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Capital and Trade as Engines of Growth in France

An Application of Johansen's Cointegration Methodology

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An aggregate production function is estimated using recent cointegrating techniques particularly appropriate for estimating long-run relationships. The empirical results suggest that the growth of output in France has been spurred by increased trade integration within the European Community and by the accumulation not only of business sector capital—the only measure of capital included in most empirical studies—but also by government infrastructure capital, residential capital, and research and development capital. Calculations of potential output indicate that trade and capital—broadly defined—account for all of the growth in the French economy during the past two decades. [JEL E23, F15, O32, O52]

THE IMPORTANCE of trade and capital as determinants of trend or potential economic growth is widely acknowledged. The collapse of world trade following the passage of the Smoot-Hawley tariffs in the United States in 1930 helped to trigger the great world depression of the 1930s. By contrast, the brisk expansion of world trade in the 1950s and 1960s contributed to unusually rapid growth in the industrial countries. More recently, the fast-growing economies of Southeast and East Asia

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have built their success on an outward orientation and rapid increases in intraregional trade. High rates of capital accumulation also spurred growth in the industrial countries in the postwar period and in the dynamic economies of Asia more recently. The slowdown in growth after the mid-1970s in France and other industrial countries coincided with a moderation in the growth of world trade and, in some countries, with a reduced pace of capital formation, particularly by the business sector.[1]

Although, empirical studies based on aggregate production functions have always emphasized the importance of capital accumulation by the business sector, the importance of other types of capital accumulation has received considerably less emphasis; the role of trade has generally been emphasized only in empirical studies based on computable general equilibrium models. This paper presents new estimates of an aggregate production function for France, focusing on the role of trade and the importance of capital accumulation by government, households, and businesses, including their expenditures on research and development (R&D).

The production function is estimated with recent cointegrating techniques suggested by Johansen (1988). This methodology emphasizes the identification of long-run relationships, and hence is particularly appropriate for studying the determinants of potential output. The empirical results suggest that increased trade within the European Community has raised efficiency and productivity in France. The empirical results also indicate that in addition to the stock of business sector capital—which is the only measure of capital included in most empirical studies—the stock of government infrastructure capital, the stock of residential capital, and the stock of R&D capital have also contributed to the growth of output in France.

The estimated production function is used to calculate potential output. These calculations indicate that trade and capital—broadly defined—account for all of the growth in the French economy in the two decades 1971–91. Although labor input is also an important determinant of output, its contribution to growth has been nil over the 1971–91 period. Thus, during the past two decades, trade and capital have been the engines of growth in France. The growth of potential output is estimated to have averaged about 2½ percent a year in 1984–91 and to continue at about 2½ percent a year in 1992–97. To foster more robust

[1] This slowdown has rekindled interest in the determinants of growth and in growth theory, as evidenced by the recent emergence of a large and expanding literature on endogenous growth. See Lucas (1988), Sala-i-Martin (1990), and Helpman (1992).

growth, France must encourage capital accumulation, implement labor market policies to reduce unemployment, and take steps to revitalize the trade liberalization process.

I. Johansen's Cointegration Methodology

Over the past few years, important advances have been made in cointegration techniques to estimate long-run relationships.[2] The basic idea of cointegration is that two or more variables may be regarded as defining a long-run equilibrium relationship if they move closely together in the long run, even though they may drift apart in the short run. This long-run relationship is referred to as a cointegrating vector. Because there is a long-run relationship between the variables, a regression containing all the variables of a cointegrating vector will have a stationary error term, even if none of the variables taken alone is stationary.

Stock (1987) demonstrates that, in the case of cointegrated nonstationary series, ordinary least squares (OLS) estimates of the cointegrating vector are not only consistent but they converge on their true parameter values much faster than in the stationary case. This property is referred to as "super consistency."[3] The proof of consistency does not require the assumption that the regressors be uncorrelated with the error term. In fact, the estimates will remain (super) consistent if any of the variables in the cointegrating vector is used as the dependent variable.

More generally, most of the classical assumptions underlying the general linear model are not required in order for OLS or maximum likelihood estimates of the cointegrating vector to have desirable properties. This is particularly important because errors in variables and simultaneity—both of which would normally be cause for concern in the data set used here—will not affect the desirable properties of the estimates. Moreover, because the cointegration approach focuses on long-run relationships, problems associated with variations in factor utilization and with autocorrelation do not arise.

A popular approach to cointegration has been to use unit-root tests,

[2] Cuthbertson, Hall, and Taylor (1992) present a survey of cointegration.

[3] The intuition behind the super-consistency result is that, for values of the parameters that do not cointegrate, the residual series will itself be nonstationary and therefore have a very large estimated variance. When the estimated parameters are close to the true cointegrating parameters, the residual becomes stationary and its variance shrinks. Since least squares and maximum likelihood methods essentially minimize the residual variance, they will be extremely good at picking out the cointegrating parameters if they exist. The super-consistency result does not hold if there are multiple cointegrating vectors.

such as the Dickey-Fuller (DF) or the augmented Dickey-Fuller (ADF) test (Dickey and Fuller (1981)), to determine the degree of integration of the relevant variables and then to apply the Engle and Granger (1987) two-step procedure, which is based on an OLS estimate of the cointegrating vector and a unit-root test of its residuals. Although it is easy to implement, there are a number of problems with the Engle and Granger two-step procedure. Banerjee and others (1986) show that there may be significant small-sample biases in such OLS estimates of the cointegrating vectors, and Hendry and Mizon (1990) illustrate that conventional DF and ADF tests generally suffer from parameter instability. In addition, the limiting distributions for the DF and ADF tests are not well defined, implying that the power of these tests is low (Phillips and Ouliaris (1990)). Perhaps most damaging is the possibility that any given set of variables may contain more than one long-run relationship: there may be multiple cointegrating vectors. OLS estimates of the cointegrating vector cannot identify multiple long-run relationships or test for the number of cointegrating vectors.

Johansen (1988) and Johansen and Juselius (1990) present a cointegration estimation methodology that overcomes most of the problems of the two-step approach. The Johansen procedure is based on maximum likelihood estimates of *all* the cointegrating vectors in a given set of variables and provides two likelihood ratio tests for the number of cointegrating vectors. Johansen and Juselius (1990) consider the following general model:

$$\mathbf{X}_t = \mathbf{\Pi}_1 \mathbf{X}_{t-1} + \cdots + \mathbf{\Pi}_k \mathbf{X}_{t-k} + \boldsymbol{\mu} + e_t, \quad \text{for } t = 1, \ldots, T, \tag{1}$$

where $\mathbf{X}_t$ is a vector of p variables; $e_1, \ldots, e_t$ are independent normal errors with mean zero and covariance matrix $\mathbf{\Lambda}$; $\mathbf{X}_{T-k}, \ldots, \mathbf{X}_0$ are fixed; and $\boldsymbol{\mu}$ is an intercept vector. Economic time series are often nonstationary, and systems such as the above vector autoregressive representation (VAR) can be written in the conventional first-difference form:

$$\Delta\mathbf{X}_t = \mathbf{\Gamma}_{k-1}\Delta\mathbf{X}_{t-k+1} + \mathbf{\Pi}\mathbf{X}_{t-k} + \boldsymbol{\mu} + e_t, \tag{2}$$

where

$$\mathbf{\Gamma}_i = -(\mathbf{I} - \mathbf{\Pi}_1 - \cdots - \mathbf{\Pi}_i), \quad \text{for } i = 1, \ldots, k-1,$$

and

$$\mathbf{\Pi} = -(\mathbf{I} - \mathbf{\Pi}_1 - \cdots - \mathbf{\Pi}_k).$$

The only level term in equation (2) is $\mathbf{\Pi}\mathbf{X}_{t-k}$. Thus, only the matrix $\mathbf{\Pi}$ contains information about the long-run relationships between the variables in the data vector. There are three cases:

1. If the matrix Π has rank zero, then all the variables in $\mathbf{X}_t$ are integrated of order one or higher and the VAR has no long-run properties;
2. If Π has rank p (it is of full rank), the variables in $\mathbf{X}_t$ are stationary; and
3. If Π has rank r $(0 < r < p)$, Π can be decomposed into two distinct $(p \times r)$ matrices α and β such that $\Pi = \alpha\beta'$.

The third case implies that there are r cointegrating vectors. The parameters of the cointegrating vectors are contained in the β matrix. Therefore, $\beta'\mathbf{X}_t$ is stationary even though $\mathbf{X}_t$ itself is nonstationary. The α matrix gives the weights with which the cointegrating vectors enter each equation of the system.

To determine the number of cointegrating vectors, r, Johansen and Juselius describe two likelihood ratio tests. In the first test, which is based on the maximal eigenvalue, the null hypothesis is that there are at most r cointegrating vectors against the alternative of $r + 1$ cointegrating vectors. In the second test, which is based on the trace of the stochastic matrix, the null hypothesis is that there are at most r cointegrating vectors against the alternative hypothesis that there are r or more cointegrating vectors. The first test is generally considered to be more powerful because the alternative hypothesis is an equality. These tests can also be used to determine if a single variable is stationary by including only that variable in $\mathbf{X}_t$.

Johansen demonstrates that the likelihood ratio tests have asymptotic distributions that are a function only of the difference between the number of variables and the number of cointegrating vectors. Therefore, in contrast with the DF and ADF tests, the Johansen likelihood ratio tests have well-defined limiting distributions. Johansen and Juselius also provide a methodology for testing hypotheses about the estimated coefficients of the cointegrating vectors based on likelihood ratio tests with standard chi-squared distributions.

II. Production Function

We estimate a Cobb-Douglas-type production function augmented to include R&D capital as a distinct factor of production and to allow a measure of trade to influence the productivity of the factors of production. More specifically, we estimate the long-run relationship between real value added in the nonfarm business sector (y), hours worked in the nonfarm business sector (h), the stock of capital (k), the stock of R&D capital ($k^{r\&d}$), and intra-EC trade as a percent of total EC output (EC):

$$y = \alpha h + \beta k + \gamma k^{r\&d} + \theta EC + \text{constant}, \tag{3}$$

where variables represented by lower-case symbols are logarithms.

The production function has some novel features. One unusual feature is the inclusion of a measure of European trade integration as a determinant of the productivity of capital and labor in France. The theoretical justification for including a measure of trade integration has recently been developed by Grossman and Helpman (1991) and Rivera-Batiz and Romer (1991). The EC variable captures the beneficial effects of trade integration in the European Community on French enterprises from heightened competition, increased specialization, exposure to new ideas and techniques, and increasing returns to scale in production and in research and development (Figure 1). As noted below, the same variable has been used to explain long-run developments in total factor productivity in Germany; a similar variable (per capita trade) is used by Mao and Rivera-Batiz (1993) in their study of growth and regional convergence in China.

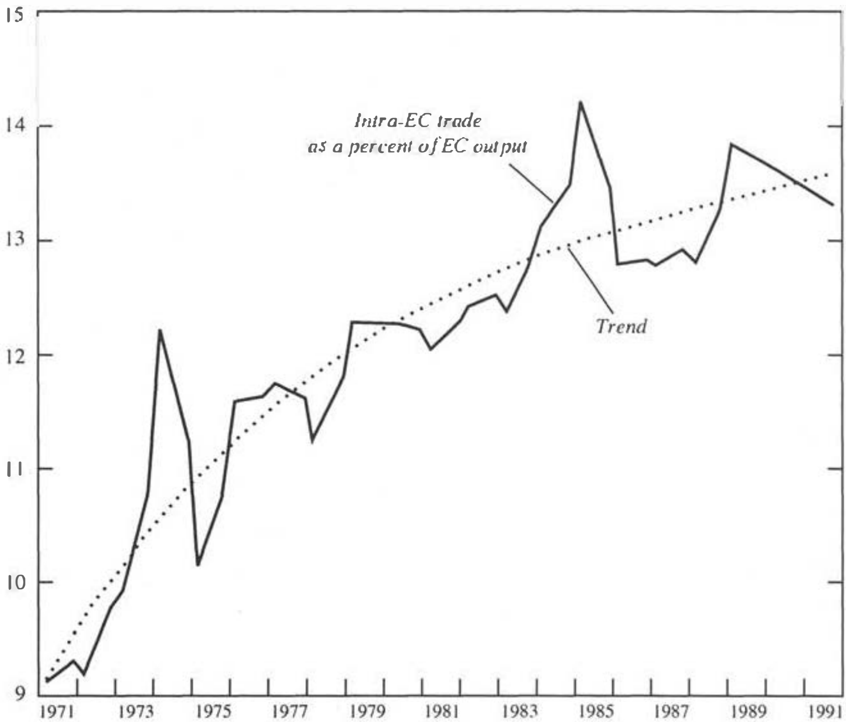
A second unusual feature is the treatment of capital. The physical capital stock is broadly defined to include the stock of government infrastructure capital and residential capital, in addition to the capital of private and public enterprises (Figure 2). The potentially important role of infrastructure capital in increasing productivity and output has received considerable attention recently, although it has proven difficult to estimate separate elasticities for infrastructure capital.[4] Including residential capital is appropriate since value added in the business sector includes imputed services from the housing stock. More generally, housing is an important aspect of an economy's infrastructure, which, like roads, bridges, and nonresidential structures, contributes to its ability to produce real goods and services.[5] This focus on a very broad definition of capital differs from most empirical studies, which typically consider only the business sector capital stock. Although infrastructure capital may not be an important determinant of short-run movements in output, it is particularly important to include infrastructure capital when studying the long-run determinants of output.

In addition to the stock of physical capital, the stock of R&D capital

[4]See the cross-country evidence presented in Ford and Poret (1991) and the evidence for the United States presented in Munnell (1990).

[5]An increase in the stock of housing, for example, may increase labor mobility.

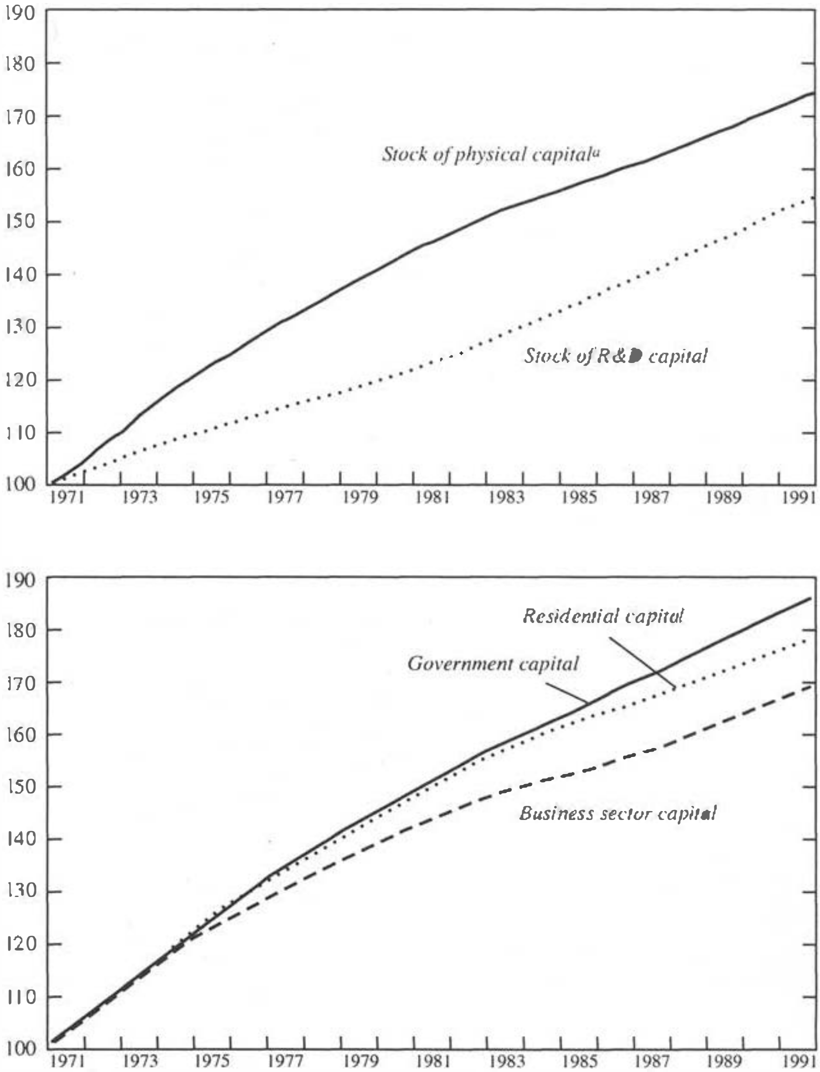
Figure 1. *EC Integration*
(In percent)



is included as a distinct factor of production. This allows the process of technological progress to be modeled explicitly, as suggested by Griliches (1988). The importance of R&D capital, which is complementary to human capital, has been emphasized in endogenous growth theories (Lucas (1988) and Helpman (1992)).

A final unusual feature of the production function is that the coefficients on capital and labor are neither constrained to sum to unity nor constrained to equal their factor shares, in which case the production function becomes a total factor productivity equation. One reason to freely estimate the coefficients on capital and labor is that R&D capital is included as an additional factor of production, and it is not clear how its factor share would be calculated. More generally, the elasticities of output with respect to each factor of production will only be equal to factor shares if factor markets are perfectly competitive, and this is not

Figure 2. *Capital Stocks*
(In logarithms, 1971:I = 100)



[a]Including business sector, residential, and government capital stocks.

assumed here. In addition, endogenous growth theories have questioned the assumption of constant returns to scale, and some have argued that the coefficient on capital should be much larger than suggested by its factor share.[6]

III. Empirical Results

The production function has been estimated using quarterly data for France from 1971:1 to 1991:4 (84 observations). Estimation results based on alternative specifications are discussed below and data sources and definitions are reported in the Appendix.

Table 1 reports the results of tests for the order of integration of the basic set of variables. The results in Table 1 have been obtained using the Johansen procedure, which, as noted above, has well-defined limiting distributions. These tests for the orders of integration do not suffer from the parameter instability associated with the DF and ADF tests and are consistent with our use of the Johansen procedure to estimate the cointegrating vectors. The null hypothesis that the levels of the variables are stationary is rejected, but the null hypothesis that the first differences are stationary cannot be rejected. Therefore, all series appear to be integrated of order one.[7]

The test statistics and the estimated cointegrating vectors from the Johansen procedure are reported in Table 2, where r denotes the number

Table 1. *Johansen Maximum Likelihood Tests for the Order of Integration*
(1971:1 to 1991:4, maximum of four lags in VAR)

Variable	Test statistic	Variable	Test statistic
y	1.53	Δy	13.34
h	1.96	Δh	9.25
k	2.04	Δk	4.31
$k^{r\&d}$	0.23	$\Delta k^{r\&d}$	7.48
EC	3.44	ΔEC	4.44

Note: The null hypothesis is stationarity. The critical values are 3.76 at the 95 percent confidence level and 2.69 at the 90 percent confidence level. Delta is the first-difference operator.

[6] See, for example, Romer (1987) and Sala-i-Martin (1990). There are a number of practical problems with imposing factor shares, one of which is that they are not constant over the sample period. In addition, there are a variety of ways to calculate factor shares, depending, for example, on the way that self-employment income is allocated to capital or labor.

[7] The DF and ADF tests give the same result.

Table 2. *Johansen Maximum Likelihood Tests and Parameter Estimates*
(1971:1 to 1991:4, maximum of four lags in VAR;
eigenvalues in descending order: 0.34, 0.21, 0.18, 0.14, 0.13E-5)

A. Cointegration likelihood ratio test based on maximal eigenvalue of the stochastic matrix

Hypothesis[a] Null	Alternative	Test statistic	95 percent critical value	90 percent critical value
$r = 0$	$r = 1$	35.27	33.32	30.84
$r \leq 1$	$r = 2$	20.14	27.14	24.78
$r \leq 2$	$r = 3$	17.15	21.07	18.90
$r \leq 3$	$r = 4$	12.43	14.90	12.91
$r \leq 4$	$r = 5$	0.0001	8.18	6.50

B. Cointegration likelihood ratio test based on trace of the stochastic matrix

Hypothesis[a] Null	Alternative	Test statistic	95 percent critical value	90 percent critical value
$r = 0$	$r \geq 1$	85.00	70.60	66.49
$r \leq 1$	$r \geq 2$	49.73	48.28	45.23
$r \leq 2$	$r \geq 3$	29.58	31.52	28.71
$r \leq 3$	$r \geq 4$	12.43	17.95	15.66
$r \leq 4$	$r = 5$	0.0001	8.18	6.50

C. Estimated cointegrating vectors (coefficients normalized on y in parentheses)

Vector	y	h	k	$k^{r\&d}$	EC
1	−10.76	7.66	5.71	1.80	0.34
	(−1.00)	(0.71)	(0.53)	(0.17)	(0.03)
2	−2.64	3.17	8.40	−7.60	−0.10
	(−1.00)	(1.20)	(3.18)	(−2.88)	(−0.04)

[a]The number of cointegrating vectors is denoted by r.

of cointegrating vectors.[8] Panel A reports the maximal eigenvalue test of the null hypothesis that there are at most r cointegrating vectors against the alternative of $r + 1$ cointegrating vectors. Starting with the null hypothesis that there are no cointegrating vectors ($r = 0$) against the alternative of one cointegrating vector ($r = 1$), the test statistic (35.27)

[8]The Johansen procedure involves the simultaneous estimation of dynamic vector autoregressive (VAR) equations, for which fourth-order lags were included. It is assumed that the variables have linear deterministic trends. Estimation has been done on Microfit 3.0, see Pesaran and Pesaran (1991).

is greater than the 95 percent critical value (33.32), rejecting the null hypothesis and indicating that there is at least one cointegrating vector. The null hypothesis of $r \leq 1$ against $r = 2$, however, cannot be rejected, suggesting that there is a unique cointegrating vector. Panel B reports the trace test of the null hypothesis that there are at most r cointegrating vectors against the alternative that there are more than r vectors. Both the null of $r = 0$ against $r \geq 1$ and the null of $r \leq 1$ against $r \geq 2$ are rejected. However, the null of $r \leq 2$ against $r \geq 3$ cannot be rejected, indicating that there are at most two cointegrating vectors.[9]

Panel C of Table 2 presents the two estimated cointegrating vectors. The coefficients in parentheses are normalized on y. In the first cointegrating vector, all of the estimated coefficients have the expected signs and are of reasonable magnitudes, although the normalized coefficients for labor and capital are both somewhat higher than their factor shares (see below). In the second cointegrating vector, the estimated coefficients are either implausibly large in terms of factor shares, incorrectly signed, or both. In light of these results, and given that the existence of two cointegrating vectors is rejected by the maximal eigenvalue test, we take the first cointegrating vector as our preferred estimate of the production function.

Compared with the estimated parameters on the labor and capital inputs, it is more difficult to judge the plausibility of the estimated parameters on the stock of R&D capital and the variable for EC trade integration. The estimated coefficient on R&D capital is similar to those found in comparable studies for the United States, Japan, and Germany, but is somewhat larger than typically found in studies based on firm- and industry-level data, perhaps because the estimation of an aggregate production function is better able to capture spillovers that increase the social, and hence the aggregate, return to research and development.[10]

Turning to the estimated coefficient on the EC variable, Coe and Krueger (1990) find the same variable to be a determinant of total factor productivity in the Federal Republic of Germany, although the estimated coefficient for France is somewhat larger than that for Germany. The fact that this variable helps to explain medium- to long-term output developments in other European countries suggests that it is a good proxy for the

[9] Studies using the Johansen procedure often obtain much less clear-cut results; see, for example, Moghadam and Wren-Lewis (1990), Boughton (1991), and MacDonald and Taylor (1993).

[10] Recent studies at the aggregate level for the United States, Japan, and Germany find an elasticity of about 0.13; see Adams and Coe (1990), Citrin (forthcoming), and Coe and Krueger (1990), respectively. Griliches (1988) reports that estimated elasticities from firm- and industry-level data tend to lie between 0.06 and 0.1.

economic impact of European integration. Moreover, as discussed below, the estimated impact on French growth of European integration is consistent with Baldwin's (1989) estimates of the impact of the single market on EC growth.

An important question is whether the stock of R&D capital and the proxy for EC integration are necessary for cointegration. The likelihood ratio test that the coefficients on $k^{r\&d}$ and EC are zero is strongly rejected (chi-squared (2) = 14.9; 95 percent critical value = 5.99).[11] If either $k^{r\&d}$ or EC is omitted, both of the Johansen likelihood ratio tests of the null hypothesis that there are no cointegrating vectors cannot be rejected. Thus, output, labor, and capital are not by themselves cointegrated; both R&D capital and EC integration are necessary additional variables for cointegration.

As discussed above, the measure of physical capital used in the estimated equations includes not only the stock of business sector capital but also the stock of government infrastructure capital and the stock of residential capital. The specification of the equation does not, however, allow the different components of capital—government infrastructure, public enterprises, private business, and residential capital—to have different impacts on output. Specifications that entered some or all of the components of capital separately yielded implausible results.[12]

Because it is much more common to include only the stock of business sector capital (k^b), Table 3 reports estimation results using it instead of the stock of total capital (k).[13] The two tests for the existence of a cointegrating vector give conflicting results. At the 95 percent confidence level, the test based on the maximal eigenvalue (Panel A) indicates that there are no cointegrating vectors (test statistic of 31.96 against a critical value of 33.32), whereas the test based on the trace (Panel B) indicates

[11] A number of other tests were performed to check the robustness of this result: (i) $k^{r\&d}$ and EC were excluded and a trend was added; (ii) EC was dropped and a trend was included; and (iii) a trend was included along with the other variables. None of these specifications resulted in a cointegrating vector with sensible coefficients.

[12] In theory it is possible to enter the components of the capital stock separately and test the summing restriction—for example, $\alpha \ln(X + Y) \approx [\alpha\bar{X}/(\bar{X} + \bar{Y}) \ln X] + [\alpha\bar{Y}/(\bar{X} + \bar{Y}) \ln Y]$, where a bar indicates the sample mean. However, entering the components of capital separately led to multiple cointegrating vectors. Since the "structural" model can consist of a linear combination of the Johansen vectors, the restrictions must be tested across all vectors; when this was done, however, the likelihood ratio tests did not converge.

[13] De Long and Summers (1991), based on cross-country data for industrial and developing countries, find equipment investment has a stronger association with growth than other components of investment. Estimates using only the stock of business equipment capital were not possible since this variable is not readily available for France.

Table 3. *Johansen Maximum Likelihood Tests and Parameter Estimates with the Business Sector Capital Stock*

(1971:1 to 1991:4, maximum of four lags in VAR; eigenvalues in descending order: 0.33, 0.25, 0.20, 0.13, 0.01)

A. Cointegration likelihood ratio test based on maximal eigenvalue of the stochastic matrix

Hypothesis[a] Null	Alternative	Test statistic	95 percent critical value	90 percent critical value
$r = 0$	$r = 1$	31.96	33.32	30.84
$r \leq 1$	$r = 2$	22.77	27.14	24.78
$r \leq 2$	$r = 3$	17.61	21.07	18.90
$r \leq 3$	$r = 4$	11.09	14.90	12.91
$r \leq 4$	$r = 5$	0.78	8.18	6.50

B. Cointegration likelihood ratio test based on trace of the stochastic matrix

Hypothesis[a] Null	Alternative	Test statistic	95 percent critical value	90 percent critical value
$r = 0$	$r \geq 1$	84.21	70.60	66.49
$r \leq 1$	$r \geq 2$	52.24	48.28	45.23
$r \leq 2$	$r \geq 3$	29.48	31.52	28.71
$r \leq 3$	$r \geq 4$	11.87	17.95	15.66
$r \leq 4$	$r = 5$	0.78	8.18	6.50

C. Estimated cointegrating vectors (coefficients normalized on y in parentheses)

Vector	y	h	k^b	$k^{r\&d}$	EC
1	−9.83	9.31	2.87	3.50	0.32
	(−1.00)	(0.95)	(0.23)	(0.36)	(0.03)
2	15.47	−3.26	−10.69	−4.07	0.12
	(−1.00)	(0.21)	(0.69)	(0.26)	(−0.008)

[a] The number of cointegrating vectors is denoted by r.

that there are at most two cointegrating vectors. Panel C reports the coefficient estimates from the two possible cointegrating vectors. Although the estimated coefficients (normalized on y in parentheses) on h, k^b, and $k^{r\&d}$ are correctly signed, their magnitudes are less plausible than in the specification using total capital (Table 2).

Table 4 reports the results of testing the first cointegrating vector reported in Table 2 for a number of restrictions on the estimated coefficients of the three factors of production: labor, capital, and R&D capital.

Table 4. *Tests of Parameter Restrictions*
($y = \alpha h + \beta k + \gamma k^{r\&d} + \theta EC$ + constant)

Parameter restrictions	Unrestricted estimates	Chi-squared test statistic (degrees of freedom)	Critical values 95 percent	Critical values 90 percent
$\alpha + \beta = 1.0$	1.24	1.03 (1)	3.84	2.71
$\alpha = 0.6$	$\alpha = 0.71$	11.45 (4)	9.49	7.78
$\beta = 0.4$	$\beta = 0.53$			
$\alpha + \beta + \gamma = 1.0$	1.41	3.86 (1)	3.84	2.71
$\beta + \gamma = 1.0$	0.70	9.83 (1)	3.84	2.71

The restriction that the sum of the coefficients on h and k is unity cannot be rejected. However, the restriction that the estimated coefficients on h and k are equal to the sample average of their factor shares (0.6 and 0.4, respectively) is rejected. The restriction that the estimated coefficients on all three factors sum to unity is also rejected; the fact that the estimated coefficients sum to 1.4 suggests that there are increasing returns to scale with respect to labor, capital, and R&D capital. Finally, the restriction that the estimated coefficients on the two factors of production that can be accumulated—physical capital and R&D capital—sum to unity is rejected. In Sala-i-Martin's (1990) discussion of economic growth, this condition is necessary for endogenous growth. This is because a sum of the coefficients on physical and R&D capital of less than unity implies decreasing returns to capital, which in turn implies—in the absence of exogenous technological progress—zero steady-state growth of per capita output.

A number of alternative specifications of the production function were estimated. A demographic variable measuring the proportion of youth (15–24 years old) in total employment was added to capture the effect of possible changes in the quality of labor input. Inflation was included to test the hypothesis that high inflation diverts resources from productive activity. The total stock of R&D capital in 21 of France's trading partners was included to test if France benefited from R&D performed abroad.[14] None of these formulations generated meaningful cointegrating vectors—either there was no cointegrating vector or there were multiple cointegrating vectors, the estimated coefficients of which had incorrect signs, implausible magnitudes, or both.

Alternative measures of trade were also tried. To test whether the EC variable was capturing the effect of increased world—rather than

[14] Empirical evidence of the importance of international R&D spillovers is presented in Coe and Helpman (1993).

European—integration, world trade as a percentage of world GDP was included both with and without the EC trade integration variable, but we were unable to obtain a cointegrating vector. If France's EC trade either as a percent of total French trade or as a percent of French output is included instead of the EC variable, the two likelihood ratio tests for the existence and uniqueness of a cointegrating vector give inconsistent results. However, in both cases the estimated coefficients in the vector with the largest eigenvalue were correctly signed and of plausible magnitudes.[15]

IV. Potential Output

In the long run, actual output should equal potential output, and hence the estimated cointegrating vector in Table 2 provides a direct and simple means of calculating potential output (y^*):[16]

$$y^* = 0.71h + 0.53k + 0.17k^{r\&d} + 0.03EC - 0.39. \qquad (4)$$

Because potential output is commonly thought to be relatively stable compared with actual output, short-run fluctuations have been removed from hours worked and from the EC integration variable in order to calculate potential output—though not to estimate the production function—in the case of the EC variable by estimating a cubic trend (see Figure 1).

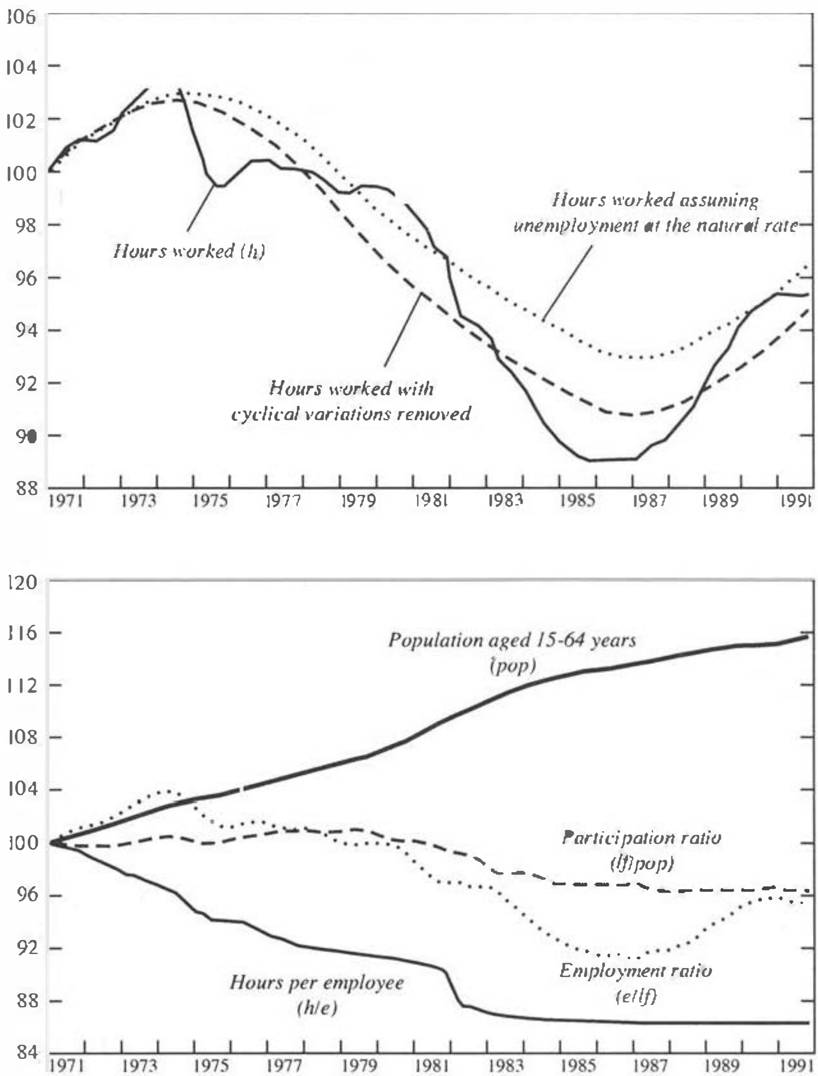
The sources of the cyclical movements in hours worked can be revealed by decomposing it into hours per employee (h/e), the employment ratio (e/lf), the participation ratio (lf/pop), and population (pop): in logarithms, $h = (h/e) + (e/lf) + (lf/pop) + (pop)$.[17] Cyclical variations in hours worked mainly reflect movements in the employment ratio and in the participation ratio (Figure 3). A polynomial trend has been used to remove cyclical variations in hours per employee and in the participation ratio. Cyclical movements in the employment ratio mainly reflect deviations of the actual rate of unemployment from the natural rate of unemployment. Since it lies beyond the scope of the present study to estimate the natural rate of unemployment for France as a function

[15] According to one of the tests, the null hypothesis that there are no cointegrating vectors cannot be rejected.

[16] See the references cited in the box on potential output in IMF (1991, p. 43); and Torres and Martin (1990). The constant in equation (4) has been calculated so that the average error over the sample period is zero.

[17] Although hours and employment refer to the nonfarm business sector, labor force and population refer to the full economy.

Figure 3. *Hours Worked*[a]
(In logarithms. 1971:I = 100)



[a]Nonfarm business sector. The decomposition of hours worked in the lower panel is calculated from $h=(h/e)+(e/lf)+(lf/pop)+pop$, where all variables are in logarithms.

of its structural determinants—two estimates of potential output are presented corresponding to two assumptions about the natural rate of unemployment.

One estimate of potential output uses the actual (cyclically adjusted) employment ratio, on the assumption that the actual unemployment rate is not too different from the equilibrium natural rate. This assumption is consistent with a hysteresis view of equilibrium unemployment and with the persistence of high unemployment and broadly stable wage inflation during the past three to four years in France. The second estimate of potential output incorporates an adjustment for hours worked based on a very simple and straightforward estimate of the natural rate of unemployment.[18] This estimate of the natural rate reflects two assumptions: that the actual unemployment rate was about the same as the natural rate in the early 1970s and that increases in the natural rate thereafter can be proxied by trend increases in the unemployment rate for prime-age males (Figure 4).[19]

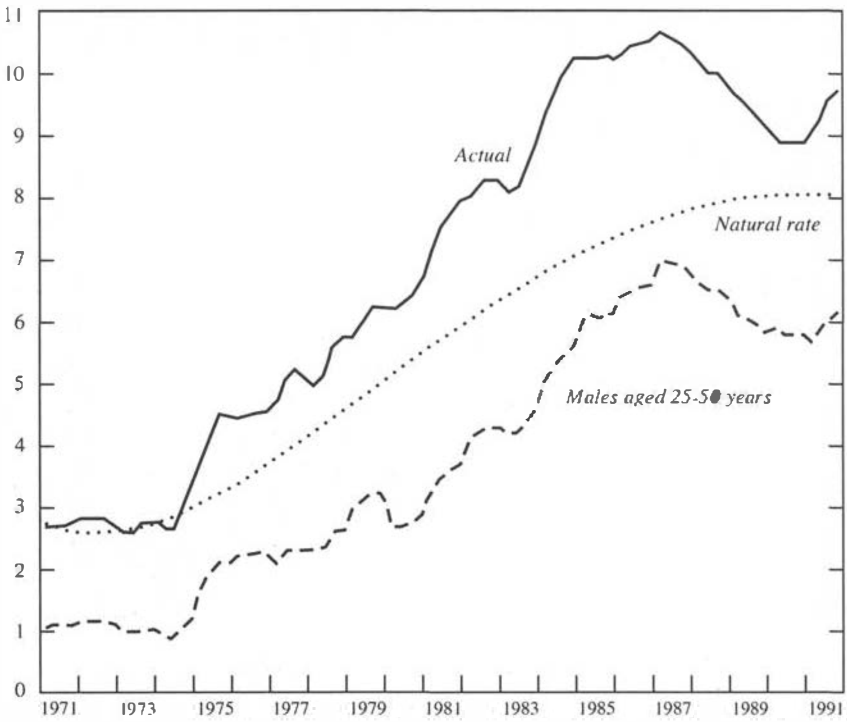
The two estimates of potential output are shown in Figure 5. After slowing from the mid-1970s to about 1986, the estimated growth of potential output increases to a little more than 3 percent in the early 1990s.[20] Since the mid-1970s, the estimated level of potential output incorporating hours worked at the natural rate of unemployment is higher than the estimate using actual hours worked, reflecting the assumption of greater labor input. By the mid-1980s, when the gap between the alternative estimates of the natural rate reached its maximum, the gap between the two estimates of potential output was about 2¼ percent. In terms of growth rates, however, the two estimates of potential output are broadly similar. From the early 1980s until about 1988, both measures of potential output exceeded actual output, and this contributed to the sustained declines in inflation from double-digit levels in 1980 to less than

[18] Using an asterisk to indicate that a variable has been cyclically adjusted or that the unemployment rate (U) is at its "natural" level, the adjustment for hours worked is $h - h^* \simeq (U^* - U)/100$, which is obtained by substituting $e/lf = \log(1 - U/100) \simeq -U/100$ into the equation used to decompose h and making a similar substitution for $(e/lf)^*$ into an equation for h^*.

[19] Although the prime-age male unemployment rate is often used in estimated wage equations instead of the aggregate unemployment rate (see Cotis and Loufir (1990)), we simply use this variable to capture the trend increase in the natural rate since the early 1970s. The natural rate of unemployment is estimated as a quadratic trend on the male unemployment rate for 24–50 year olds plus the differential between the aggregate and the prime-age male unemployment rates in the early 1970s. The estimate of the natural rate at the end of the sample is in line with estimates typically found in models of the French economy, which are on the order of 7–8 percent.

[20] This may be a slight overestimate as the GDP figures for 1991 have recently been revised downward.

Figure 4. *Unemployment Rates*
(In percent of labor force)



3 percent in 1988. Inflation rose to about 3½ percent in 1989–90 when actual output rose above both estimates of potential output. Since 1990:4, actual output has again fallen below both estimates of potential output, and inflation has fallen back to about 3 percent. This relationship between the level of the output gap and changes in inflation is statistically significant.[21]

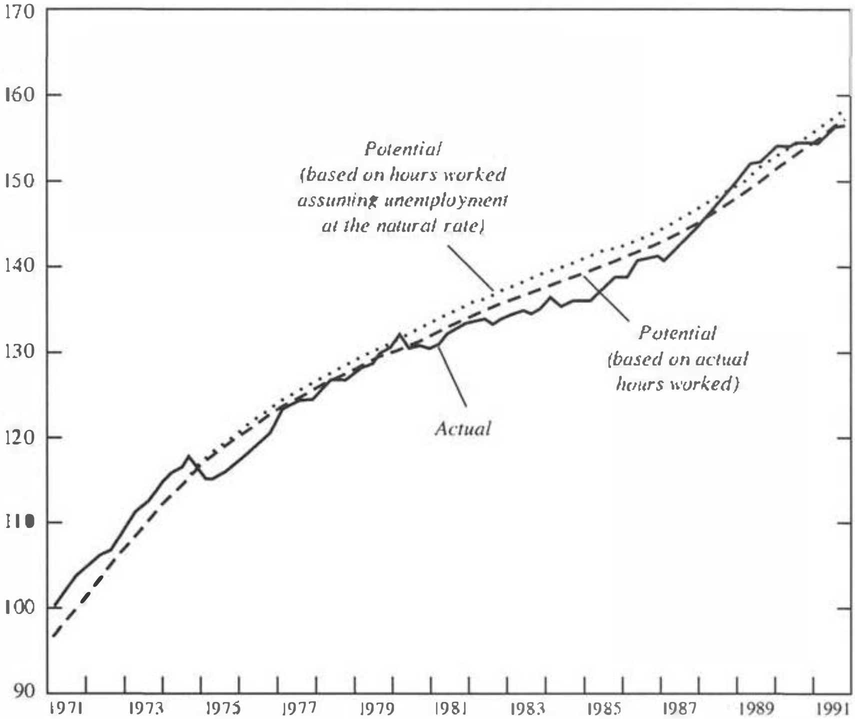
[21] Regressing the change in consumer price inflation ($\Delta^2 p$) against the output gap, assuming hours worked at the estimated natural rate ($y - y^*$), gives

$$\underset{}{\Delta^2 p} = 0.001 + \underset{(2.45)}{0.07(y - y^*)_{-1}} - \underset{(4.04)}{0.45\Delta^2 p_{-1}} - \underset{(2.49)}{0.29\Delta^2 p_{-2}} - \underset{(2.36)}{0.26\Delta^2 p_{-3}};$$

$$R^2 = 0.20,\ \text{s.e.e.} = 0.006,\ \text{DW} = 2.03,\ \text{LM}[\chi^2(1)] = 0.30,\ \text{LM}[\chi^2(4)] = 5.23.$$

The regression has been estimated using OLS, and t-statistics are in parentheses. Regressions with the output gap assuming actual hours worked gave similar results.

Figure 5. *Output*[a]
(In logarithms, actual output = 100 in 1971:1)



[a]Real value added in the nonfarm business sector.

Turning to the estimated sources of potential output growth summarized in the top section of Table 5 and Figures 1–3, it is clear that capital and trade have been the engines of growth in France during the past two decades. The slowdown in growth from the mid-1970s to the mid-1980s is accounted for by the sharp reduction in hours worked and by the slowdown in physical capital formation—real gross fixed capital formation actually declined in six of the ten years from 1975 to 1984. Increases in R&D capital account for more than 15 percent of the total increase in potential output over the 1971–91 period. The contribution of R&D capital to the growth of potential output increased slightly in the late 1980s.

The estimation results suggest that European trade integration has given a substantial boost to the growth of potential output in France. The

Table 5. *Potential Output Growth*[a]
(Annual percentage changes)

	1971–91	1971–75	1976–83	1984–91
Nonfarm business sector				
Potential output[b]	3.1	5.2	2.4	2.4
due to:				
Physical capital	2.0	2.9	2.0	1.4
R&D capital	0.5	0.4	0.4	0.5
European trade integration	0.7	1.3	0.7	0.3
Hours worked[b]	−0.1	0.5	−0.7	0.1
Actual output	2.8	3.7	2.3	2.6
Gross domestic product[c]				
Potential output	3.0	4.9	2.5	2.3
Actual output	2.7	3.4	2.5	2.5
Memoranda items				
Unemployment rate (end year)				
Actual	9.4	4.2	8.4	9.4
Natural	8.1	3.2	6.6	8.1
Nonfarm business output as a share of GDP	0.1	0.3	−0.1	0.1

[a] Calculations are based on annual data.
[b] Assuming unemployment is at the natural rate.
[c] The growth of GDP is equal to the growth of output in the nonfarm business sector minus the growth of nonfarm business output as a share of GDP.

beneficial effects of European integration were most pronounced in the early 1970s when intra-EC trade was increasing much more rapidly than it has in the more recent period. As noted, Coe and Krueger (1990) report a similar result for the Federal Republic of Germany.[22] It is interesting to note that Baldwin (1989) estimated that the 1992 single market program would increase the EC's long-term growth rate by 0.2 to 0.9 percentage points. This estimate, which is based on a completely different methodology from the one used here, is consistent with our estimate of the impact that European integration has had, and is likely to have in 1992–97, on growth in France.

Declines in hours worked contributed to a slight reduction in potential output growth over the 1971–91 period. The drop in hours worked reflected sharp declines in hours per worker up to the early 1980s and, to

[22] The share of potential output growth over the past two decades attributable to closer European integration is estimated to have been less in Germany than in France, reflecting the somewhat less open French economy at the start of the 1970s.

a lesser extent, declines in the employment rate from the mid-1970s to the mid-1980s and in the participation rate in the 1980s (see the lower panel of Figure 3). Population increased by an annual average of about ¾ percent during the full 1971–91 period. In 1984–91, hours per worker and the participation rate remained broadly stable and population growth more than offset the relatively small increase in the natural rate of unemployment, implying a small positive contribution of hours worked to the growth of potential output.

To calculate potential output for 1992–97, it has been assumed that weekly hours remain broadly stable. The contribution of capital reflects the medium-term projection for fixed investment and an assumption that the depreciation rate remains unchanged from the 1990–91 average. The contribution of R&D capital is based on a regression relating real R&D expenditures to real output.[23] Given the completion of the single market at the end of 1992, it is assumed that the contribution of intra-EC trade as a percent of EC output to potential output growth will remain the same as in the 1984–91 period but well below its contribution in 1971–83. These projections and assumptions imply an average annual growth of potential output of about 2.5 percent for 1992–97. The estimate of potential output growth is similar to Artus's (1992) estimate for 1992–93 and is almost the same as the 2.6 percent projected for 1989–95 in Adams, Fenton, and Larsen (1987).

The IMF staff's medium-term projections for 1992–97 are based, in part, on the projection for potential output presented here.[24] Below-potential growth in the 1991–93 period results in a substantial widening of the output gap. Growth is expected to recover during 1994 and to grow above potential in 1995–97, thereby reducing the gap.

V. Concluding Remarks

Recent cointegrating techniques that focus on the identification of long-run relationships are particularly appropriate to the study of long-run growth. The application of these techniques to French data has yielded a number of interesting empirical results, two of which relate to the role of capital. The first is the relatively large estimated elasticity of

[23]The estimated regression is log(R&D expenditures) = 1.1 log(output) + constant, $R^2 = 0.8$, for annual data 1970–89. The stock of R&D capital was then calculated for 1992–97 by cumulating R&D expenditures with an assumed obsolescence rate of 5 percent.

[24]The medium-term projections are summarized in Annex II of the IMF (1993).

output with respect to R&D capital. The second is that a broad concept of physical capital—one that includes public infrastructure, residential and nonresidential structures, and plant and equipment capital—performs better than the more common, narrower concept of business sector capital. A third important—and new—result is the empirical estimate of the beneficial effects of European trade integration on French growth.

The estimated production function is not, strictly speaking, characterized by endogenous growth. The factors of production that can be accumulated—physical capital (broadly defined) and R&D capital—exhibit decreasing returns to scale. As Sala-i-Martin (1990) emphasizes, this implies, in the absence of exogenous technological progress, a steady-state growth of per capita output of zero. More generally, the underlying relationships are between the level of output and the levels of the factor inputs and the degree of trade integration. Although capital accumulation and increased trade have boosted growth, a higher *level* of capital or trade integration will not, in the long run, have an impact on the *growth* of output.

These results have a number of policy implications. European integration has boosted French growth in the past, and steps to accelerate the process of integration can be expected to enhance potential growth in the future. The large increases expected in the services trade with the completion of the single market, additional steps toward closer economic and monetary union, and closer integration with central and eastern European countries may result in a substantially larger contribution to future potential output growth in France than assumed above. Similarly, government infrastructure investment and policies that encourage—or create an environment conducive to—productive investment and research and development will also increase potential output. Finally, labor market policies that reduce the natural rate of unemployment over the medium term, thereby increasing labor input, will boost potential output growth.

The empirical results suggest a number of areas for further study. In order to fully appreciate the implications for inflation, it is necessary to combine the estimates of potential output with a more satisfactory estimate of the natural rate of unemployment in the context of a fully specified wage-price system. A second area for further study is the determinants of R&D expenditures and the extent to which R&D contributes to endogenous growth. Finally, there is a need for further study of the impact on growth of other structural features of the French economy, such as the Common Agricultural Policy, and how structural reform would affect medium-term growth prospects in France.

APPENDIX

Data Sources and Definitions

Real value added, hours worked, and employment in the nonfarm business sector are from the INSEE data tape, in each case subtracting the farm sector (secteur agriculture, sylviculture, pêche) from the total for the business sector (secteurs marchands). The relevant INSEE codes for real value added are PN1_V008 and PN1_U018; for hours worked, ACM_V001 and ACM_U011; and for employment, EFM_V001 and EFM_U011.

The stock of business sector capital, the stock of residential capital, labor force, and population are from the OECD Analytical Data Bank. The stock of infrastructure capital is taken from the annual estimates of Ford and Poret (1991), reported by them as INF.N (p. 80), interpolated to a quarterly frequency. The share of the labor force aged 15–24 is calculated from the OECD's *Labour Force Statistics*.

The stock of R&D capital is calculated analogously to the stock of physical capital with an assumed obsolescence rate of 5 percent: $k^{r\&d} = k^{r\&d}_{-1}(1 - 0.05) +$ (real R&D expenditures). A benchmark for $k^{r\&d}$ was calculated using the procedure suggested by Griliches (1980). Real R&D expenditures are gross domestic expenditures on R&D deflated by an average of the GDP deflator and an index of business sector wages. R&D expenditures are from the OECD's *Main Science and Technology Indicators* (1991:1, p. 16). R&D expenditures for 1991 were estimated using the same procedure reported in the text to project R&D expenditures for 1992–97. Annual data for the stock of R&D capital were interpolated to a quarterly frequency.

Data to construct the EC variable are from the IMF's *Direction of Trade Statistics*. The EC variable is constructed with data for all 12 current members of the EC, even though not all 12 countries were members during the full 1971–91 period. World trade as a percent of world output was constructed from the IMF World Economic Outlook data base. Annual data were interpolated to a quarterly frequency.

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