A Systems Approach to Estimating the Natural Rate of Unemployment and Potential Output for the United States

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A Systems Approach to Estimating the Natural Rate of Unemployment and Potential Output for the United States

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Abstract

The methodology used in this paper has three distinguishing features: the natural rate of unemployment and potential output are jointly estimated; estimation integrates wage and price data with "real" and structural data; and third, the methodology encompasses many of the methods found in the literature. The results indicate that potential output growth has recovered somewhat during the early 1980s, but remains below the rapid rates of increase in the late 1960s. The natural rate, after rising during the late 1960s and the 1970s, is found to have declined in the 1980s. The paper concludes with an assessment of medium-term prospects for potential output and the natural rate.

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Summary

In past empirical research on the natural rate of unemployment and potential output, the two concepts are typically estimated independently or recursively (i.e., by deriving estimates of one on the basis of the value of the other, which is either proxied, assumed, or previously estimated). The methodology used in this paper has three distinguishing features. First, the natural rate of unemployment and potential output are jointly estimated based on a system of simultaneous equations. Second, the estimation procedure integrates wage and price data with "real" and structural data. Third, the methodology encompasses many of the estimation methods found in the literature. Estimates of the natural rate of unemployment and potential output obtained in this way are consistent with each other, robust in terms of their relationship to actual wage and price inflation, and based firmly on their underlying structural determinants.

A number of alternative single-equation estimation results are reported for the wage, price, unemployment, and output equations. The equations are then combined and estimated as a system. In this system there are no proxies for potential output or the natural rate of unemployment that are jointly estimated and fully consistent. The estimation based on a systems approach also helps clarify the conditions that prevail in equilibrium when the actual unemployment rate is equal to the natural rate of unemployment and when actual output is equal to potential output. These conditions are: there are no pressures for wage or price inflation to rise or fall, real wages grow at the same rate as labor productivity at potential output and prices at the same rate as normalized unit labor costs, and income shares are constant.

The estimation results indicate that the growth of potential output in the United States has recovered somewhat from the slow pace during the 1970s but remains below the rapid rates of the late 1960s. Similarly, the natural rate of unemployment is estimated to have declined in the 1980s, after rising substantially during the 1970s. The results also suggest that in 1988 actual output exceeded potential output and the unemployment rate was below the natural rate, implying an intensification of inflationary pressures.

The paper concludes with an assessment of the medium-term prospects for potential output. A further improvement in the growth of labor productivity is expected on the basis of likely evolutions of total factor productivity and the capital-labor ratio, but is expected to be offset to a significant extent by a continued slowdown in the growth of labor input that is in prospect. Accordingly, a modest pickup in the growth of potential GNP (to an average annual rate of slightly above 2 1/2 percent) is likely in the period 1989-94. This estimate takes into account another conclusion of the paper that the natural rate is expected to decline to about 5 percent by 1994.

I. Introduction

The closely related concepts of the natural rate of unemployment and potential output are central to many economic policy discussions. In the near term, these concepts summarize the extent to which inflationary or disinflationary pressures exist in labor and product markets; or, alternatively, the capability of the economy to increase the growth of employment and output without increasing inflation. Over the medium to long run, they determine the sustainable pace of noninflationary output and employment growth.

Since neither the natural rate of unemployment nor potential output is observed, empirical counterparts to these theoretical constructs must be estimated. 1/ The paper begins with a brief discussion of the most common approaches (Section II). 2/ In general, the natural rate of unemployment or potential output are either estimated independently or recursively by deriving estimates of one from the other, and do not allow for information on wage and price developments to simultaneously influence the estimates.

There are three distinguishing features of the methodology used in this paper to estimate the natural rate of unemployment and potential output; first, they are jointly estimated based on a system of equations; second, the estimation procedure systematically integrates wage and price data with "real" and structural data in the determination of the natural rate of unemployment and potential output; and third, the methodology encompasses many of the methods found in the literature. In this way estimates of the natural rate of unemployment and potential output are obtained which are consistent with each other, robust in terms of their relationship to actual wage and price inflation, and rich in terms of their underlying structural determinants.

The research strategy was to conduct the preliminary specification search in terms of independently estimated single equations; these are presented and discussed in Section III. The wage, price, unemployment, and output equations are then combined, with the appropriate cross-equation restrictions, and estimated as a system in Section IV. This allows trend output and productivity used in the preliminary unemployment, wage, and price equations to be replaced with expressions for potential output and productivity derived from the production function; and it allows an expression for the natural rate of unemployment from the unemployment equation to be explicitly incorporated into the wage

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1/ Both concepts became widely used in the United States in the 1960s. For potential output, the basic reference is the 1962 Economic Report of the President and Okun (1962); for the natural rate of unemployment, the seminal papers are Phelps (1967) and Friedman (1968).

2/ For a survey of the relevant empirical literature, see Appendix II in SM/88/162, and Iden (1989).

equation. In this system of equations, the natural rate of unemployment and potential output are jointly estimated and fully consistent.

Inflationary pressures which now exist in labor and product markets, and prospects for the likely development of the natural rate of unemployment and potential output over the medium term, are discussed in Section V. This section also includes a comparison of the estimates for potential output with those prepared by the previous Administration in early 1989 1/ and discusses the sources of the differences.

II. Alternative Approaches to Estimating the Natural Rate of Unemployment and Potential Output

1. Smoothing methods

Before discussing estimates of potential output and the natural rate of unemployment derived from econometrically estimated equations, it is useful to distinguish them from seemingly theory-free estimates inferred from unemployment rate and output data. An attractive feature of this class of estimates, which are essentially based on smoothing the data or selecting periods when output or unemployment are judged to be at their natural levels, is their simplicity. The estimates can be useful benchmarks for when inflationary pressures may emerge in labor and product markets. For other policy purposes, the usefulness of these types of estimates--which hereafter will be referred to as "trend" estimates--is limited by the absence of information concerning the determinants of the natural rate or potential output.

With regard to estimating potential output, the most common procedure is to fit a trend either to actual output or through its peaks (see Chart 1, top panel). 2/ The choice between these two methods implies different views of the business cycle and, some would argue, of the role of macroeconomic policy. The essential point is whether the gap between actual and potential output is, on average over some cyclically neutral historical period, zero or positive. In the latter case, there is presumably scope for appropriate macroeconomic policies to increase the mean level of output; in the former case, macroeconomic policies may be able to reduce the variability, but not the mean, of output. 3/ In either case, the estimates are sensitive to judgements about the timing and degree to which trends are allowed to change, and the cyclical position of the initial and final observations. The latter greatly affects trend estimates at the end of the historical period, a period important for policy purposes.

1/ Presented in the Annual Report of the Council of Economic Advisors, January 1989.

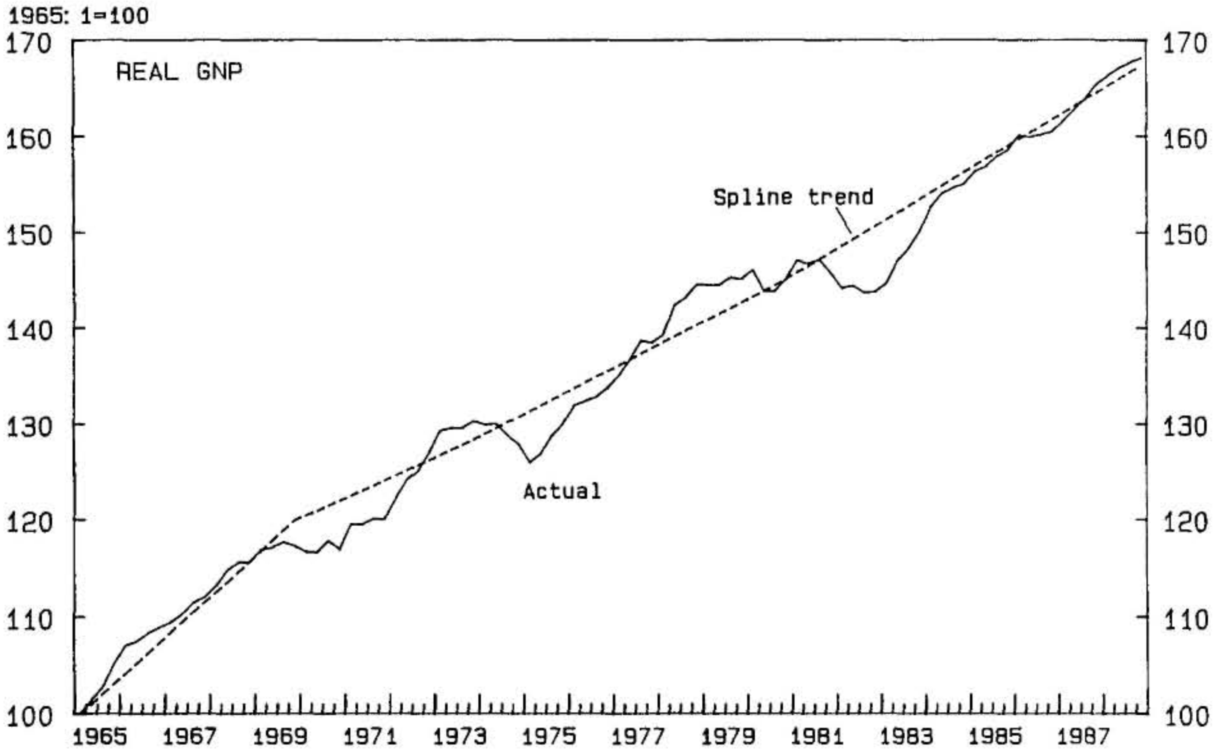
2/ Most commonly either a linear, quadratic, spline, or trend through peak methodology is used as a proxy for potential output; see for example Klein (1962).

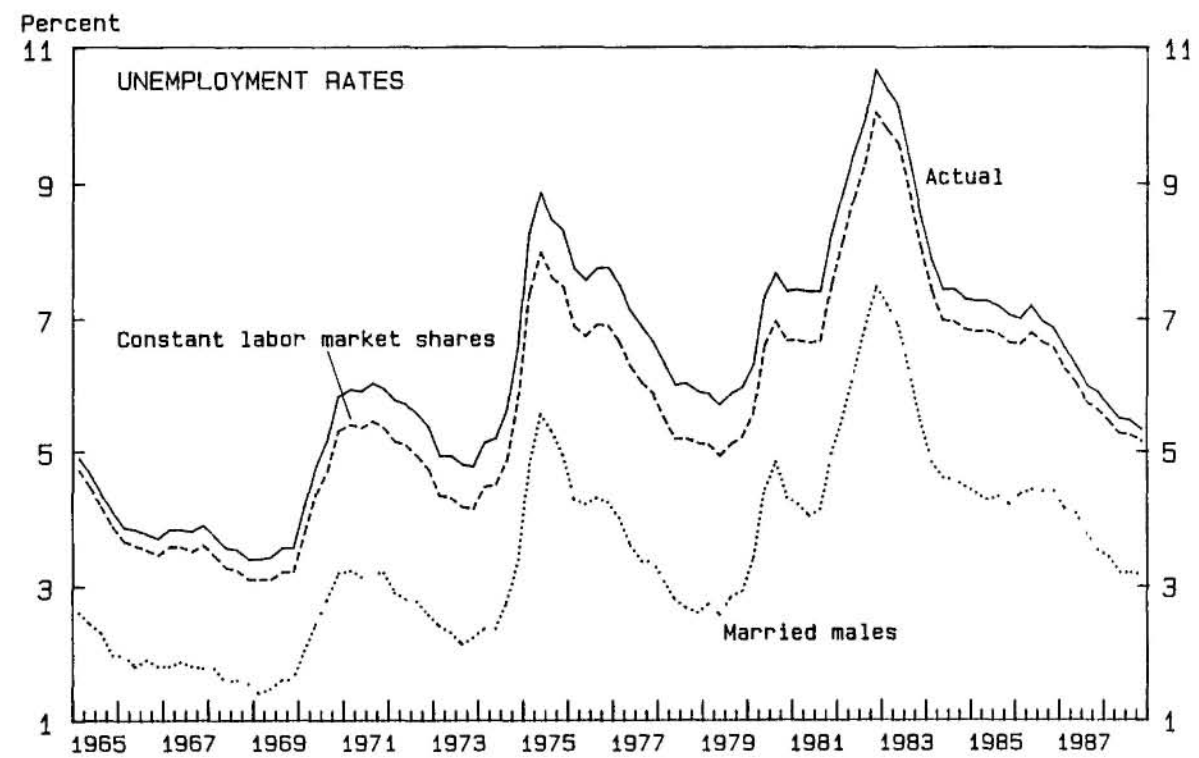
3/ See Delong and Summers (1988).

CHART 1

UNITED STATES

OUTPUT AND UNEMPLOYMENT RATES





Similarly, specific unemployment rates during periods of "high employment" are often used as proxies or estimates of the natural rate of unemployment (Chart 1, lower panel). Perry (1970) and Gordon (1985), for example, use an unemployment rate where the shares of various labor market groups are held constant. Others use the unemployment rate for specific segments of the labor force, the unemployment rate for married or prime-age males, for example. 1/ The implicit assumption in these approaches is that it is possible to identify groups whose "natural" rate of unemployment has been stable over some time period.

2. Econometric approaches 2/

Most econometric attempts to estimate the natural rate of unemployment or potential output typically involve one or two of the following key relationships describing goods and labor markets. Equations for the unemployment rate, wages, output, and prices can be expressed in general form as follows (lower case symbols indicate logarithms, Δx represents the change in x): 3/

$$U = \alpha_0 + \alpha_1(y-y^{tr}) + f(\text{STRUCTURAL}) + \alpha Z^u + e_u \quad [1]$$

$$\Delta w = \Delta p^{exp} + \beta_1(U-U^{NAT}) + \beta_2\Delta q + (1-\beta_2)\Delta q^{tr} + \beta Z^w + e_w \quad [2]$$

$$y = \gamma_0 + \gamma_1 h + \gamma_2 k + \gamma_3 rd + \gamma Z^y + e_y \quad [3]$$

$$\Delta p = (\Delta w-\Delta q^{tr}) + \delta_1(y-y^{tr}) + \delta Z^p + e_p \quad [4]$$

The first equation relates the unemployment rate (U) to a cyclical variable represented by the deviation of actual output (y) from trend output (y^{tr}), and a set of structural variables. The Z's represent vectors of other relevant variables (including dummy variables for specific periods), and the e's are error terms. Equation [2] is a Phillips curve relating the growth of wages (Δw) to inflation expectations (Δp^{exp}), the gap between the actual and the natural rate of unemployment (UNAT), and

1/ Modigliani (1988) and Vroman and Abowd (1988).

2/ The following discussion is based in part on Adams, Fenton, and Larsen (1987).

3/ The general specification of the estimated short-run equations would include a distributed lag operator on each variable.

a weighted average of the growth of actual and trend labor productivity (Δq, Δq^{tr}). The production function (equation [3] relates output (y) to labor (h) and capital (k) inputs, and to the stock of research and development capital (rd). Finally in equation [4], the growth of prices (Δp) is determined by the growth of normalized unit labor costs ($\Delta w - \Delta q^{tr}$) and the output gap ($y - y^{tr}$).

a. Phillips curves

Perhaps the most common method of estimating the natural rate of unemployment is to infer it from the parameters of an estimated Phillips curve. If the natural rate and trend productivity growth (Δq^{tr}) are subsumed in the constant term (β_0, not included above), 1/ equation [2] becomes a relatively standard Phillips curve from which the implicit natural rate can be calculated as:

$$U^{NAT} = \{\beta_0 - (1-\beta_2)\Delta q^{tr}\}/\beta_1$$

The economic interpretation of this estimate of the natural rate is that it is the rate of unemployment which is consistent with real wage growth being equal to the growth of trend labor productivity; i.e., the rate of unemployment consistent with stable income shares. Unless nominal wage growth fully reflects cyclical or short-run labor productivity growth (β_2=1), the calculated natural rate of unemployment will be inversely related to trend productivity growth. 2/

This Phillips curve approach to estimating the natural rate of unemployment has the advantage of explicitly taking into account the relationship between wage inflation and the labor market gap. This is important because much of the policy interest in the natural rate of

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1/ The specification of the wage equation in [2] does not include a constant because the natural rate and trend productivity growth are explicitly included in the equation. If these terms are not explicitly included, they are implicit in the constant which is equal to $-\beta_1 U^{NAT} + (1-\beta_2)\Delta q^{tr}$. Unless the constant is interpreted in this way, the wage equation will not have the property that in equilibrium the growth of real wages is equal to trend productivity growth.

2/ A variant of this method involves substitution of the price expectations and price equations into the wage equation, and then solving for the non-accelerating inflation rate of unemployment--the NAIRU. The economic interpretation of the NAIRU is similar to the interpretation of the Phillips-curve-based estimate of the natural rate given above except that the NAIRU also reflects changes in the unemployment rate needed to offset the inflation implications of any shocks coming through the price or price expectations equations. For an approach to the estimation of potential output that explicitly distinguishes between the NAIRU and the natural rate, see Stockton and Struckmeyer (1986).

unemployment derives from its implications for wage inflation. An important disadvantage is that, in general, the structural determinants of the natural rate do not play an important role in its estimation. 1/

b. Unemployment rate equations

An alternative approach to estimating the natural rate of unemployment, one which focuses explicitly on its structural determinants, is based on an unemployment rate equation. 2/ The key requirement of this approach is to distinguish in estimation between cyclical and structural unemployment. Based on an estimated version of equation [1], and setting the output gap at its cyclically neutral level, the natural rate can be calculated as

$$U^{NAT} = \alpha_0 + f(STRUCTURAL)$$

where all right-hand side parameters are at their long-run values. Structural variables would include, for example, demographic factors, unemployment insurance replacement ratios, relative minimum wages, and the degree of unionization of the work force. To the extent that statistically significant parameter estimates are obtained for the structural variables, these estimates add empirical substance to the analysis of the possible effects of structural policies.

This approach, has the disadvantage of not incorporating any information on actual wage developments, and requiring proxies for trend or potential output. In practice, smoothing techniques are typically used to estimate trend output. The natural rate is then calculated based on a somewhat circular assumption about the level of the output gap consistent with "full employment".

c. Okun's Law

Another widely used method of calculating potential output is based on Okun's law. 3/ This "law" is an assumed relationship linking the gap between the actual and the natural rates of unemployment, and that between actual and potential output,

$$(y-y^{pot})\cdot 100 = g(U-U^{NAT})$$

1/ In principle, the structural determinants of the natural rate could be included in the estimated Phillips curve in which case they would enter the calculation of the natural rate. For an example of an approach that attempts to include structural variables in a wage equation, see Gordon (1982).

2/ See Barro (1977), Collyns (1984), Adams et al. (1987), and Coe (1989).

3/ Okun (1962).

Given estimates or assumptions about the natural rate of unemployment, potential output can be calculated as

$$y^{pot} = y - g(U-U^{NAT})/100$$

where g is the Okun coefficient. Alternatively the natural rate of unemployment can be calculated given estimates or assumptions about potential output. 1/

Aside from the possibility that the Okun coefficient may not be stable, this approach has a number of drawbacks. The most important is that these estimates of potential output depend entirely on the estimates of the natural rate of unemployment, and embody no further information on the structural determinants of potential output. In particular labor and capital inputs play no explicit role in the determination of potential output.

d. Production functions

A more structural approach to the estimation of potential output is to explicitly model output in terms of underlying factor inputs. 2/ Given an estimated production function like [3], potential output can be calculated as that level of output which results when all factors are at their "normal" or "natural" levels. Determining the normal levels of factor inputs is an important step and is usually done by incorporating estimates of the natural rate of unemployment into the calculation of normal labor input, or by relating factor inputs, and hence output, to the deviation of output from its "normal" level. Alternatively, the "normal" levels of factor inputs can be determined from a fully specified model in which a general production function (or its dual, the cost function) is estimated jointly with a set of derived factor demand and supply functions. While such an approach has considerable theoretical appeal, and can deliver more efficient estimates of key relationships, its implementation can become very complex when allowance is made for adjustment costs. 3/ Largely as a result of this complexity, and because the Cobb-Douglas form of the production function given by equation [4], appears adequate to describe the behavior of broad sectors of

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1/ The Congressional Budget Office's estimates of potential output and the natural rate follow this methodology; see "Methodology of Medium-Term Economic Projections," Appendix B in Congressional Budget Office (1988).

2/ This approach has been used at the IMF, see Artus (1977), Adams et al. (1987), and Masson et al. (1988); and at the OECD, Torres and Martin (1989) and the references cited therein.

3/ For an example of the complexities, see Pindyck and Rotemberg (1983).

many economies, the more simple approach described earlier is often adopted.

This production function approach is now fairly common and has the advantage of explicitly relating potential output to factor inputs, including, in principle, factors such as research and development which might directly influence technical progress. Although incorporating estimates of the natural rate of unemployment into the calculation of potential output ensures some consistency, the implications of the estimates of potential output are not, in general, exploited in the determination of the natural rate of unemployment, wages, or prices. Moreover, any method in which potential output is estimated as a function of an assumed "trend", which is itself a proxy for normal or potential output, involves some circularity. A further drawback of the production function approach when used in isolation is that, given its use as an indicator of inflationary pressures, the estimation procedure does not exploit the information contained in price developments.

3. A systems approach

Each of the methods discussed above has some attractive features. The fact that they are complementary and not mutually exclusive, suggests that richer and more robust estimates might be obtained from a systems approach that makes use of all four equations. 1/ Such an approach is implemented below based on a two-stage procedure.

The first stage involves a preliminary specification search over alternative lag distributions, fuctional forms, etc.; this is based on single equation estimates similar to equations [1] through [4]. For these purposes, proxies for potential output and labor productivity are used, and the natural rate of unemployment is subsumed in the constant term of the wage equation. In the second stage, the expression for the natural rate derived from the unemployment equation is substituted into the wage equation; and the expressions for potential output and for labor productivity at potential output derived from the production function are substituted into the unemployment, wage, and price equations. The four equations, with the necessary cross-equation parameter restrictions, and allowing for covariances across the error terms, are then estimated as a system. In this system, there are no proxies for either the natural rate of unemployment or potential output because both are estimated consistently and simultaneously together with the other parameters in the system.

1/ For an approach that integrates the estimation of the production function with the estimates of the wage and price equations, see Stockton and Struckmeyer (1986).

III. Single-Equation Estimation Results

Given the size and complexity of the complete system, the preliminary specification search was based on single equation estimates using ordinary least squares and quarterly data from 1965:I to 1988:IV (96 observations). 1/ For these first-shot estimates, a spline function was used to construct proxies for trend output (y^{tr}, Chart 1) and trend labor productivity growth (Δq^{tr}, Chart 2). 2/ A demographically adjusted unemployment rate (U-DEM), with the age-sex composition held constant at 1965:I levels, has been used in both the estimated wage and unemployment rate equations (Chart 1). 3/

Although these single equation estimates are preliminary, they are interesting in their own right. Alternative equations are discussed to give a sense of the robustness of the estimated parameters and of the specification used for the system estimates. For each equation, issues of dynamic specification, functional form, and stability are addressed with reference to the relevant empirical literature.

Almost all of the estimated coefficients are readily interpreted as elasticities or semi-elasticities because variables are generally entered as logarithms or in units of percent (or their logarithmic equivalents). 4/ Thus an estimated coefficient of -0.6 on the adjusted unemployment rate (U-DEM) in the Phillips curve equation means that a 1 percentage point increase in the unemployment rate results in a 0.6 percentage point decrease in the annual rate of wage inflation (Δw).

1. Phillips curves

a. Specification issues

A relatively general specification of the Phillips curve, one which subsumes many of the alternative specifications found in the literature, relates the growth of nominal wages (Δw) to excess demand in the labor market as measured by the unemployment rate (U-DEM); inflation expectations (Δp^{exp}); the growth of labor productivity (Δq and/or Δq^{tr}); and

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1/ Except for the production function which, on account of data availability, was estimated from 1965:I to 1987:IV.

2/ The growth rates of these trends change at business cycle peaks but are constant in the intervening segments. The spline trends were not allowed to change at the 1981:III peak which is only separated from the previous peak by two quarters.

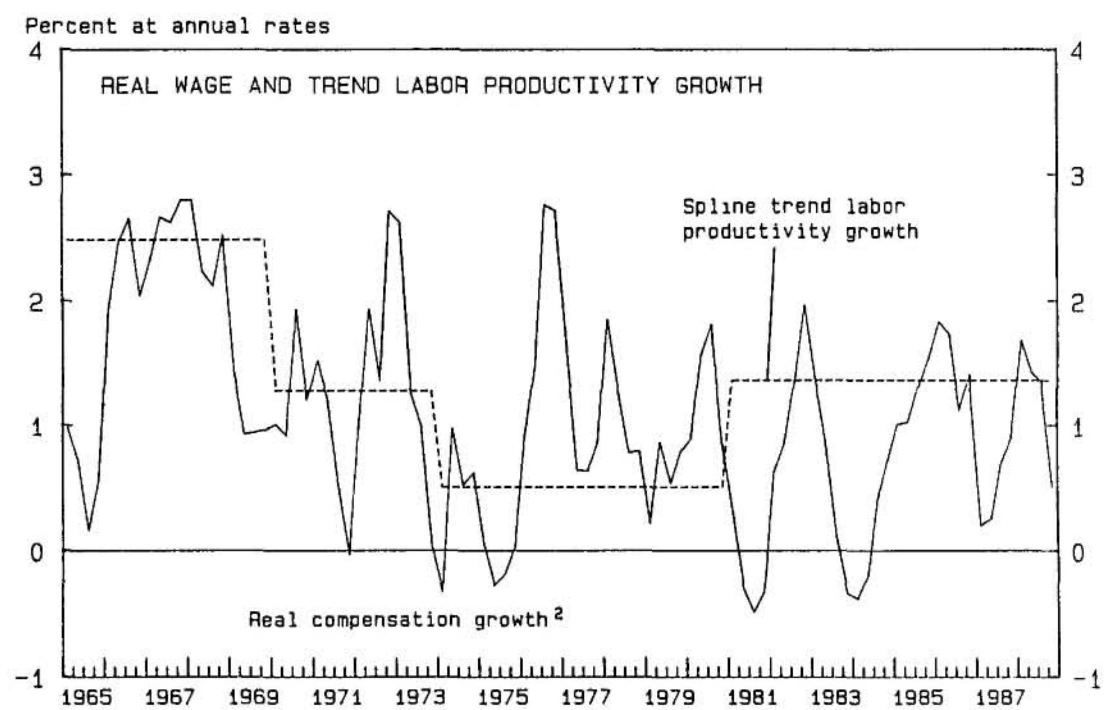
3/ The age groups are 15 to 24, 25 to 54, and 55 and older.

4/ Thus the first differences of logarithms have been multiplied by 400 to make them comparable to annual percentage rates of growth; and the differences between logarithms have been multiplied by 100 to make them comparable to percents. To avoid complicating the notation, these multiplications are not explicitly specified in the tables and equations.

CHART 2

UNITED STATES

COMPENSATION, UNEMPLOYMENT, AND PRODUCTIVITY[1]



[1]Compensation is measured on an hourly basis for the nonfarm business sector.
[2]Four quarter moving average.

various supply shocks (equation [2] above). 1/ This formulation is sufficiently general to apply either to atomistic segments of the labor market, where competitive pressures exert a direct impact on wage growth, or to more centralized bargaining environments where competitive pressures operate indirectly through income shares and relative bargaining powers.

Economic theory suggests a number of restrictions on the long-run relationship between wages, prices, and productivity. In equilibrium, when inflation expectations are realized, real wages should grow in line with labor productivity, implying stable income shares. Moreover, for such an equilibrium to be independent of the inflation rate, the coefficients on inflation expectations should sum to unity. The specification of equation [2] above is consistent with these a priori considerations.

By contrast, economic theory offers few, if any, restrictions on the short-term dynamics. In the short run, wage increases may deviate from their long-run rate as a result of expectational errors or deviations of productivity growth from its trend rate. The process whereby adjustment to long-run equilibrium occurs is generally left unspecified, but presumably reflects the response of wage increases to excess demand in the labor market and the adjustment of inflation expectations. In the United States, institutional features such as staggered wage contracts suggests that the lags in this adjustment process may be relatively long.

There are a number of issues regarding the specification of the estimated Phillips curve which were explored, and are only summarized here. Reflecting the importance of staggered and overlapping wage contracts in the unionized sector, as well as inertia in the response of wages to past inflation, inflation expectations were found to be well characterized by lags of about three years on past inflation. 2/ A linear specification of the unemployment rate adjusted for demographic factors fitted the data as well or better than non-linear specifications such as the reciprocal or the logarithm of the unemployment rate. 3/ An error correction formulation of the wage equation, where the deviation of real wages from their long-run level is included as an additional explanatory variable, was rejected by the data. Since the error-correction formulation effectively converts the equation to a

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5/ For a discussion of the role of supply shocks in the wage equation, see Gordon (1982) Many of the specification issues discussed below are addressed in a multi-country context in Coe (1985).

2/ Long lags have been found in many studies, e.g., Vroman and Abowd (1988) and Gordon (1982). Forward-looking specifications of inflation expectations did not appear to adequately describe wage behavior.

3/ The unemployment rates for married men and for prime aged males are strongly correlated with the demographically adjusted unemployment rate (Chart 1), and did not perform significantly better in the equations.

relationship between the levels of wages, prices, the unemployment rate and productivity, the results suggest that the Phillips curve specification, which is in terms of rates of change, is appropriate.

b. Estimation results

A number of alternative wage equations are reported in Table 1. The measure of wages used is hourly compensation in the private nonfarm business sector. This relatively broad measure of labor costs includes wages and salaries as well as employers' contributions to social security and private insurance and pension funds (nonwage labor costs). Labor productivity (q) is also measured on an hourly basis for the nonfarm business sector. Consumer (p^c) and output prices (p) are the implicit deflators for personal consumption expenditures and for output in the nonfarm business sector, respectively.

The first equation indicates that even a very simple specification including only the demographically adjusted unemployment rate (U-DEM) and consumer price inflation (a 5-quarter, $\phi(L)dp^c$, and 12-quarter, $\theta(L)dp^c$, moving average) does a good job of explaining wage developments. The estimated coefficients are well determined with the expected signs, and the sum of the coefficients on the change in consumer prices is indistinguishable from its expected value of unity. In this equation, neither productivity growth (Δq^{tr} or Δq) or the natural rate are entered explicitly. The constant term in the equation, which implicitly incorporates these two variables, is thus very important, as suggested by its relatively large estimated coefficient.

The second equation in Table 1 includes the change in the unemployment rate in the wage equation (Δ(U-DEM)). An estimated negative coefficient on the change, in conjunction with the level of the unemployment rate, would suggest that, for a given level of unemployment, wage pressures intensify when unemployment is falling. Alternatively, if the change but not the level of the unemployment rate were significant, this would suggest hysteresis-type effects, which have recently been discussed in the context of European unemployment rate developments. 1/ The estimated coefficient on the change in the unemployment rate is incorrectly signed and not statistically different from zero when this term is entered, either alone or in conjunction with the level of the unemployment rate, which remains statistically significant. 2/

1/ For a discussion of hysteresis effects, see the papers included in Cross (1988).

2/ Gordon (1985) finds some evidence of change effects in the wage equation. See also Blanchard (1986).

Table 1. Phillips Curve Equations 1/

	1	2	3	4	5	6
Constant	6.051 (0.68)	6.300 (0.72)	3.446 (1.02)	3.322 (1.02)	3.429 (0.94)	-0.202 (0.26)
U-DEM	-0.827 (0.15)	-0.850 (0.15)	-0.468 (0.15)	-0.454 (0.15)	-0.531 (0.14)	-0.577 (0.15)
$\phi(L)\Delta p^c$	0.345 (0.17)	0.280 (0.18)	0.521 2/ (0.15)	0.558 2/ (0.16)	0.574 2/ (0.14)	0.640 2/ (0.14)
$\theta(L)\Delta p^c$	0.656 (0.22)	0.698 (0.23)	0.479 2/	0.442 2/	0.426 2/	0.360 2/
$\theta(L)\Delta q$			0.385 (0.18)	0.388 (0.18)	0.350 (0.17)	0.559 2/ (0.15)
Δq^{tr}						0.441 2/
$\Delta(p^c-p)$				-0.124 (0.09)	-0.132 (0.08)	-0.158 (0.08)
Δ(U-DEM)		0.527 (0.45)				
ΔNWLC					0.790 (0.20)	0.900 (0.20)
D(68:I)			5.693 (1.28)	5.463 (1.28)	5.245 (1.20)	5.114 (1.21)
D(70:III to 71:III)			0.827 (0.59)	0.800 (0.59)	0.634 (0.55)	0.970 (0.56)
D(72:I, 73:I, 74:II)			2.748 (0.75)	2.822 (0.75)	1.674 (0.75)	1.421 (0.77)
D(82:IV to 88:IV)			-0.640 (0.37)	-0.552 (0.37)	0.081 (0.38)	
TREND						0.081 (0.03)
$TREND^2$						-0.00048 (0.0002)
R^2	0.640	0.645	0.700	0.707	0.751	0.731
SEE	1.482	1.500	1.250	1.243	1.153	1.170
DW	2.11	2.17	2.07	2.09	2.17	2.13
F-statistics						
Autocorrelation (1-4) (CV = 2.5)	0.45	0.61	1.36	1.38	0.59	0.26
ARCH (1-4) (CV = 2.5)	0.92	1.15	1.09	1.05	1.38	0.69
Break 85:IV (CV = 1.9)	0.54	0.49	0.64	0.63	0.90	0.94
Break 82:IV (CV = 1.7)	0.55	0.49	0.69	0.67	0.77	0.84

1/ The dependent variable is the annual percentage change in hourly compensation in the private nonfarm sector. All equations are estimated on quarterly data over the period 1965:I to 1988:IV (96 observations) using PC GIVE version 6.0. Standard errors are shown in parentheses. Critical values (CV) at the 5 percent level of significance are shown for F-statistics. Detailed descriptions of variables are given in the text. $\phi(L)$ and $\theta(L)$ indicate, respectively, 5- and 12-quarter moving average lag operators. Δ indicates the first difference.

c. The recent "moderate" behavior of wages

The moderate growth of labor compensation during the 1980s has been much commented upon. Not only has the growth of labor compensation been low relative to productivity growth (see Table 2), it also appears to have been weaker than predicted by previously estimated wage equations. 1/ This suggests either that the natural rate of unemployment has shifted or that there has been some other change in the relationship between wages and its historical determinants.

Table 2. Wage, Price, and Productivity Developments 2/

	Compen- sation 3/	Consumer Prices 4/	Real Consump- tion Wages 5/	Real Product Wages 5/	Labor Produc- tivity 3/
1965:I-1969:IV	5.86	3.45	2.41	2.27	1.59
1970:I-1973:IV	6.77	5.08	1.69	1.98	1.90
1974:I-1980:IV	8.85	8.05	0.80	0.72	0.53
1981:I-1988:IV	4.94	4.29	0.65	0.90	1.35

The ex-post forecast errors from the first wage equation reported in Table 1, estimated from 1965:I to 1982:IV, are shown in Table 3. The equation overpredicts compensation growth in 20 out of the 24 quarters from 1983 to 1988 with an annual average forecast error of 1 percentage point. Although the equation passes the Chow test for structural breaks

1/ See, in particular, Vroman and Abowd (1988), Gordon, (1988), and Neumark (1989).
2/ Annual percentage rates of change.
3/ Hourly, private nonfarm business sector.
4/ Annual percentage change in the personal consumption deflator.
5/ The real consumption wage is hourly compensation relative to the consumption deflator, the real product wage is relative to output prices in the private nonfarm sector.

in 1982:IV and 1985:IV (see Table 1), there is some evidence of structural instability from recursive estimation and from dummy variables. 1/

Table 3. Forecast Errors From the Wage Equation 2/

	Average Annual Forecast Error (Actual Less Predicted)	Number of Quarterly Overpredictions
1983	-1.72	4
1984	-1.02	3
1985	-0.47	4
1986	-0.20	3
1987	-1.45	3
1988	-1.30	3
Average error	-1.03	
Total overpredictions		20

While there have been a number of attempts to explain the overprediction of wage inflation in the 1980s, its statistical significance and the underlying causes remain unclear. Possible explanations include the declining role of trade unions (Neumark (1989) and Mitchell (1987)), increased foreign competition (Vroman and Abowd (1988)), shifts in income distribution between labor and capital (Gordon (1988)), and a decline in the natural rate of unemployment. 3/ Recently, Taylor (1988) has suggested that the moderate wage growth may be the result of wage earners persistently underpredicting the warranted growth of real wages during an exceptionally strong recovery of economic activity.

1/ Recursive estimation techniques and out-of-sample forecast analysis are better able to detect structural breaks than the Chow test. See Hendry (1989). When the equation is estimated up to 1988:IV including a dummy variable with a value of unity from 1982:IV to 1988:IV, the estimated coefficient is negative and statistically significant.

2/ These errors are out of sample forecasts (based on the realized values of the right hand side variables) from the first equation reported in Table 1 estimated from 1965:I to 1982:IV, expressed in percentage points.

3/ The Congressional Budget Office (1988) has estimated that the natural rate declined by 1/4 of a percentage point since 1981.

d. Further estimation results

The failure of the wage equation to accurately predict the growth of compensation may be the consequence of implicitly incorporating the natural rate unemployment and trend productivity growth in the constant, and thus constraining them to be related in an offsetting manner. Alternative specifications discussed below attempt to explain the over-prediction by incorporating additional explanatory variables, particularly labor productivity growth (Δq). The degree of unionization and other structural variables, including marginal tax rates, were also entered directly in the equations, but were not statistically important or were incorrectly signed.

The four right-most equations in Table 1 include a series of dummy variables to capture unusual wage behavior in the late 1960s and early 1970s, a period when a variety of policies attempted directly to influence wage developments. 1/ A dummy variable is also included to explicitly test for the overprediction of wage growth after 1982:IV; the estimated coefficient is statistically significant in some of the equations suggesting that wage growth has indeed been unusually moderate.

In these equations the coefficients on inflation are constrained to sum to unity and a 12-quarter moving average of labor productivity growth, the lag specification which best contributed to explaining the growth of wages, is included. The estimated coefficient on productivity growth (Δq) is significant, correctly signed, and relatively robust across alternative specifications. Although productivity growth enters with a 12-quarter moving average, it is still somewhat procyclical and captures some of the impact of economic activity, as is indicated by the estimated coefficient on unemployment which is almost halved. Similarly, the size of the constant in the equation, which now incorporates trend productivity with a coefficient of about 0.5 rather than unity, is also reduced substantially.

In general, employees are concerned with wages relative to consumer prices (real consumption wages), while employers are concerned with wages relative to output prices (real product wages). This suggests that wage growth will be related to an average of consumer and output price inflation. The final three equations in Table 1 include the gap between the rate of growth of consumer and output prices ($\Delta p^c - \Delta p$). This variable is approximately equal to the change in the terms of trade and allows a test of whether changes in relative prices are shared between labor and capital. The more important is output price inflation relative to that for consumer prices, the more

1/ Dummy variables denoted D(70:I to 71:I), for example, are equal to unity from 1970:I to 1971:I and zero in all other periods. As is apparent from the positive coefficients estimated for the first three dummies in Table 1, it is difficult to find evidence that incomes policies in the late 1960s and early 1970s had any significant wage reducing effects.

are profits and employment protected from adverse supply shocks. 1/ The estimated coefficient is marginally significant and suggests weights of about 0.8 on consumer prices and 0.2 on output prices.

As noted, wages are defined here as hourly compensation in the private nonfarm business sector, and hence include nonwage labor costs (employers' contributions for social security and private insurance and pension schemes) in addition to earnings. The specification of the equations discussed thus far implies that the wage bargain is for compensation, rather than earnings. This can be explicitly tested by including the change in nonwage labor costs as a percent of total wages and salaries (ΔNWLC) in the estimated equations, as is done in the final two equations in Table 1. The estimated coefficient is not significantly different from unity which suggests that the wage bargain is struck over earnings rather than total compensation. 2/ This does not imply, of course, that nonwage benefits are unimportant to employees; it only implies that employers' contributions are largely independent of the factors influencing wages--inflation, unemployment and labor productivity.

As discussed in the next section, nonwage labor costs as a share of wages and salaries (NWLC), increased steadily from the mid-1960s to the early 1980s and then declined somewhat. When this variable is entered in the equation, the declines tend to lower the predicted growth of wages during the 1980s, and the dummy variable for the post 1982:IV period is no longer important. Thus a part of the explanation for the moderate growth of compensation during the 1980s appears to be related to the decline in employers' contribution rates. 3/

As noted above, if the estimated coefficient on labor productivity growth in the wage equation is less than unity, then the growth of trend labor productivity is implicitly subsumed with the natural rate of unemployment in the constant term. The pattern of trend productivity growth

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1/ See Marston and Turnovsky (1985).

2/ If employers' contributions are approximately proportional to wages and salaries, then $\Delta w = \Delta e + \Delta NWLC$ where Δe is the growth of earnings. If the bargaining is for compensation growth (Δw), then changes in the employers' contribution rate (ΔNWLC) will be offset by changes in the growth of earnings (Δe); i.e., the estimated coefficient on ΔNWLC in the estimated equation will be zero. Conversely, if the bargaining is for earnings, changes in employers' contributions will be fully reflected in compensation, i.e., the estimated coefficient on ΔNWLC will be unity. The finding that the estimated coefficient on the current change in nonwage labor costs is not significantly different from unity does not, of course, rule out the possibility that earnings may adjust slowly to changes in nonwage labor costs. The inclusion of lagged terms, however, was not able to detect such an effect.

3/ The role of nonwage labor costs as a determinant of the natural rate of unemployment is discussed in the following section.

(Δq^{tr})--a decline in the 1970s followed by an upturn in the 1980s--together with the post-1982 dummy, implies in all of the estimated equations a hump-shaped pattern for the natural rate: after rising in the 1970s, the implicit natural rate declines in the early 1980s.

Over long periods of time, however, there does not appear to be a clear relationship between trend productivity growth and unemployment rates. 1/ This suggests that estimating the natural rate in this way may incorrectly attribute movements in the natural rate related to structural factors to changes in trend productivity growth. The final equation in Table 1 constrains the coefficients on actual and trend productivity growth to sum to unity. A quadratic time trend is entered to allow the natural rate to have a turning point; without this quadratic trend, the equation overpredicts badly and the 1980s dummy is statistically significant. As expected, the size of the estimated constant is reduced substantially when the trend is included. Due to the presence of the quadratic trend, this equation gives a similar pattern for the natural rate of unemployment to that implied by the other equations.

2. Unemployment rate equations

In the estimated Phillips curve equations, the natural rate is implicitly subsumed in the constant or proxied with a time trend. The purpose of this section is to derive an expression for the natural rate of unemployment which can be explicitly incorporated into the Phillips curve. This is done based on an estimated unemployment rate equation which distinguishes between the cyclical and structural determinants of unemployment. The long-run relationship between the unemployment rate and its structural determinants is then used to calculate the natural rate of unemployment.

a. Dynamic specification, cyclical, and supply shock variables

Unlike the wage and price equations, there are few, if any, institutional or theoretical priors as to the length of lags or the steady-state values of specific parameters in an unemployment rate equation. The hiring and firing practices of firms do, however, suggest that the unemployment rate is likely to react with a lag to changes in its determinants. For this reason the relationship of the unemployment rate to its cyclical and structural determinants was initially specified as a general autoregressive distributed lag model (of up to four quarters) and then tested down by dropping insignificant variables. 2/ This relatively unrestricted estimation procedure captures the cyclical

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1/ For a discussion of this point see Blanchard (1988).

2/ The same procedure was used in Coe (1989). In most empirical studies which attempt to distinguish between structural and cyclical components of the unemployment rate, the dynamics are much more constrained than in the estimates reported below.

dynamics well, increasing the likelihood that the structural component of the unemployment rate will be correctly identified.

A number of alternative equations are reported in Table 4. Based on the standard criteria, the equations do a good job of explaining quarterly developments in the unemployment rate. There is no evidence of a systematic pattern in the errors or of instability, either of which would suggest the omission of relevant variables.

The variables determining the cyclical movements of the unemployment rate are the current and lagged deviation of actual output from the estimated trend ($y-y^{tr}$). 1/ Short-run movements in the unemployment rate are also captured by the dynamic specification. The offsetting pattern of the estimated coefficients on the two lagged dependent variables means that the lag distributions on the independent variables initially declines then rises somewhat before tailing off to zero. The dynamics implied by the offsetting parameters on the output gap are superimposed on this general dynamic pattern.

The terms of trade (specified as the price of exports relative to the price of imports, p^x-p^m) and the relative price of gasoline (p^g-p), two supply shock variables which might affect the unemployment rate, are included in the final two equations in Table 4. (Developments in these and other variables discussed below are presented in Chart 3.) The estimated coefficients on both variables are correctly signed, but only marginally significant while reducing the significance of some of the structural variables. For supply shocks to have long-lasting effects on unemployment, some degree of rigidity preventing the adjustment of relative or real wages is necessary. Although it may be possible to capture the impact of labor market rigidities indirectly through their interaction with supply shocks, it is preferable to include, if possible, structural variables more directly related to labor market rigidities.

1/ Capacity utilization in manufacturing was included as an additional cyclical variable but the estimated coefficient was not statistically significant. An alternative approach would be to relate cyclical unemployment to unanticipated movements in the money supply, as in Barro (1977). To the extent that output is affected by unanticipated money growth, the two approaches are not inconsistent. Given recent difficulties in interpreting the movements of the monetary aggregates, and the uncertain and changing roles that the aggregates play in the formulation of monetary policy, the task of identifying a useful empirical proxy for unanticipated money growth, which of course is unobserved, is not straightforward.

Table 4. Unemployment Rate Equations 1/

	1	2	3	4	5	6
Constant	-1.616 (0.75)	-1.252 (0.68)	-1.929 (0.86)	12.127 (3.84)	-0.929 (1.0)	-0.679 (0.79)
$y-y^{tr}$	-0.188 (0.03)	-0.188 (0.03)	-0.189 (0.03)	-0.208 (0.03)	-0.182 (0.03)	-0.178 (0.03)
$(y-y^{tr})_{-1}$	0.122 (0.03)	0.122 (0.03)	0.124 (0.03)	0.083 (0.03)	0.109 (0.03)	0.108 (0.03)
NWLC	0.069 (0.02)	0.058 (0.02)	0.080 (0.02)	0.176 (0.08)	0.058 (0.02)	0.054 (0.02)
UIRR	0.016 (0.01)	0.014 (0.01)	0.017 (0.01)	0.019 (0.01)	0.008 (0.01)	0.011 (0.01)
$SL \cdot RMW_{-1}$	0.016 2/ (0.006)	0.027 (0.01)		0.041 (0.03)		0.018 (0.01)
UNN	0.016 2/ (0.006)		0.035 (0.01)	-0.176 (0.07)	0.039 (0.01)	
SL				0.034 (0.04)		
SF				-0.310 (0.09)		
p^g-p						-0.003 (0.002)
p^x-p^m					-0.011 (0.006)	
$(U-DEM)_{-1}$	1.160 (0.09)	1.164 (0.09)	1.164 (0.09)	1.007 (0.10)	1.110 (0.10)	1.142 (0.10)
$(U-DEM)_{-2}$	-0.315 (0.08)	-0.317 (0.08)	-0.321 (0.08)	-0.318 (0.08)	-0.279 (0.08)	-0.316 (0.08)
R^2	0.985	0.985	0.985	0.987	0.985	0.985
SEE	0.213	0.213	0.213	0.201	0.210	0.212
Mean lag (quarters)	5.5	5.5	5.4	2.2	4.9	4.7
F-statistics:						
Autocorrelation (1-4) (CV = 2.5)	0.21	0.23	0.33	0.94	0.10	0.20
ARCH (4) (CV = 2.5)	0.70	0.75	0.64	0.53	1.20	0.72
Break 85:IV (CV = 1.9)	0.52	0.53	0.53	0.61	0.50	0.40
Break 82:IV (CV = 1.7)	1.00	1.00	1.01	1.00	0.93	0.93

1/ See note to Table 1. The dependent variable is the unemployment rate minus the impact of changing demographic shares (U-DEM).
2/ Constrained to be equal.

b. Demographic impacts on unemployment

The impact of demographic factors on the natural rate of unemployment has often been emphasized. 1/ If different labor market groups have different natural rates of unemployment, perhaps because of different reservation wages or other characteristics, the changing demographic composition of the labor force may affect the natural rate of unemployment. The importance of this compositional effect can be estimated by constructing an unemployment rate with constant labor market shares (Chart 1).

In addition to this compositional effect of demographic changes, the relative minimum wage variable (RMW) has been multiplied by the labor-force share of youth aged 16 to 24 (SL), the group most likely to be affected by the minimum wage. This implies that the impact on unemployment of a given change in the minimum wage will be greater the larger is the proportion of youth in the labor force.

The total impact of both of these demographic effects turns out to be relatively small. The fourth equation in Table 4 tests for more direct effects on unemployment by also including the share of the labor force which is young (SL) and female (SF) (Chart 3). The proportion of youth, which has returned to about the same levels as in the mid-1960s, does not appear to have a significant effect on unemployment over and above the two effects noted above. The estimated coefficient on the share of the labor force which is female, which has increased steadily from the mid-1960s, is significant and negative. 2/ Given that unemployment rates for women are typically higher than for men, implying, if anything, a higher natural rate, it is difficult to rationalize a negative impact on unemployment rates from the increased proportion of women in the labor force.

c. Structural determinants of the natural rate

Many, perhaps most, of the structural features of labor markets are constant or evolve very slowly; and those which do change, may be difficult to quantify. In the estimated equations in Table 4, the main structural variables affecting the natural rate of unemployment are union members as a percent of total private sector employment (UNN), relative minimum wages (RMW), the average weekly unemployment insurance replacement ratio adjusted for the proportion of employment covered by the unemployment insurance system (UIRR), and employers' contributions as a percent of total wages and salaries (NWLC) (Chart 3). Average and

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1/ See Perry (1970), Collyns (1984), and Adams et al. (1987).

2/ The estimated coefficients on both these labor force groups are qualitatively similar to those reported in Table 4 when the variables are entered alone or in conjunction with the two supply shock variables discussed above.

marginal income tax rates were also entered in the equations but the estimated coefficients were insignificant and/or incorrectly signed.

The amount of time the unemployed search, an important determinant of the duration of unemployment, can be expected to depend, at least in part, on a comparison between the offered and reservation wage. The latter will be related to, among other factors, minimum wages, unemployment insurance benefits, and, perhaps, the degree of unionization. In the empirical analysis reported here, minimum wages and average weekly unemployment insurance benefits have been expressed relative to average wages of employees of private households, a relatively low paying service "industry" which is likely to be more relevant for a typical unemployed person, and works better empirically, than a measure of aggregate wages.

Developments in relative minimum wages (adjusted for the share of youth) and unionization, particularly the decline in the 1980s (Chart 3), are sufficiently similar that it is not possible to get precise estimates of the contribution of each variable. 1/ In view of this multicollinearity, which can be seen by comparing the first three equations presented in Table 4, 2/ the coefficients on these two variables are constrained to be identical in the first equation.

The estimated coefficients on employers' contributions as a percent of total wages and salaries (NWLC) are statistically significant in each of the reported equations, and large relative to the other estimated structural coefficients. Except for the fourth equation in Table 4, the size of the estimated parameters is also robust across the different specifications. In line with developments in most industrialized countries, 3/ there were steady increases in employers' contributions as a

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1/ Neumark (1989), based on a Phillips curve approach, finds some evidence that the degree of unionization affects the growth of union wages, but not the growth of aggregate wages.

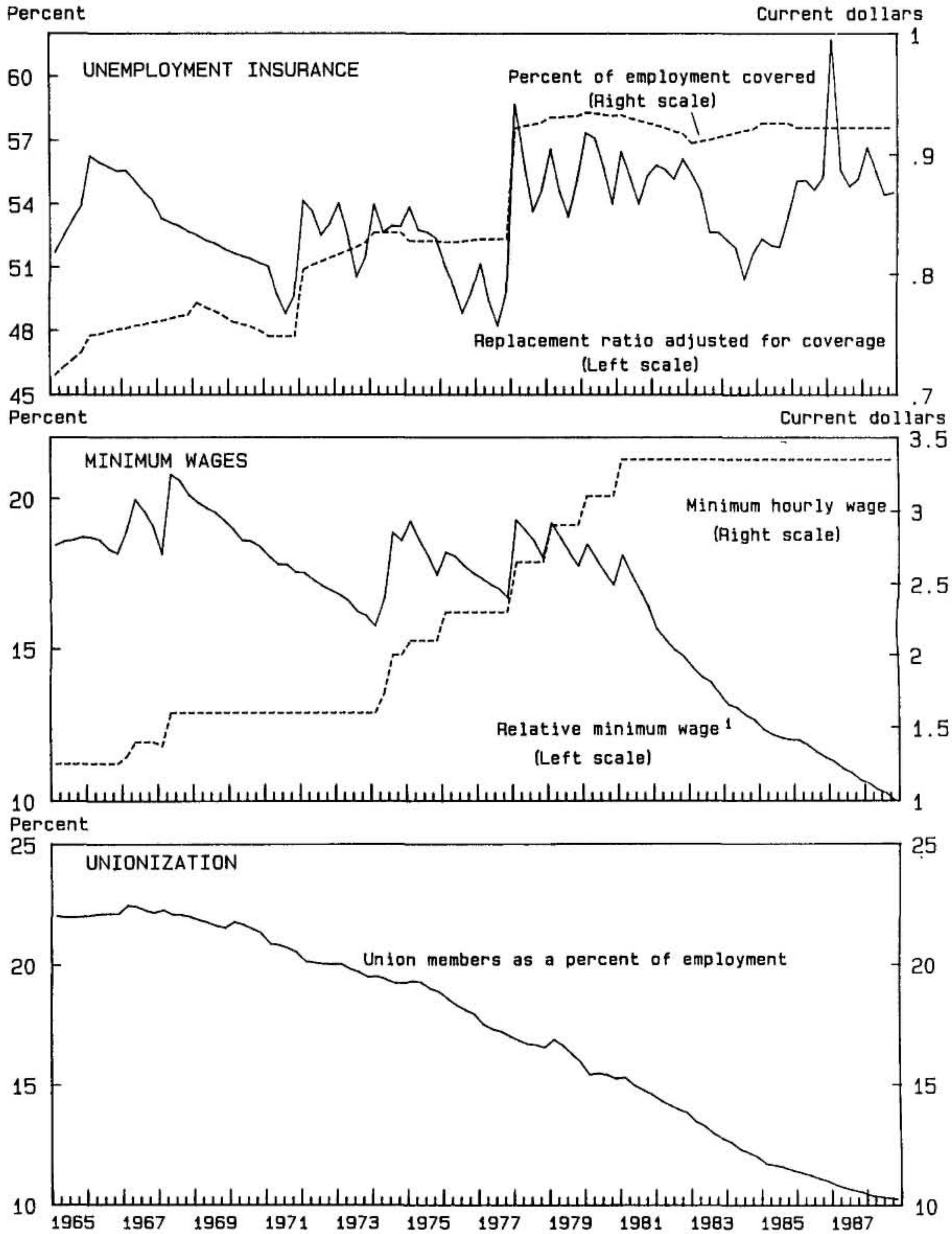
2/ When relative minimum wages and the degree of unionization are included separately in the equations, they are both significant, have similar coefficient estimates, and do equally good jobs of explaining unemployment rate developments (the second and third equations in Table 4). When both variables are included in the same equation, however, neither is significant although the goodness of fit of the equation is virtually unchanged from those with either variable alone.

3/ See Chan-Lee et al. (1987). The possible impact of these nonwage labor costs are often emphasized in discussions of European unemployment. One way that increases in employers' contributions may affect unemployment is through their impact on unit labor costs: if inflation is to be kept stable, the NAIRU would have to increase to reduce wages enough to offset the increased employers' contributions. See Layard and Nickell (1987). This transmission mechanism is different from that implied by the inclusion of employers' contributions in an unemployment rate equation, although the two mechanisms are neither inconsistent nor mutually exclusive.

CHART 3

UNITED STATES

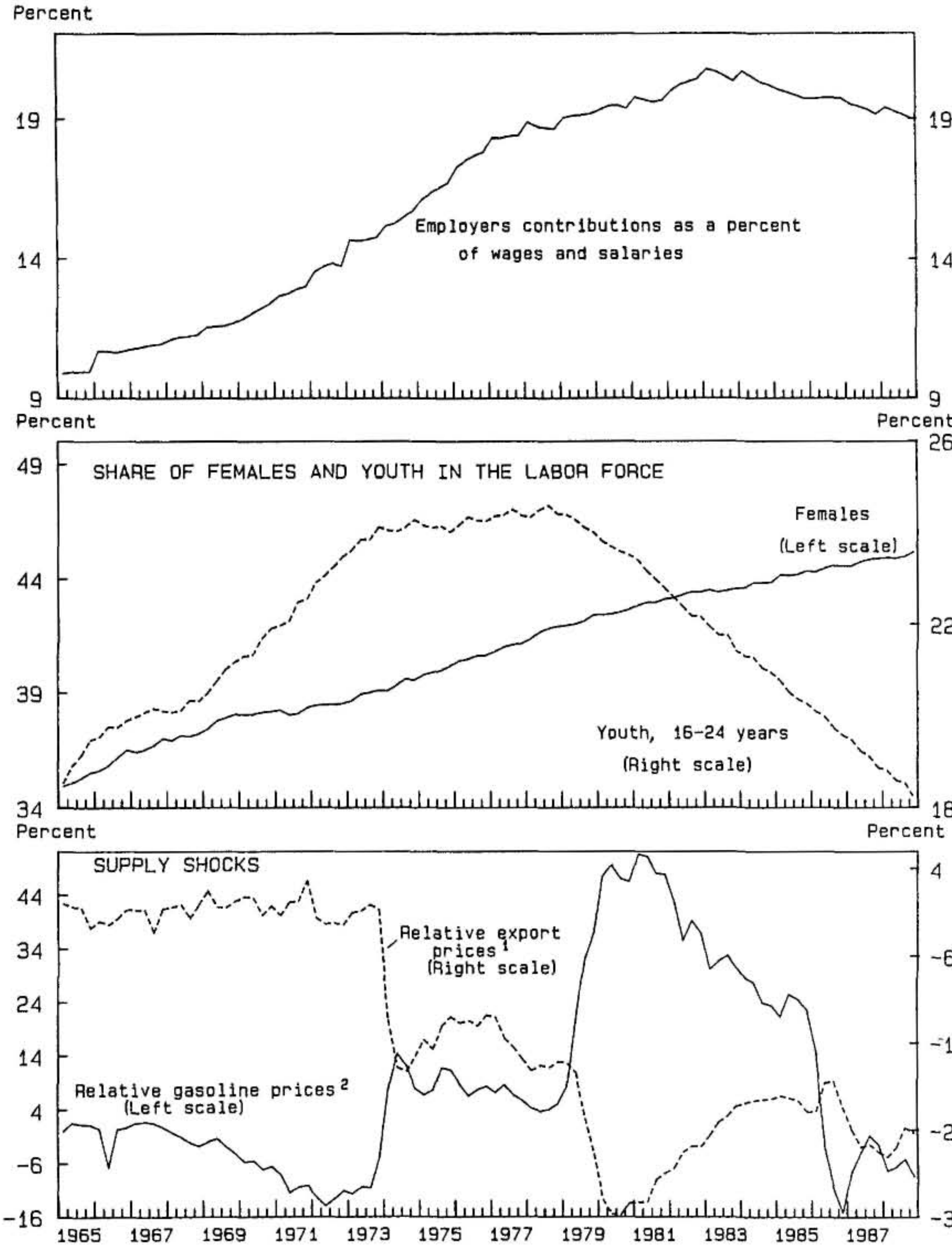
STRUCTURAL AND SUPPLY FACTORS AFFECTING UNEMPLOYMENT



[1] Minimum wage multiplied by the share of youth in the labor force.

CHART 3 (Concluded)

UNITED STATES
STRUCTURAL AND SUPPLY FACTORS AFFECTING UNEMPLOYMENT



[1]Export prices relative to import prices.

[2]Gasoline prices relative to the output deflator.

percent of wages and salaries from the early 1960s until the early 1980s (Chart 3). In the United States, these developments reflected increases in employers' contributions for social security and for private insurance and pension funds, both of which increased from about 5 percent of wages and salaries in 1965 to about 10 percent in the early 1980s (Table 5). 1/

Table 5. Employers' Contributions

(As a percent of total wages and salaries)

	1965	1970	1975	1980	1983	1987
Total	9.9	12.1	16.5	19.4	20.5	19.3
Social security	5.0	6.2	8.4	9.3	10.2	10.1
Other contributions	4.9	5.9	8.1	10.1	10.4	9.2
Health insurance	1.6	2.2	3.1	4.3	5.3	5.1
Pensions and profit sharing	2.1	2.4	3.4	4.0	3.4	2.3
Other 2/	1.2	1.3	1.6	1.8	1.7	1.8
Memorandum:						
Employers' social security contribution rate (percent)	3.62	4.80	5.85	6.13	6.70	7.15
Maximum taxable earnings (dollars per year)	4,800	7,800	14,100	25,900	35,700	43,000

Sources: U.S. Department of Commerce, 1988, Survey of Current Business, July 1988, National Income and Product Accounts Tables 1.14 and 6.13; and United States Historical Abstract, various issues.

1/ The increases in employers' contributions for private insurance and pension funds were primarily due to increased costs of health insurance and increased contributions for pensions and profit sharing. See Ippolito (1986).

2/ Includes group life insurance, workers' compensation, supplemental unemployment contributions, and directors' fees.

The presence of employers' contributions as a structural variable in the unemployment equation implies that nonwage labor costs are different, in some important respect, from "wage" labor costs. As discussed above, the evidence from the compensation equations suggests that one difference is that the wage bargain appears to be struck over earnings, not compensation. 1/ To the extent that increases in employers' contributions are not offset by wages, employee compensation will increase and profits will decline. 2/ There is also a fixed cost aspect to nonwage labor costs, 3/ and income ceilings mean that the average contribution rate paid by the employer declines as the level of wages increase. More generally, many benefits are interlocked with tenure, particularly those which involve deferred pay, and hence with firm-specific human capital. 4/ Consequently increased benefits may go hand-in-hand with increased screening and higher recruitment costs as firms search longer to fill vacancies and become more reluctant to hire low paid workers or workers likely to stay with the firm for a relatively short period. This implies that the duration of vacancies and the equilibrium unemployment rate will increase. 5/

Thus, increases in employers' contributions may tend to increase the equilibrium rate of unemployment for a number of reasons: they increase the rigidity of compensation with regard to labor market conditions, inflation, and productivity developments; they lower profits and profit expectations; 6/ and, they may make employers more reluctant to hire.

1/ This result is consistent with studies based on firm-level data; see Smith and Ehrenberg (1983) and Leibowitz (1983).

2/ This is likely to be the case not only for government mandated social security contributions, but also for other contributions because about three quarters of pension-covered workers are covered by defined benefit, as opposed to defined contribution, plans. Under defined contribution plans, which include profit sharing plans, the employer contributes a prespecified amount; under defined benefit plans, the employer contributes what is necessary to maintain benefits at a prespecified level, this amount will vary according to the earnings from the invested pension funds.

3/ Administrative costs required to set up and administer employee health insurance and pension plans are likely to be especially burdensome for small businesses. Oi (1983) reports evidence of economies of scale in the provision of benefit plans.

4/ See Triplett (1983) and Oi (1983).

5/ These channels are emphasized in Hall (1979) and Flanagan (1988).

6/ A bargaining model in which equilibrium unemployment is positively related to employers' taxes, and which does not depend on employers' taxes being independent of the determinants of wages, is presented in Pissarides (1985).

d. An equation for the natural rate of unemployment

By solving for the long-run relationship between the unemployment rate and its structural determinants, an equation for the natural rate of unemployment can be derived from the dynamic equations reported in Table 4. This long-run focus seems particularly appropriate for an equation describing one of the key structural features of the economy. Based on the first equation in Table 4, for example, the natural rate can be calculated as (standard errors in parentheses):

$$U^{NAT} = DEM + a_0 + \underset{(0.07)}{0.446NWLC} + \underset{(0.07)}{0.101UIRR} + \underset{(0.04)}{0.102SL \cdot RMW} + \underset{(0.04)}{0.102 \cdot UNN} \quad [5]$$

In order to calculate the constant in this equation, it is necessary to make an explicit assumption about the cyclically neutral level of the output gap. This will not, in general, be zero. 1/ Moreover, as noted above, the calculation of the level of the natural rate becomes somewhat circular if the full-employment level of output is already known or has to be assumed. In the systems estimates of the natural rate presented in Section 4, the constant as well as the structural parameters in the natural rate equation are estimated jointly with the wage, price, and output equations.

Movements in the natural rate will be related to developments in the structural variables. The natural rate which is implied by the above equation increases by about 3 to 4 percentage points from the mid-1960s to the early 1980s, and then declines by about 1 to 2 percentage points in the period to 1988. This hump-shaped time profile is characteristic of all of the alternative specifications of the unemployment rate equations. Thus, a substantial part of the increase in actual unemployment rates from 1965 to their peak in 1983 may be attributed to increases in the natural rate of unemployment. A fuller discussion of the estimated natural rate of unemployment and its determinants is presented in Section 4 based on the system estimation results.

3. Production function equations

a. Specification issues and explanatory variables

The production function has been estimated in the form of a multifactor productivity equation. This approach has been adopted to facilitate discussion of the outlook for productivity growth as well as discussion of the productivity slowdown. There is, of course, an enormous literature on the productivity slowdown and, although a large

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1/ For ordinary least squares estimates of trend, trend output will by definition be equal to actual output on average over the full sample period.

number of possible reasons have been identified, there is not a consensus on their empirical significance. 1/ Among the more prominent reasons advanced for the productivity slowdown in the United States are the large increases in energy prices, a slowdown in the advance of relevant knowledge, and a decline in the quality of labor input. Explanatory variables related to each of these possible explanations of the slowdown are included in the estimated multifactor productivity equations reported below.

The growth of multifactor productivity is generally taken as an indicator of technical progress, and a time trend is often included as a proxy for this in estimated equations. 2/ Although this may work well empirically, it is preferable to include, if possible, explanatory variables more directly related to technical progress and the generation of relevant knowledge. This has been done by including estimates of the stock of research and development expenditures, distinguishing between the part financed by the Federal government and the part privately financed, in the estimated equations. 3/

Multifactor productivity is defined here as output (y) minus a weighted average of the inputs of labor (manhours, h) and capital (k) (see Chart 4). Thus, in terms of the specification of equation [3] above, the coefficient on labor is constrained to be the share of labor compensation in national income (λ), with its compliment ($1-\lambda$) the constrained coefficient on capital. 4/ Actual income shares in the private nonfarm sector, which for labor are in the range 0.63 to 0.71, are used; thus, strictly speaking, the equation should not be interpreted as a Cobb-Douglas production This measure of multifactor productivity, including the use of moving weights, is very similar to that

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1/ The relevant literature is summarized in articles in the symposium on "The Slowdown in Productivity Growth" in The Journal of Economic Perspectives, Vol. 2, Fall 1988. See also Denison (1985). International comparisons are presented in Maddison (1987) and Englander and Mittlestädt (1988).

2/ Adams et al. (1987), Perloff and Wachter (1979).

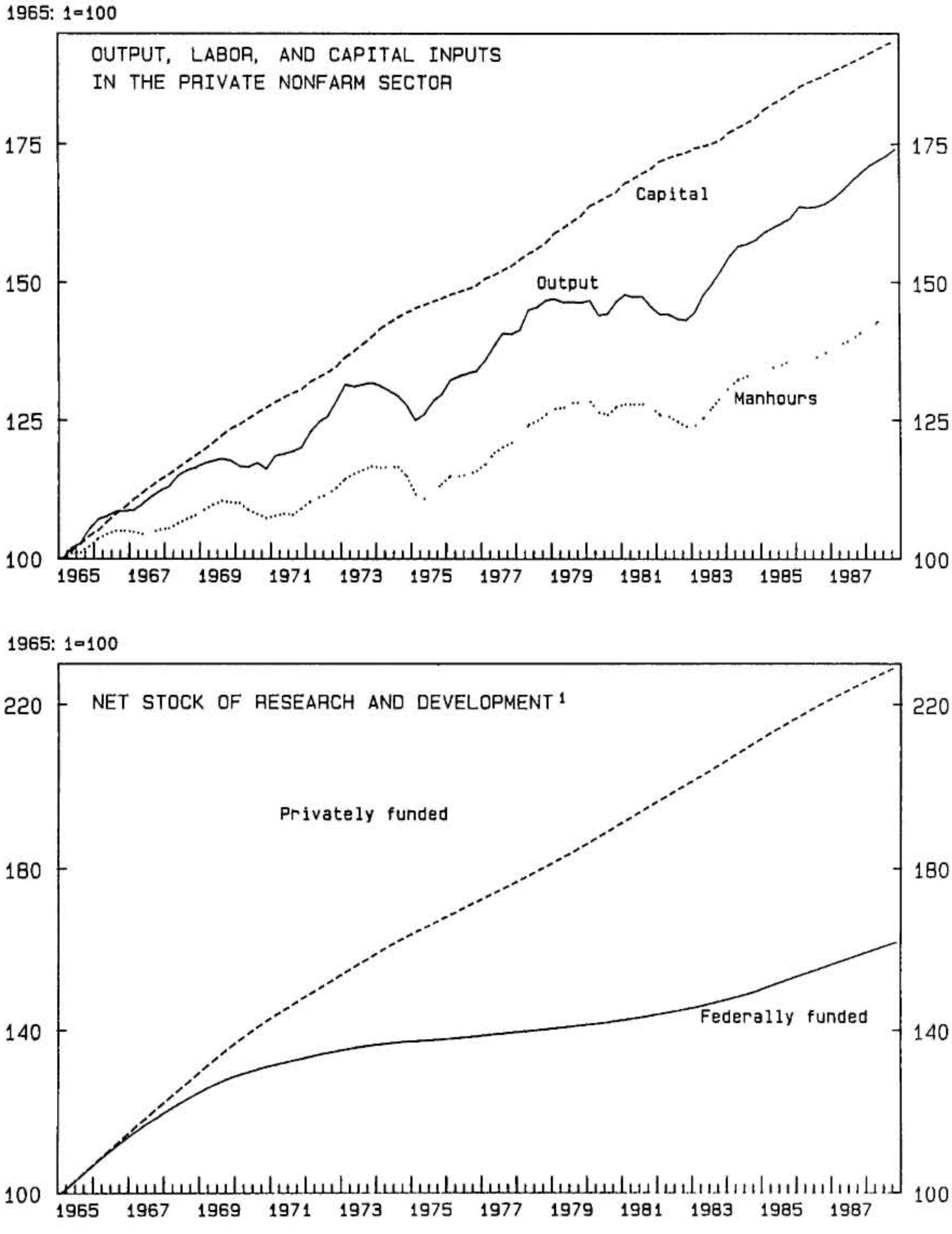
3/ The stocks of research and development capital have been calculated using the perpetual inventory method based on National Science Foundation data for R&D expenditures and 1953 benchmarks of the real stock of R&D from Kendrick, (1976). Gross and net stocks, the latter assuming that 5 percent of the stock of R&D becomes irrelevant each year, were constructed and tested in the estimated equations; the estimates of the net stock worked best empirically.

4/ All variables are in logarithms, implying that multifactor productivity is defined as the ratio of output to a geometric weighted average of inputs.

CHART 4

UNITED STATES

OUTPUT AND FACTOR INPUTS



[1] In constant 1982 dollars.

regularly reported by the Bureau of Labor Statistics in the Monthly Labor Review. 1/

The intensity with which factors, including capital, are utilized varies procyclically. For this reason, a measure of capacity utilization or the output gap is usually included as an additional explanatory variable in estimated production functions or multifactor productivity equations. 2/ This may cause econometric problems given that actual output is the dependent variable, or in multifactor productivity form is included in the dependent variable, and is also in the numerator of the output gap. Another, potentially more serious problem with including the output gap might arise in the system estimation: the expression for potential output, which is itself derived from the estimated production function, would then have to be substituted back into the production function.

The fact that the denominator of the output gap is usually based on a smoothing of actual output, suggests that it may be possible to capture the impact of varying factor utilization rates in the dynamic specification. 3/ For this reason, and in light of the potential problem with the system estimates, the output gap was not included as an explanatory variable in the multifactor productivity equations. Rather, the same estimation strategy used for the unemployment rate equations was adopted here: variables were initially entered contemporaneously and with three discrete lags and then tested down.

Estimating the production function as a multifactor productivity equations not only constrains the dynamic relationship between output and labor and capital inputs, it also imposes constant returns to scale on the underlying production function. While the latter may or may not be true, the former is difficult to justify. To relax both of these restrictions, current and lagged values of labor and capital inputs were also included as explanatory variables in the estimated multifactor productivity equations. 4/

1/ The primary difference is that the BLS index of the input of capital services in the private nonfarm sector, which is only available annually, has been interpolated to a quarterly frequency using as a reference series a quarterly measure of the capital stock constructed from the relevant investment data and published estimates of the annual capital stock, etc. The quarterly data for output and manhours in the private nonfarm sector are from the BLS.

2/ Artus (1977) and Adams et al. (1987).

3/ If, for example, the output gap is defined as the difference between actual output and trend output, the latter defined as a distributed lag on actual output, then the gap can be substituted out to give an equation with output as the dependent variable and a lagged dependent variable on the right-hand side.

4/ This also tests the hypothesis that technical progress is embodied in capital; see Romer (1987).

In addition to energy prices, the quality of labor input is another factor which is often highlighted in growth accounting analyses of the productivity slowdown. This is sometimes proxied by years of schooling or measures of performance on standardized tests. 1/ In the equations reported below, labor input is interacted with the employment shares of youth and females as a proxy for the impact on the productivity of labor input of demographic changes and/or changes in labor quality.

b. Estimation results

A number of alternative specifications of multifactor productivity equations are reported in Table 6. 2/ All equations include the stock of privately financed R&D (rd) lagged two periods, and current and lagged man hours (h) multiplied by a demographic share variable (youth, SE, or female, SF). The estimated equations track developments in multifactor productivity well, with no evidence of autocorrelated errors or instability.

The first equation in Table 6 also includes the stock of R&D financed by the Federal Government (rd^f). The estimated coefficient is incorrectly signed. Other studies often find a smaller impact from federally, as opposed to privately, financed R&D. This may reflect the fact that much government sponsored R&D is for defense, which may have a lower payoff than other research in terms of measured productivity growth. 3/

Whether labor input (h) is multiplied by the employment share of youth (age 16 to 24, SE) or females (SF), as in the third equation in Table 6, the effect (after two quarters) of increases in either share is to reduce multifactor productivity. The specification with youth is marginally better, and the argument that new entrants to the labor force are less productive than more experienced workers seems more defensible than the argument that women are less productive than men.

When lag distributions on labor and capital inputs are included in the estimated equations in addition to labor input adjusted by the share of youth, the estimated coefficients are not significantly different than zero. Labor input and labor input adjusted by the share of youth are, of course, strongly correlated. If labor input is entered without any demographic interaction, the estimated coefficient is significantly negative and reduces by about one-half the constrained coefficient based on factor shares. The interpretation of the equations reported in Table 6, with a demographic/labor-quality adjustment to labor input, is more straightforward than the alternative with a very small estimated impact from labor input.

1/ Denison (1985) and Bishop (1989).

2/ Because the capital stock data for 1988 are extrapolated based on actual investment data, the equations reported in Table 6 are only estimated to 1987:IV.

3/ Baily and Chakravarti (1988) and Griliches (1988).

4. Price equations

a. Specification issues

Much of the empirical work on price determination at the macro level has been based on some variant of the markup hypothesis. 1/ According to this hypothesis, prices are set as a markup over unit costs, with the markup varying with the state of excess demand in goods markets. A dynamic form of the markup hypothesis is specified in equation [4] above where the increase in the (value added) deflator in the nonfarm business sector is related to the rise in normalized unit labor costs ($\Delta w-\Delta q^{tr}$) and to excess demand as measured by the gap between actual and trend output ($y-y^{tr}$). Given that these are value-added prices, the coefficient on normalized unit labor costs would be expected to be unity.

In equilibrium, with actual output equal to trend, inflation will equal the growth of normalized unit labor costs, implying a constant markup and stable income shares. It is worth noting that this equilibrium condition ($\Delta p = \Delta w - \Delta q^{tr}$) is consistent--indeed, is a restatement--of the equilibrium condition discussed above in connection with the Phillips curve, i.e., the increase in real wages is equal to the growth of trend productivity ($\Delta w - \Delta p = \Delta q^{tr}$).

In both the price equation and the Phillips curve there are strong theoretical priors about some long-run parameters. Many of the specification issues are also similar. One issue is whether the price equation should specify a level as opposed to a rate-of-change relationship between prices and normalized unit labor costs. This was tested by including an error-correction term in the equation; 2/ the estimated coefficient was not significantly different from zero suggesting a growth-rate formulation is appropriate, the same result obtained with the wage equation. Another issue common to both equations is the role of changes in, as opposed to the level of, the gap terms.

b. Estimation results

A number of estimates of the price equation are presented in Table 7. Based on a preliminary search over alternative lag distributions, normalized unit labor costs are defined as a 12-quarter moving average of actual compensation growth minus either a 12-quarter moving average of actual labor productivity growth ($\theta(L)(\Delta w-\Delta q)$) or trend productivity growth ($\theta(L)(\Delta w-\Delta q^{tr})$). All variables refer to the private nonfarm business sector (Table 2, Charts 1 and 2).

1/ See Blanchard (1987).

2/ The error-correction term was the lagged logarithm of the ratio of prices to normalized unit labor costs.

The first equation in Table 7 includes only the increase in normalized unit labor costs and the level of the output gap, both of which are highly significant and have the expected signs. The estimated coefficient on the increase in unit labor costs is not statistically different from its expected value of unity. There is, however, evidence of autocorrelation and heteroskedasticity in the residuals, and there are some very large residuals in the late 1960s and early 1970s.

The second equation in Table 7 includes a number of dummy variables and the acceleration of gasoline prices. As in the wage equations, the dummy variables are for periods of unusual inflation developments in the late 1960s and the early 1970s, a period that included exogenous price shocks and the Nixon price controls. Including the dummy variables does not significantly change the estimated coefficients on the other variables but does contribute to a substantial improvement in the summary and diagnostic statistics.

In addition to gasoline prices, other supply variables such as the terms of trade were included in the equations. Possible impacts on profit margins of various measures of foreign competition were also tried. The estimated coefficients on these variables were either insignificant and/or incorrectly signed. Although the estimated coefficient on the acceleration of gasoline prices is correctly signed and statistically significant, it is relatively small and implies that gasoline prices have had only a small impact on the rise in (value added) output prices.

The third equation reported in Table 7 includes the change as well as the level of the output gap. If, at a given level of the output gap, inflationary pressures are stronger when the gap is rising its change would enter the equation with a positive sign. The results, which are not affected by whether the dummy variables are included in the equation, suggest a statistically significant but perversely signed impact from the change in the output gap. 1/ This result is similar to that reported above for the wage equation.

The second and fourth equations in Table 7 are the same except for the definition of trend productivity. Using a 12-quarter moving average of actual productivity growth improves the fit of the equation modestly relative to the use of trend productivity growth. The size of the estimated coefficient on the output gap is also increased. The last two equations reported in Table 7 impose homogeneity by constraining the estimated coefficients on the increase in normalized unit labor costs to unity. While the restriction that the estimated coefficient on unit labor costs equals unity is not rejected for either equation, the estimated impact of the output gap is larger in the final equation where the

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1/ Gordon (1988) does not find any impact from the change in the output gap.

moving average rather than trend productivity is used. 1/ There is some evidence of serial correlation in the equation with trend productivity. 2/

IV. System Estimates of the Natural Rate of Unemployment and Potential Output

1. System specification and estimation results

a. Specification of the system

Table 8 reports the equation specifications for the system estimates. 3/ Compared to the single-equation estimates based on the specification of equations [1]-[4] above, the primary differences in the specifications reported in Table 8 are:

- trend output (y^{tr}) in the unemployment rate and price equations has been replaced by the expression for potential output derived from the multifactor productivity equation;
- trend labor productivity growth (Δq^{tr}) in the Phillips curve and price equations has been replaced by the expression for labor productivity growth at potential output;
- the implicit natural rate of unemployment in the constant term in the Phillips curve has been replaced by the expression for the natural rate derived from the unemployment equation;
- the constant terms in the Phillips curve and price equations have been incorporated into the expressions for the natural rate and potential output, reflecting the homogeneity of these equations when the unemployment and output gaps are zero.

With these substitutions, the system includes no proxies for potential output or trend labor productivity, and the natural rate of unemployment is explicit. The complexity of the equation specification reflects the

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1/ The coefficient on the output gap was not sensitive to whether trend output was proxied by the spline method or by a moving average.

2/ The F test, shown in the table, suggests second- or third-order autocorrelation in the residuals.

3/ The specifications are based on the first equation in Table 4 for the unemployment rate equation, the final equation in Table 1 for the Phillips curve, the second equation in Table 6 for multifactor productivity, and the penultimate equation in Table 7 for the price equation. The same dummy variables reported in Tables 1 and 7 are also included with the exception of the dummy for the 1980s in the wage equation; the estimated coefficients are very similar to those obtained in the single equation estimates and are not shown.

fact that the unobserved natural rate of unemployment and potential output are themselves estimated as part of the system.

There is an interesting symmetry in the equation specifications in Table 8: the two price equations--for labor [2] and output [4]--are in growth-rate form, homogeneous of degree one in nominal variables, and have finite lag distributions; the two structural equations--for the unemployment rate [1] and multifactor productivity [3]--are in level form and have infinite geometric lag distributions. The dynamic specification of the unemployment rate and multifactor productivity equations means that, even though the expressions for the natural rate of unemployment and potential output are linear in their structural determinants, the parameters are nonlinear transformations of the short-run parameters from the unemployment rate and output equations (cf. equations [5] and [6] above). As is apparent from the specification of the complete system in Table 8, this leads to complex nonlinear cross-equation parameter restrictions.

An important advantage of the system approach is that the full set of relevant information is brought to bear in the estimation of all parameters. Thus, the relationships between wage inflation and the labor-market gap, and between price inflation and the product-market gap, are explicitly incorporated into the estimation procedure. The manner in which this is done means not only that the wage and price equations include gap terms, which is fairly standard procedure, but that the estimated parameters which define the natural rate of unemployment and potential output--and hence the gaps--are themselves estimated jointly with the parameters in the wage and price equations.

As previously noted, the determinants of potential output have been expressed at their "natural" or "potential" levels. For labor input (h), this is done by calculating total manhours based on trend average hours per employee, trend participation rates, and the "natural rate of employment", i.e. employment consistent with unemployment being at the natural rate. 1/ The stocks of capital (k) and R&D (rd), are smoothed with a three-year moving average. Expressing the determinants of potential

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1/ Trend participation rate was based on an ordinary least squares estimate of a linear trend, trend average hours per person was based on an estimated quadratic trend. Both trends were estimated from 1965:I to 1988:IV. In order to prevent the system specification from becoming overly complex, an iterative approach was adopted instead of substituting the expression for the natural rate into the expression for potential output. Beginning with an initial estimate for the natural rate of unemployment, "natural" labor input was defined in the expression for potential output; the new estimate for the natural rate was then used to derive a new measure of natural labor input; this process was repeated until the estimate for the natural rate converged. The specification in Table 8 omits this, as well as the smoothing of the other variables in the expression for potential output.

Table 8. Three-Stage Least Squares Estimates

I. Equation Specifications

[1] Unemployment rate

$$\text{U-DEM} = \alpha_0 + \alpha_1\big[y - \{\delta_0 + ((\gamma_1+\gamma_2)/(1-\gamma_4))SE\cdot h + (\gamma_3/(1-\gamma_4))rd_{-2} + \lambda h + (1-\lambda)k\}\big]$$
$$+ \alpha_2\big[y_{-1} - \{\delta_0 + (\gamma_1+\gamma_2)/(1-\gamma_4))SE\cdot h_{-1} + (\gamma_3/(1-\gamma_4))rd_{-3} + \lambda h_{-1} + (1-\lambda)k_{-1}\}\big]$$
$$+ \alpha_3 NWLC + \alpha_4 UIRR + \alpha_5 SL\cdot RMW_{-1} + \alpha_5\cdot 0.44\cdot UNN + \alpha_6(\text{U-DEM})_{-1} + \varepsilon_U$$

[2] Phillips curve

$$\Delta w = \beta_1\phi(L)\Delta p^c + (1-\beta_1)\theta(L)\Delta p^c + \beta_2\Delta(p^c-p) + \beta_3\theta(L)\Delta q$$
$$+ (1-\beta_3)\big\{\big((\gamma_1+\gamma_2)/(1-\gamma_4)\big)\Delta(SE\cdot h) + (\gamma_3/(1-\gamma_4))\Delta rd_{-2} + \Delta((\lambda-1)h) + \Delta((1-\lambda)k)\big]$$
$$+ \beta_4\big[U - \{DEM + \beta_0 + (\alpha_3/(1-\alpha_6))NWLC + (\alpha_4/(1-\alpha_6))UIRR$$
$$+ (\alpha_5/(1-\alpha_6))SL\cdot RMW_{-1} + (\alpha_5\cdot 0.44/(1-\alpha_6))UNN\}\big]$$
$$+ \beta_5\Delta NWLC + \varepsilon_w$$

[3] Production function

$$y - \lambda h - (1-\lambda)k = \gamma_0 + \gamma_1 SE\cdot h + \gamma_2(SE\cdot h)_{-1} + \gamma_3 rd_{-2} + \gamma_4\{y - \lambda h - (1-\lambda)k\}_{-1} + \varepsilon_y$$

[4] Output prices

$$\Delta p = \delta_1\big[\theta(L)\Delta w - \{((\gamma_1+\gamma_2)/(1-\gamma_4))\Delta(SE\cdot h) + (\gamma_3/(1-\gamma_4))\Delta rd_{-2} + \Delta((\lambda-1)h) + \Delta((1-\lambda)k)\}\big]$$
$$+ \delta_2\big[y - \{\delta_0 + ((\gamma_1+\gamma_2)/(1-\gamma_4))SE\cdot h + (\gamma_3/(1-\gamma_4))rd_{-2} + \lambda h + (1-\lambda)k\}\big]$$
$$+ \delta_3\Delta^2 p^g + \varepsilon_p$$

Notes

- The expression for the level of potential output appears in the two sets of curly brackets in [1] and in the second set of curly brackets in [4]. The expression for the growth of labor productivity at potential output appears in the first set of square brackets in [2] and the first set of curly brackets in [4]. The expression for the natural rate of unemployment appears in the set of curly brackets in [2].
- $\phi(L)$ and $\theta(L)$ indicate, respectively, five- and twelve-quarter moving average lag operators. Δ indicates the first difference; Δ^2 indicates the change in the first difference.
- Equations [2] and [4] also include unreported dummy variables with coefficient estimates similar to those reported in Tables 1 and 7.

Table 8. Three-Stage Least Squares Estimates (Concluded)

II. Coefficient Estimates (Standard Errors)

[1]	[2]	[3]	[4]
α_0 = -0.793 (.52)	β_0 = -3.514 (2.6)	γ_0 = -0.003 (.001)	δ_0 = 0.041 (.007)
α_1 = -0.232 (.02)	β_1 = 0.489 (.14)	γ_1 = 0.0257 (.004)	δ_1 = 1.0 (Const.)
α_2 = 0.144 (.03)	β_2 = -0.188 (.08)	γ_2 = -0.0271 (.004)	δ_2 = 0.225 (.04)
α_3 = 0.068 (.02)	β_3 = 0.462 (.13)	γ_3 = 0.019 (.005)	δ_3 = 0.019 (.007)
α_4 = 0.012 (.008)	β_4 = -0.853 (.16)	γ_4 = 0.840 (.04)	
α_5 = 0.009 (.007)	β_5 = 0.802 (.18)		
α_6 = 0.775 (.05)			

III. Summary Statistics

	[1]	[2]	[3]	[4]
R^2	0.987	0.803	0.952	0.784
SEE	0.188	1.075	0.0070	1.376
DW (Durbin h)	(2.237)	2.211	(2.032)	1.833
Estimation period	1965:I to 1988:IV, 96 observations			

Endogenous variables are considered to be (U-DEM), U, Δw, Δp, Δq, h, $(y-\lambda h-(1-\lambda)k)$. Instruments are the lagged values of the endogenous variables and all exogenous and predetermined variables.

IV. Variable Definitions (Lower Case Indicates Logarithms)

U	Civilian unemployment rate
DEM	Impact on the unemployment rate of changing labor force shares
y	Real output in the private nonfarm sector (PNFS)
SE, SL	Share of persons aged 16-24 in total employment and in the labor force, respectively
h	Total person hours (PNFS)
rd	Real stock of privately financed research and development capital
λ	Share of employee compensation in total income (PNFS)
k	Real stock of capital (PNFS)
NWLC	Employers' contributions as a percent of total wages
UIRR	Unemployment insurance replacement ratio adjusted for coverage
RMW	Relative minimum wages
UNN	Union members as a percent of total employment
w	Hourly compensation (PNFS)
p^c	Implicit deflator for private consumption expenditures
p	Implicit output deflator (PNFS)
q	Output per hour (PNFS)
p^g	Implicit deflator for consumption of gasoline

See text for more complete definitions and sources.

output in this way means that the constant in the expression for the natural rate will not, in general, be the same as the long-run constant implied by the estimated short-run, dynamic equation.

b. Estimation results

Given that most macroeconomic shocks simultaneously influence wages, prices, unemployment, and productivity, the errors across the equations will be interdependent. In view of this simultaneity, the system has been estimated using non-linear three stage least squares. 1/ The endogenous variables in the system are the contemporaneous values of the dependent variables as well as the unemployment rate, labor input, and the growth of labor productivity. The estimation period is from 1965:I to 1988:IV.

The system estimation results are shown in Table 8. All of the estimated equations fit the data well judged by the usual statistical criteria, and there is little evidence of serial correlation. Notwithstanding the use of instrumental variables, the standard errors of all equations are lower than their single equation counterparts.

The system results reported in Table 8 are generally similar to the single-equation estimates discussed above. One difference concerns the unemployment rate equation where the second lagged dependent variable was consistently insignificant and was dropped. The estimated coefficients on the structural variables in this equation were generally smaller compared with the single equation estimates and became marginally less significant. In the multifactor productivity equation, the elasticity of output with respect to R&D capital was reduced somewhat. In the Phillips curve equation, the most important changes were an increase in the absolute size of the estimated coefficient on the unemployment gap and the finding that the dummy variable for the 1980s--which picked up over prediction of wage growth in some of the single equation estimates--became insignificant. 2/ Thus, explicitly incorporating the expression for the natural rate into the Phillips curve appears to solve the overprediction of wage growth discussed above. In the price equation, the main change was a reduction in the estimated impact from the output gap.

1/ In contrast to the single equation estimates, the system estimates used an extended memory version of TSP because it was not feasible to code the appropriate parameter restrictions in PC-GIVE.

2/ As noted earlier the dummy variables for the late 1960s and early 1970s were included in the equations, but their estimated coefficients are not recorded in Table 8.

Table 9. Quasi-Likelihood Ratio Tests for Restrictions in the System Estimates 1/

	Relevant Coefficient	Test Statistic 2/	Estimated Coefficients: Con-strained	Estimated Coefficients: Uncon-strained
Homogeneity:				
Inflation in the wage equation	$(1-\beta_1)$	--	1.0	1.000
Productivity in wage equation	$(1-\beta_3)$	0.132	1.0	0.871
Unit labor cost in the price equation	(δ_1)	0.396	1.0	1.048
Constant: 3/				
In the expression for the natural rate	(β_0)	0.372	-3.061	-3.514
In the expression for the potential output	(δ_0)	32.700	-0.021	0.041
Constrained coefficients on relative minimum wages and unionization in the unemployment rate equation 4/	(α_5)	0.319	0.009 0.004	0.009 0.004

1/ These tests are based on the system estimation results reported in Table 8.

2/ The test statistic is distributed χ^2 with 1 (the number of restrictions) degree of freedom. The critical value at the 10 percent level is 2.71.

3/ The unconstrained coefficient estimates are those reported in Table 8; the constrained coefficient estimates are the long-run values of the constants in the unemployment and production function equations which replace the coefficients noted above.

4/ The first line refers to the estimated coefficient on relative minimum wages, the second line to the estimated coefficient on unionization.

The estimated system incorporates a number of constrained parameters. Quasi-likelihood ratio tests of these restrictions are reported in Table 9. All of the homogeneity constraints in the wage and price equations are clearly consistent with the data, which is reassuring given the strong theoretical priors regarding homogeneity. The second group of tests concern the constant terms in the expressions for the natural rate and potential output. While the long-run value of the constant in the unemployment rate equation is not significantly different from the estimated constant in the expression for the natural rate, this is not true for the associated constants in the multifactor productivity and price equations. This result reflects the transformations which convert the determinants of potential output to their "natural" or "normal" levels. Finally, given the multicollinearity between relative minimum wages and unionization noted above, the coefficient on the latter was constrained to be 0.44 times the coefficient on the former; this restriction is not rejected by the data.

The system estimation results imply the following expressions for the natural rate of unemployment and potential output

$$U^{NAT} = DEM - 3.514 + 0.302NWLC + 0.053UIRR + 0.040SL \cdot RMW + 0.017UNN$$

$$y^{pot} = 0.041 + 0.697h + 0.303k - 0.009SE \cdot h + 0.119rd$$

where the determinants of potential output are evaluated at their natural or normal levels, and the coefficients applied to labor and capital inputs are factor shares in 1988:IV. Compared to the expressions derived from the single equation estimates, all of the estimated long-run elasticities are somewhat smaller. The estimated elasticity of output with respect to R&D capital is now more consistent with estimates found in the literature, as summarized by Griliches (1988). At current levels of relative minimum wages and the share of youth in the labor force, the estimated impact of a 10 percent increase in the minimum wage is to increase the natural rate of unemployment by about 0.04 percentage points. 1/ This relatively small effect is very close to estimates found in the literature. 2/

1/ With reference to the equation for the natural rate given in the text, a 10 percent increase in the minimum wage raises the RMW variable by about 5 1/2 percent while the share of youth (SL) is equal to 0.18.

2/ As summarized by Brown (1988, p. 139), recent studies which control for the teenage population share estimate the impact of a 10 percent increase in the minimum wage to be a rise in teenage unemployment rates of 0.75 percentage points or less. Given that about 6.5 percent of the labor force are teenagers, the estimated 0.04 percentage point effect on the aggregate unemployment rate would translate into a 0.62 percentage point effect on the teenage unemployment rate.

The system presented here focuses on the supply side of the economy. The above expressions determine the natural rate of unemployment and the level and growth of potential output, and associated factor productivities. In equilibrium the actual unemployment rate will be equal to the natural rate, and actual output and productivity will be equal to potential, in terms of levels and growth rates. In this situation (i) there are no pressures for wage or price inflation to rise or fall, (ii) real wages grow at the same rate as trend productivity and prices at the same rate as trend unit labor costs, and hence (iii) income shares and the mark-up over unit costs (i.e. unit profits) are constant. 1/

2. Estimates of potential output and the natural rate of unemployment

Estimates of the historical path of the output gap and the unemployment gap are shown in Chart 5. Based on the individual coefficient estimates reported in Table 8, developments in potential output and the natural rate can be decomposed to show the contributing factors.

a. Potential output

The estimates of potential output growth in the private nonfarm business sector are shown in Table 10, along with the contributions to growth of changes in potential factor inputs and multifactor productivity. In each case, the growth contribution of a factor input is defined as its potential growth rate times its share in total costs. 2/ The growth of multifactor productivity at potential output is decomposed into those parts due to private expenditures on research and development and the share of youth in employment, as a proxy for the experience of the workforce.

A first important feature of the results is that the growth of potential output is estimated to have recovered somewhat from its depressed rates during the late 1970s, but remains below the rapid rates of increase in the late 1960s. The estimates suggest that potential output growth in the nonfarm business sector rose to 2 3/4 percent over the period 1981 through 1988, compared with 2 1/2 percent between 1974 and 1980 and 3 1/2 percent in the late 1960s.

1/ The dynamic adjustment of the economy to long-run equilibrium works primarily through the impact of the labor market and output gaps on wage and price inflation. In the short run, these gaps are essentially determined on the demand side of the economy. In the long run wage and price inflation is, of course, determined by the growth of monetary aggregates less trend changes in velocity.

2/ This approach, which follows that used in growth accounting exercises, was used by Adams et al. (1987).

Given much interest in the prospects for growth over the medium term, it is instructive to consider the causes of the estimated slowdown in the growth of potential output during the 1970s and the pickup in the 1980s. Two causes of the slowdown in the 1970s are identified in Table 10. According to the estimates, slower growth in factor inputs contributed 1/4 percentage points, with a slightly larger contribution from labor not being sufficient to offset a decline in the contribution of capital. The remainder is accounted for by slower growth of multifactor productivity, the growth rate of which declined from 1 percent in the late 1960s to two tenths that rate in the mid 1970s. The slowdown in multifactor productivity growth was due to a smaller contribution of research and development expenditures and the effects of a larger share of young and inexperienced workers in the labor force.

Table 10. Contributions to the Growth of Potential Output in the Private Nonfarm Business Sector

(Percentage changes, at annual rates)

	1965:I 1969:IV	1970:I 1973:IV	1974:I 1980:IV	1981:I 1988:IV
Potential output	3.5	3.1	2.6	2.8
Contributions of 1/				
Labor	1.0	1.1	1.2	1.3
Capital	1.6	1.3	1.2	1.1
Multifactor productivity	0.9	0.7	0.2	0.4
Of which:				
Research and development	0.9	0.8	0.6	0.7
Youth	--	-0.1	-0.3	-0.2
Single factor productivities				
Labor productivity	2.0	1.5	0.9	0.9
Capital productivity	-1.1	-1.1	-1.2	-0.9

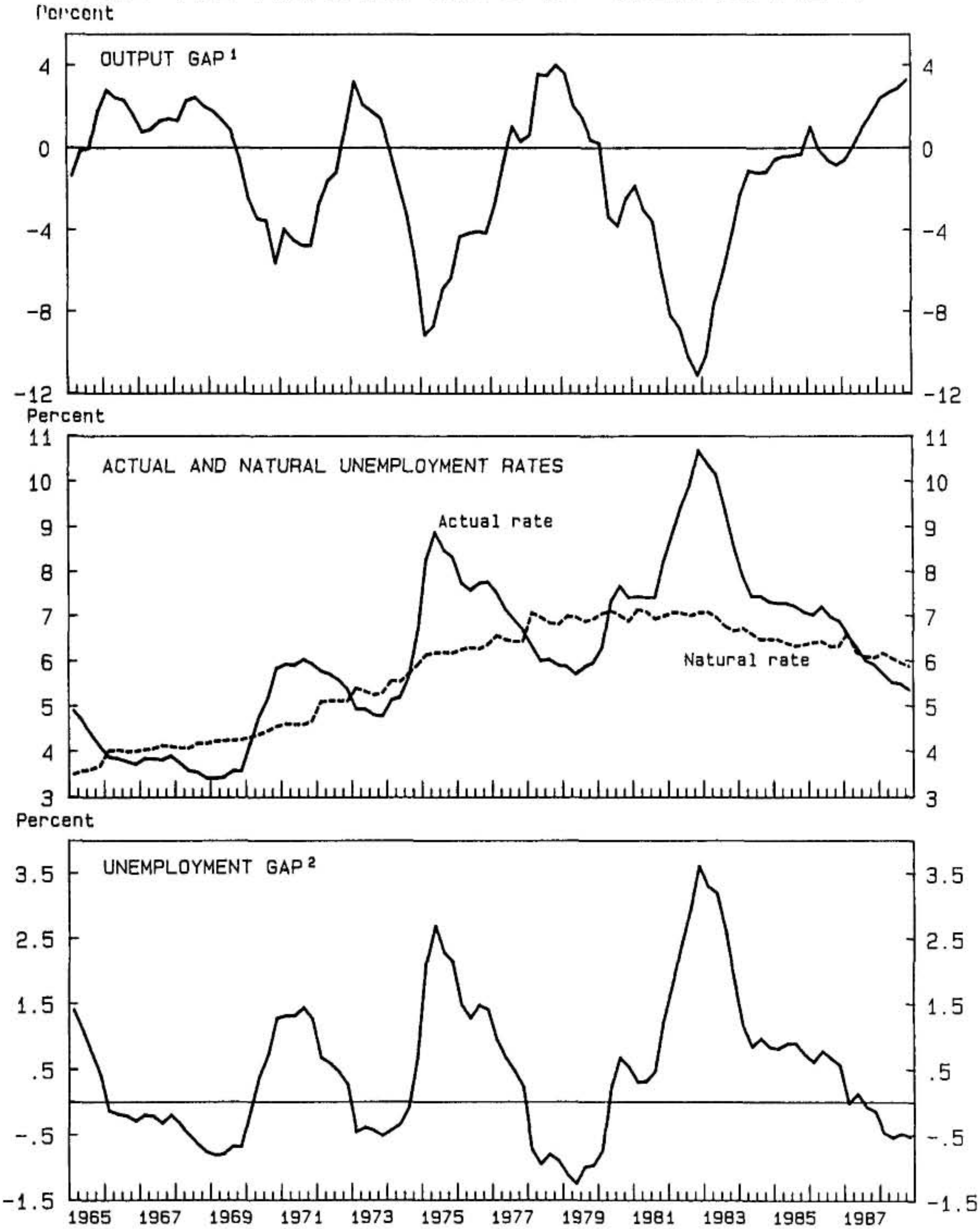
The modest pickup in the growth of potential output in the 1980s is estimated to reflect an improvement in the growth of multifactor productivity. This improvement, which leads to a growth of multifactor productivity of almost 1/2 percentage point a year, reflects a small pickup in the contribution of research and development expenditures, and a

1/ The growth contribution of a factor is defined as its growth over a given period, multiplied by its share in output.

CHART 5

UNITED STATES

OUTPUT AND UNEMPLOYMENT GAPS
AND THE NATURAL RATE OF UNEMPLOYMENT



[1]Defined as the logarithm difference between actual and potential output in the private nonfarm sector.
[2]Defined as the difference between the actual and the natural rate of unemployment.

somewhat smaller negative impact from youth. The improvement, while of key importance for the medium-term growth projections, implies that multifactor productivity is still only growing at half its rate in the late 1960s. 1/

b. The natural rate of unemployment

The natural rate of unemployment is estimated to have increased steadily from 3 1/2 percent in the mid-1960s to a peak of 7 1/4 percent in 1980, and to then have fallen back to about 5 3/4 percent in 1988 (Chart 5). Thus roughly half of the increase in actual unemployment rates from the mid-1960s to their peak in the early 1980s can be attributed to increases in the natural rate. This hump-shaped pattern was also characteristic of the natural rate estimates from the independently estimated unemployment rate and Phillips curve equations. Given the problems of multicollinearity discussed above, the estimated level and time profile of the natural rate may be a more robust result than the decomposition presented below.

Bearing this caveat in mind, Table 11 presents a decomposition of the sources of the changes in the estimated natural rate. In the period up to 1980, the demographic impact of the changing composition of the labor force contributed to increases in the natural rate, as did increases in unemployment insurance replacement ratios. The estimation results indicate that the dominant factor, however, was the large increases in employers' contributions as a percent of wages and salaries. The decline in the natural rate of unemployment in the 1980s has reflected declines in almost all of its determinants, particularly the changing composition of the labor force and relative minimum wages adjusted for the share of youth in the labor force.

1/ The failure of productivity growth to revive significantly during the 1980s raises the question as to what is happening to the explosion of computing power. For a comprehensive discussion of this issue, see Baily and Gordon (1988).

Table 11. Contributions to Changes in the Natural Rate of Unemployment

	1965-1970	1970-1975	1975-1980	1980-1985	1985-1988
Changes in the actual unemployment rate	0.5	3.5	-1.3	--	-1.7
Changes in the natural rate	0.8	1.8	0.8	-0.6	-0.4
Due to:					
Demographics	0.2	0.4	-0.1	-0.3	-0.2
Unemployment insurance replacement ratios	-0.1	0.1	0.2	-0.2	0.2
Relative minimum wages	--	--	--	-0.2	-0.1
Unionization	--	--	-0.1	-0.1	--
Employers' contributions	0.7	1.3	0.9	0.3	-0.2
Memorandum:					
Unemployment rate (end-year)					
Actual	5.0	8.5	7.2	7.2	5.5
Natural	4.6	6.2	6.9	6.3	5.9

c. Output and unemployment gaps

An interesting feature of the estimated output and unemployment gaps is that they are not symmetrical around zero (Chart 5). Departures of actual output below the estimated potential output, and of actual unemployment above the estimated natural rate, are commonly large and of relatively long duration. Positive output and employment gaps are estimated to be considerably smaller and, except for the late 1960s, shorter. Over the full sample period, the estimated gaps are not zero. Thus the estimated gaps more closely resemble a trend through peaks concept of potential output, rather than a concept whereby potential output is equal to mean output over the business cycle. 1/

1/ See Delong and Summers (1988).

Table 12. Output and Unemployment Gaps in Selected Periods

(Percentage points)

	Output Gap 1/	Unemployment Gap 2/	Okun Co-efficient 3/
1965:I	-1.4	1.4	1.0
1968:III	2.4	-0.6	4.0
1973:I	3.2	-0.5	6.4
1975:I	-9.2	2.1	4.4
1980:I	0.2	-0.7	0.3
1982:IV	-11.2	3.6	3.1
1988:IV	3.2	-0.5	6.4

As noted in Section 2, a common approach to determining potential output is to apply the Okun coefficient to an estimate of the gap between the actual and natural unemployment rates. There is, of course, no necessary reason why the Okun coefficient should be stable over time. Variations in the coefficient might reflect a number of factors including changes in the intensities with which labor and capital are used, and changes in labor force participation behavior. As can be seen from Table 12, which shows the Okun coefficient for selected periods, the coefficient does vary from one period to the next but shows no secular trend. Based on regression analysis, the average value of the

1/ Logarithmic difference between actual and potential output, multiplied by 100.

2/ Difference between actual and natural unemployment rate, in percentage points.

3/ Ratio of output gap to unemployment gap, absolute value. An ordinary least squares regression of the output gap on the unemployment gap (over the period 1965:I to 1988:IV) without a constant term produced a slope coefficient of -2.9. A comparable estimation with the unemployment gap as the dependent variable produced a slope coefficient of -0.3.

coefficient over the estimation period is between 2 3/4 and 3; 1/ this range includes Okun's original estimate of 3 but is somewhat higher than a number of more recent estimates. 2/

V. Medium-Term Prospects for Potential Output and the Natural Rate of Unemployment

The medium-term outlook for the growth of potential GNP can be assessed on the basis of the estimation results and a number of assumptions about the behavior of the structural determinants of potential output and the natural rate of unemployment. As with any analysis of this type, it must be stressed that the projections are no more realistic than the assumptions on which they are based, and that alternative assumptions about the structural determinants of potential output would lead to different estimates.

In assessing the prospects for potential output growth and the natural rate, it is useful first to consider the starting position. In the first half of 1987, the estimates indicate that the United States economy was essentially at full employment and full capacity (Chart 5). Since then the growth of potential has slowed somewhat, and has averaged almost 2 percentage points less than actual output growth (annual rate); and while the natural rate has continued to decline somewhat, actual rates of unemployment have fallen more sharply. Thus, in 1988 the gap between actual and potential output is estimated to have averaged 2 3/4 percent, suggesting that excess demand pressures in goods markets tended to increase the annual rate of inflation by about 3/4 percentage point. Similarly, the actual unemployment rate is estimated to have been about 1/2 of a percentage point below the natural rate of unemployment tending to increase the annual rate of wage inflation by about 1/4 percentage points at an annual rate.

The outlook for potential GNP depends on the assumed behavior of potential factor inputs in the private nonfarm business sector, the growth of multifactor productivity, and the evolution of other sectors of the economy which determine the behavior of GNP for a given level of output in the private nonfarm business sector. These are discussed below.

1/ Reflecting the nature of least squares techniques, a regression of the output gap on the unemployment gap will not produce an Okun coefficient that is the reciprocal of the regression undertaken in the opposite direction. (This is because least squares minimizes vertical rather than perpendicular distances.) The range for the Okun coefficient cited in the text reflects the results from regressions run with either the output or the unemployment gap as the dependent variable.

2/ Recent estimates include that of Perloff and Wachter (1979) who estimate an Okun coefficient of 2 1/4; and Adams et al. (1987) who estimate a coefficient of 2.

The growth of potential labor input in the private nonfarm business sector is determined by four elements: (i) the growth of the population of working age; (ii) changes in the labor force participation rate; (iii) changes in average hours worked per person; and, (iv) changes in the employment rate, as implied by shifts in the natural rate of unemployment. 1/ The first three factors contribute to the underlying growth of potential labor input whereas shifts in the natural rate of unemployment contribute to once-for-all changes in its level.

The projections for the growth of labor input are those prepared by the previous Administration in 1989 2/ (Table 13). According to the projections, the growth of the civilian labor force is expected to slow over the medium term, mainly as a result of changes in the demographic composition. The gradual decline in the growth rate of the adult population, which has occurred since the late 1960s and 1970s, is expected to continue with the growth of the population of working force age declining from 1 1/2 percent between 1948 to 1981 to less than 1 percent over the medium term. In contrast, labor force participation rates and average hours worked are assumed to follow similar paths to those during the 1970s and early 1980s. Reflecting the continued entry of women into the labor force, the labor force participation rate is projected to increase at half a percentage point a year--its average rate of increase since the early 1970s. Average hours worked are projected to continue to decline at half a percent a year. On the basis of these assumptions, the growth rate of the civilian labor force is projected to decline from an annual average growth rate of 1 3/4 percent between 1948 and 1981 to 1 1/3 percent over the projection period.

The path for the natural unemployment rate has important implications for potential labor input, given the growth of the labor force. The projections for the natural rate of unemployment suggest that the natural rate will decline gradually over the projection period and reach 5 percent by 1994, compared with 5 3/4 percent in 1988. This reduction reflects the assumption that the share of youth in the labor force continues to decline, and that the other determinants of the natural rate continue to develop as they have from 1985 to 1988, also contributing to a lower natural rate of unemployment. The decline in the unemployment rate is comparable to that projected by the Administration and leads to the same projected growth of potential labor input of 1 1/2 percent a year.

As an aside, it is interesting to consider the estimated impact on the natural rate of unemployment of proposals to raise the minimum wage. If instead of assuming no changes in minimum wages in the period to 1994, implying continued declines in relative minimum wages, it was

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1/ It was assumed that there was no change in the relationship between total employment and employment in the nonfarm business sector.

2/ As contained in the Economic Report of the President, January 1989.

Table 13. Medium-Term Growth Projections

(Percentage changes, in percent)

	1989-94	
	This Paper	Administration 1/
Factor inputs		
Labor	1.6	1.6
Of which, due to:		
Growth in population, 16 years and over	0.9	0.9
Changes in participation rates	0.5	0.5
Changes in average hours worked	-0.1	-0.1
Growth of labor force	1.4	1.4
Changes in employment rate	0.1	0.1
Nonfarm business employment as a share of total employment	0.2	0.2
Capital	3.8	--
Capital-labor ratio	2.2	--
Factor productivities		
Labor productivity	1.4	1.9
Capital productivity	-0.2	--
Multifactor productivity	0.6	--
Of which, due to:		
Private research and development expenditures	0.8	--
Share of youth in labor force	-0.2	--
Nonfarm business output	3.0	3.6
Less nonfarm business output as a percentage of GNP	0.4	0.4
Real GNP	2.6	3.2
Memorandum item:		
Contributions to the growth of labor productivity from:		
Capital deepening	0.8	--
Multifactor productivity growth	0.6	--

1/ As contained in the Economic Report of the President, January 1989, page 286.

assumed that the minimum wage was increased to $4.55 per hour, the natural rate of unemployment would be about 0.15 percentage points higher in 1994. This is not a negligible effect; the increase in teenage unemployment rates might be as large as 2 to 2 1/2 percentage points.

The growth rate of the capital stock over the projection period is assumed to reflect a continuation of trends in investment spending during the 1980s. As a share of (net) valued added, real net investment in the nonfarm sector averaged slightly less than three percent between 1980 and 1988 and is assumed to rise to 3 1/2 percent on average over the projection period. 1/ This outcome is assumed to reflect a process of further capital deepening as the growth of the labor force slows, and to be undertaken in response to attendant upward pressure on real wages. Under the assumed conditions, capital input in the private nonfarm sector is projected to increase at an annual rate of 3 3/4 percent over the medium term--somewhat higher than its growth in the 1980s--while the capital-labor ratio on average would rise by 2 1/4 percent a year.

In view of its historical importance, the assumptions about the growth of multifactor productivity are crucial to the projections. A key question in this regard is whether the relatively low rates of productivity growth since the early 1970s are a good guide to future developments, or whether there might be a rebound to the relatively rapid growth rates of the 1960s (see Table 10). Based on the projected maturing of the workforce and a pickup in expenditures on research and development, multifactor productivity growth is projected to increase to a little over 1/2 percent a year in the medium term, compared with its estimated growth of 1 percent in the late 1960s. This projection, which implies that multifactor productivity would grow at a slightly faster pace than during the early 1980s, is critical to the view that potential output growth can be sustained at a relatively rapid rate in the face of the projected slowing in the growth of the labor force.

The projections of potential output growth implied by the above assumptions are shown in Table 13. While the growth of potential output in the private nonfarm business sector is projected to increase marginally above its growth rate in the early 1980s, the projection must be viewed in the context of a slowdown in the projected growth of labor input to a little less than 1 1/2 percent, compared with an average growth of almost 2 percent in the early 1980s. Under these conditions, the pickup in growth to an annual rate of 3 percent requires either

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1/ Reflecting declines in relative computer prices, real and nominal investment shares have behaved very differently during the 1980s. In addition, a continuation of the movement toward shorter-lived capital goods has meant that the gross and net measures of investment have diverged. For a discussion of the significance of these developments, see De Leeuw (1989).

that the contribution of capital to growth increases or that there be improvements in the growth of multifactor productivity.

Despite projected increases in rates of capital deepening and multifactor productivity growth, the estimate of the growth of potential GNP is considerably less optimistic than that presented by the Administration in early 1989. Whereas the Administration projected GNP growth of 3.2 percent a year, which would imply that improvements in labor productivity more than offset a slowing of the labor force, the estimates presented here suggest that potential GNP will only grow at an annual rate of 2.6 percent. The difference reflects a less sanguine view about productivity developments.

Reflecting favorable trends in the economy, including lower energy prices and inflation, as well as policy initiatives with respect to research and development and education, the Administration projected that labor productivity growth will increase to 2 percent in the medium term--and hence return to its average growth rate in the post war period. In contrast, the projections presented here suggest that labor productivity growth, while recovering from its depressed rates during the 1970s and early 1980s, will only increase by 1 1/2 percent a year. This improvement, while sufficient to offset the projected slowing of the labor force, implies that potential output growth does not increase significantly above its rate in the early 1980s.

As regards the sources of productivity growth, the projections suggest that capital deepening would account for almost half of the projected growth of labor productivity over the projection period, while the remainder would be accounted for by the growth of multifactor productivity. The growth in multifactor productivity reflects two factors: the impact of larger expenditures on research and development; and a smaller negative contribution from youth as the work force matures and becomes more experienced.

In summary, although a substantial continued improvement in the growth of labor productivity is expected over the medium term, this is offset by the assumed continued slowdown in the growth of labor input. Under these conditions, compared with the 1980 to 1988 period, there is only likely to be a modest pickup in the growth of potential GNP to an average annual rate slightly above 2 1/2 percent in the period from 1989 to 1994. This estimate also reflects the expectation that the natural rate of unemployment will decline to about 5 percent by 1994.

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