	63H1-92H2	61H1-91H2	67H1-93H2
Constant	-0.0227	-1.522	-0.0165	0.0024	-0.0209	-0.05305	-0.0328
	(-1.3)	(-4.4)	(-1.2)	(0.3)	(-1.2)	(1.6)	(-1.7)
Δ(w - p)-1	0.2707	--	0.4784	0.3478	--	--	-0.4571[2]
	(2.7)		(4.2)	(3.6)			(3.8)
(w - p - pr*)-1	-0.0829	-0.0986	-0.0878	-0.0503	-0.1356	-0.3710	-0.1100
	(-1.9)	(-4.5)	(-2.4)	(-2.6)	(-2.2)	(-5.9)	(-2.2)
Δpr*	--	0.5121	--	--	--	--	1.0000[3]
		(3.3)					
ΔΔp	-0.5187	-0.3899	-0.2625	-0.2611	--	-0.1674	-0.3845
	(-4.4)	(-5.2)	(-1.9)	(-3.1)		(-1.7)	(-2.2)
ΔΔp-1	--	--	-0.2895	--	--	--	--
			(-2.8)				
u	--	-0.0503	--	--	--	--	--
		(-4.9)					
Δu	--	--	-0.0134	--	-0.0227	-0.0849	--
			(-2.5)		(-1.8)	(-3.7)	
u-1	--	--	--	--	-0.0051	-0.0483	--
					(-2.4)	(-8.5)	
U/100	-0.0021[1]	--	--	0.2117	--	--	-0.4917
	(-3.8)			(-5.8)			(-2.1)
U-1/100	--	--	-0.2056	--	--	--	-0.1956
			(-3.7)				(-2.6)
Δ(pc - p)	0.3330	--	--	0.4667	0.4260	--	0.2635
	(2.4)			(4.2)	(3.6)		(1.3)
ΔTE	0.5351	--	--	0.3434	0.2880	--	0.9984
	(2.7)			(1.8)	(0.8)		(2.4)
ΔTE-1	--	--	0.7297	--	--	0.1528	--
			(2.5)			(2.1)	
ΔTI-1	--	--	0.7441	--	--	--	--
			(2.8)				
Δ(pm - p)	--	--	--	--	--	0.4068	--
						(2.4)	
SE of regression	0.0045	0.0021	0.0135	0.0069	0.0132	0.0058	0.0045
R-squared	0.6631	0.8534	0.6795	0.8577	0.4664	0.6812	0.5532
Autocorrelation	2.5 (2)	2.4 (2)	4.1 (2)	0.1 (2)	0.5 (2)	4.3 (2)	1.1 (2)
Functional form	0.1 (1)	0.3 (1)	0.1 (1)	0.7 (1)	0.5 (1)	0.2 (1)	2.6 (1)
Normality	0.2 (2)	0.5 (2)	0.0 (2)	17.2 (2)	1.9 (2)	1.5 (2)	0.2 (2)
Heteroscedasticity	2.2 (1)	0.1 (1)	0.1 (1)	0.2 (1)	0.0 (1)	1.1 (1)	1.0 (1)
Predictive failure	2.7 (5)	6.3 (5)	3.1 (5)	2.1 (5)	1.0 (5)	3.9 (5)	2.5 (5)
Structural stability	10.7 (6)	2.3 (5)	7.8 (9)	2.5 (7)	2.5 (7)	11.6 (7)	13.3 (8)

1. Prime-age males.
2. Δ(w - p - pr*)-1.
3. Imposed coefficient.

ANNEX II. 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 (including intercept terms) which are exogenous or are assumed to be unchanged are generally ignored, unless otherwise stated.

Equilibrium in the goods market

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 = wage costs (per hour in those countries
- r = user-cost of capital
- rp = r-p, the real user cost of capital
- wp = w-p, real wage cost

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

$$q^* = \alpha(n+e^*) + (1-\alpha)k \qquad (A.3)$$

where e^* = trend labour efficiency
α = labour share parameter

Intensity of factor utilisation, IFU, is then defined as the deviation of actual output from normal output:

$$IFU = q - q^* \qquad (A.4)$$

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 intensity of factor utilisation, so that:

$$p = \{\alpha(w-e^*) + (1-\alpha)r\} + b_1\, IFU \qquad (A.5)$$

The specification of the factor demand and price equations ensure that in the long-run steady state actual output coincides with normal output.

Thus, equations (A.1)-(A.4) can be combined to give:

$$IFU = \alpha\, wp - \alpha\, e^* + (1-\alpha)\, rp \qquad (A.6)$$

and the price equation (A.5) can also be rearranged as:

$$- b_1\, IFU = \alpha\, wp - \alpha\, e^* + (1-\alpha)\, rp \qquad (A.7)$$

Equating the right hand sides of (A.6) and (A.7) then shows that for any value of b_1 normal and actual output coincide so that intensity of factor utilisation must be unchanged in the long-run, i.e. IFU=0, so that actual output is equal to normal output as required.

Equilibrium in the labour market

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 :

$$(w-p) = \gamma_0 + pr^* - \gamma_1\, U + \delta x \qquad (A.8)$$

If the economy is described by a Cobb-Douglas technology then the wage share is given by $\alpha = (W.N)/(P.Q)$. Taking logs of this expression and re-arranging, noting that $pr = q - n$, gives expression (A.9), where the asterisks denote a steady state equilibrium consistent with stable inflation.

$$(w-p)^* = pr^* + a, \qquad (A.9)$$

where a is the log of the labour share parameter. Assuming that in the long run the real wage is equal to this warranted real wage, then combining this expression with the wage equation (A.8) shows that there is a unique equilibrium rate of unemployment given by:

$$U^* = [(\gamma_0 - a) + \delta x]/\gamma_1 \qquad (A.10)$$

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". 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:

$$p = \{\alpha(w-e^*) + (1-\alpha)r\} + b_1 \text{ IFU} - b_2 \Delta\Delta w - b_3 \Delta\Delta r \qquad \text{(A.11)}$$

Here the addition of the terms $-b_2\Delta\Delta w$ and -b3$\Delta\Delta r$ 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.11) can be further simplified to (A.12) if it is assumed that following the shocks considered below, the real user-cost of capital, rp=(r-p), remains unchanged. Thus:

$$p = (w-e^*) + \beta_1 \text{ IFU} - \beta_2 \Delta\Delta w + \varepsilon_p \qquad \text{(A.12)}$$

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:

$$(w-p) = pr^* - \gamma_1 U - \gamma_2 \Delta\Delta p + \varepsilon_w \qquad \text{(A.13)}$$

where the $-\gamma_2\Delta\Delta p$ 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.12) and (A.13), can be simplified and combined to give:

$$\beta_1 \text{ IFU} - \gamma_1 U = \beta_2 \Delta\Delta w + \gamma_2 \Delta\Delta p \qquad \text{(A.14)}$$

But, in long-run equilibrium price and wage inflation must be stable, i.e. $\Delta\Delta w$ and $\Delta\Delta p$ are unchanged, and as outlined above, the constraints on the factor demand equations ensure that IFU 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):

$$\beta_1 \Sigma \text{ IFU} - \gamma_1 \Sigma U = \beta_2 \Sigma \Delta\Delta w + \gamma_2 \Sigma \Delta\Delta p \qquad \text{(A.15)}$$

where "Σ 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:

$$\beta_1 \Sigma \text{ IFU} - \gamma_1 \Sigma \text{ U} = (\gamma_2 + \beta_2)\, \pi \qquad \text{(A.16)}$$

The Sacrifice Ratio -- indicating the cumulative percentage point increase (decrease) in the unemployment rate, Σ 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 Σ IFU from equation A.16 in terms of Σ 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:

$$n = \theta_1(L)\, q - \theta_2(L)\, wp \qquad \text{(A.17)}$$

$$k = \theta_3(L)\, q - \theta_4(L)\, rp \qquad \text{(A.18)}$$

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.17) and (A.18) into (A.4) and (A.5) and summing all deviations from the impact of the shock to the time of the new equilibrium gives:

$$\Sigma \text{ IFU} = \{1\text{-}\alpha\theta_1(L)\text{-}(1\text{-}\alpha)\theta_3(L)\}\, \Sigma\, y$$

$$+\, \alpha\theta_2(L)\, \Sigma\, wp + (1\text{-}\alpha)\theta_4(L)\, \Sigma\, rp \qquad \text{(A.19)}$$

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 :

$$\Sigma \text{ IFU} = \alpha\, \Sigma\, wp \qquad \text{(A.20)}$$

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:

$$\Sigma\, wp = -\, \gamma_1\, \Sigma \text{ U} - \gamma_2\, \pi \qquad \text{(A.21)}$$

Then, eliminating Σ wp from (A.20) and (A.21) and substituting for Σ IFU in (A.17), and re-arranging, gives the following expression for the sacrifice ratio:

$$\text{Sacrifice Ratio} = \frac{-\Sigma U}{\pi} = \left[\gamma_2 + \frac{\beta_2}{1+\beta_1.\alpha}\right]\frac{1}{\gamma_1} \qquad \text{(A.22)}$$

If there is no long-run effect from intensity of factor utilisation on pricing behaviour, i.e. $\beta_1 = 0$, then this expression simplifies to:

$$\text{Sacrifice Ratio} = \frac{-\Sigma U}{\pi} = \frac{(\gamma_2 + \beta_2)}{\gamma_1} \qquad \text{(A.23)}$$

Hence from equations (A.22) and (A.23) 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 effects 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.12) and (A.13), (where wedge, e, and ε_p are all unchanged by assumption):

$$- \beta_1 \text{ IFU} + \gamma_1 \text{ U} = - \beta_2 \, \Delta\Delta w - \gamma_2 \, \Delta\Delta p + \varepsilon_w \qquad \text{(A.24)}$$

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

$$\text{U} = \frac{\varepsilon_w}{\gamma_1} \qquad \text{(A.25)}$$

Thus the increase in the unemployment rate necessary to restore equilibrium is directly proportional 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):

$$- \beta_1 \, \Sigma \text{ IFU} - \gamma_1 \, \Sigma \text{ U} = - \beta_2 \, \Sigma \, \Delta\Delta w - \gamma_2 \, \Sigma \, \Delta\Delta p + \Sigma \, \varepsilon_w + \Sigma \, \varepsilon_p \qquad \text{(A.26)}$$

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

$$- \beta_1 \, \Sigma \text{ IFU} - \gamma_1 \, \Sigma \text{ U} = \Sigma \, \varepsilon_w + \Sigma \, \varepsilon_p \qquad \text{(A.27)}$$

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

$$\Sigma \, \text{IFU} = \frac{\alpha . \Sigma \varepsilon_p}{1 + \alpha . \beta_1} \qquad \text{(A.28)}$$

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

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

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 $(1/\beta_1)$.

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