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LEVELS OF FARM SECTOR PRODUCTIVITY: AN INTERNATIONAL COMPARISON

Invited paper submitted by the United States of America*

Abstract. This article focuses on the relative levels of farm sector productivity for the United States and nine European Union countries for the period 1973 to 1993. At the beginning of the study period, Belgium had the highest level of productivity relative to the United States at 1.689. Ireland had the lowest relative productivity at 0.759. By 1993, the range of levels had narrowed significantly, from 0.709 for Ireland to 1.392 for the Netherlands. Further evidence of convergence can be seen

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in the coefficient of variation, which fell steadily form 0.261 in 1973 to 0.227 in 1993. Results based on regression analysis show a highly significant inverse relation between the rate of productivity convergence and the initial level of productivity, consistent with the "catch-up" hypothesis. The results generally support the existence of a positive interaction between capital accumulation and productivity growth, suggesting embodiment.

I. Introduction

1. The purpose of this paper is to provide a farm sector comparison of levels of output, input, and productivity for the United States and nine European countries--Germany, France, Italy, the Netherlands, Belgium, the United Kingdom, Ireland, Denmark, and Greece. Our first objective is to compare levels of farm output in 1990 and to allocate differences in these levels among differences in levels of capital, land, labor, and intermediate inputs and differences in total factor productivity.

2. In order to compare levels of output, input, and productivity in different countries, we require data on relative output and input prices. A price index which converts the nominal output value ratio between two countries into an index of relative real output is referred to as a purchasing power parity in the international comparisons literature (*e.g.*, see Voeller [1981] and Eichhorn and Voeller [1983]). In section 2, we define a bilateral output price index or purchasing power parity, which is the international counterpart to the Fisher and Shell (1972) national output price deflator. This output price index requires the assumption of revenue maximizing behavior on the part of producers in both countries; that is, the price index is based on the economic theory of production.[1]

3. The use of the bilateral indexes to compare each pair of the possible pairs of countries gives results that may not satisfy Fisher's (1922) circularity test. Direct comparisons between countries may give different results when compared with indirect bilateral comparisons through other countries. Eltetö and Köves (1964) and Szulc (1964) proposed a method, which achieves transitivity while minimizing the deviations from the bilateral comparisons, and we adopt their procedure for our international comparisons.

4. The results of this comparison are presented in section 4. We find that output relative to the United States in 1990 varied from 0.021 for Ireland to 0.243 for France. Differences in levels of total factor productivity were much smaller than differences in relative output. The level of productivity for Ireland relative to the United States in 1990 was 0.679. Relative productivity for France was 0.995. We conclude that differences in output levels were more closely associated with differences in levels of capital, land, labor, and intermediate inputs than with differences in levels of total factor productivity.

5. Our second objective is to compare relative levels of output, inputs, and productivity among all ten countries for the period 1973 to 1993. Our time series estimates are obtained by combining the rates of growth of output, inputs, and productivity for the individual countries

with relative levels for 1990. We present the results of our time series comparison among countries in section 5.

6. Our time series results show that among the nine European countries only the Netherlands and Ireland increased output levels relative to the United States. Relative levels of capital and land inputs increased for most countries. The patterns of change for relative labor input bear little resemblance to those for relative levels of capital and land inputs. For Germany, France, Italy, and Denmark, relative labor input fell dramatically. Belgium's relative labor input did not change much over this period. Although labor input fell in absolute terms, the Netherlands, the United Kingdom, Ireland, and Greece had dramatic increases in relative labor input. Levels of intermediate input relative to the United States increased for all countries except Germany and the United Kingdom.

7. Finally, relative productivity levels among the United States and the nine European countries have narrowed substantially over the study period. In section 6, we use regression analysis to test two hypotheses (which are not mutually exclusive) concerning technology convergence. The first is the "catch-up" hypothesis, which states simply that those countries that lagged furthest behind the leading countries in terms of productivity levels should exhibit the most rapid rates of productivity growth. The second hypothesis is that technological innovation is embodied in capital and intermediate inputs. If input measures do not reflect changes in input quality, then a positive relationship should be observed between the rate of productivity growth and the rates of growth of capital and intermediate inputs.

8. Support is found for the two hypotheses. First, we find a strong inverse relationship between the rates of growth of relative productivity and the initial levels of productivity. Second, our results generally support the existence of a positive relationship between capital accumulation and productivity growth, although the effect was strongest during the period 1973 to 1981. Indeed, net investment in fixed capital was negative in most countries during the period 1982 to 1993. The regression results yield a positive but statistically insignificant interaction between productivity growth and the rate of growth of intermediate input.

II. Methodology

9. An index of relative real output between two countries is obtained by dividing the nominal value of output ratio for the two countries by the corresponding output price index. In this section, we define a bilateral output price index or purchasing power parity assuming revenue-maximizing behavior on the part of producers in both countries. We then consider how best to use the bilateral indexes in order to make multilateral comparisons that treat all countries symmetrically.

10. Assume that there are I countries to be compared. The production sector of each country uses M inputs. There are N outputs that can be produced.

11. The input vector in country i is $v^i \equiv (v_1^i , \ldots , v_M^i) \geq 0_M$ where v_m^i is the amount of input m used in country $i , i = 1 , \ldots , I$, and $m = 1 , \ldots , M$.

12. The positive price vector for the outputs produced by country i is denoted by $p^i \equiv (p_1^i, \ldots, p_N^i) \gg 0_N$ for $i = 1, \ldots, I$. The corresponding output vector for country i is $y^i = (y_1^i, \ldots, y_N^i) \geq 0_N$ with $p^i \cdot y^i \equiv \sum_{n=1}^{N} p_n^i y_n^i > 0$.

13. The technology set for the private production sector in country *i* is the set $S^i \equiv \{(y^i, v^i)\}$, a set of feasible output and input vectors. We assume that each technology set S^i is a closed and convex subset of $\Re^{N+M}$. The private national product function for country *i* is defined as:

$$(1) \qquad g^i(p, v) \equiv \max_y \{ p \cdot y : (y, v) \in S^i \}, i = 1, \ldots, I,$$

where $p \equiv (p_1, \ldots, p_N) \gg 0_N$ is a positive vector of output prices and $v \equiv (v_1, \ldots, v_M) \geq 0_M$ is a nonnegative input vector. The number $g^i(p, v)$ is the maximum value of output that country *i* can produce given that it faces prices *p* and employs inputs *v*.

14. In analogy to the Fisher and Shell (1972) output price deflator, $g^i(p^{t+1}, v) / g^i(p^t, v)$, which is a measure of the price level in country *i* in period $t + 1$ relative to the price in period *t*, we define the output price index for country *i* relative to country *j* using the country *i* technology and input vector as:

$$(2) \qquad P^i(p^i, p^j) \equiv g^i(p^i, v^i) / g^i(p^j, v^i),$$

where the functions g^i are defined by (1), $p^i \gg 0_N$ is the output price vector for country *i*, and $v^i \geq 0_M$ is the corresponding input vector utilized by country *i* during the period under consideration. The output price index defined by (2) is the value of output produced by country *i* during the reference period divided by the value of output that country *i* could produce if it faced prices p^j. Thus $P^i(p^j, p^i)$ is a measure of the level of output prices in country *i* relative to the level in country *j*.

15. In definition (2), we used the technology set S^i and the input vector v^i as reference quantities. An analogous output price index for country *i* relative to country *j*, $P^j(p^j, p^i)$, may be defined using the country *j* technology set (or its dual national product function) and input vector:

$$(3) \qquad P^j(p^i, p^j) \equiv g^j(p^i, v^j) / g^j(p^j, v^j).$$

$P^j(p^j, p^i)$ defined by (3) is also a measure of the level of output prices in country *i* relative to that in country *j*.

16. The theoretical indexes defined by (2) and (3) cannot be calculated unless we know the functions g^i or the dual technology sets S^i. However, Samuelson (1950), Fisher and Shell (1972, pp. 57-58), and Diewert (1983, pp. 1056-1058) have established that the theoretical indexes satisfy the following observable bounds:

(4) $$P^j(p^i, p^j) \geq p^i \cdot y^j / p^j \cdot y^j \equiv P_L,$$

and

(5) $$P^i(p^i, p^j) \leq p^i \cdot y^i / p^j \cdot y^i \equiv P_P,$$

where P_L and P_P are the widely used Laspeyres and Paasche price indexes, respectively. These bounds cannot be improved upon unless we make additional assumptions about the technology.

17. Suppose that the private national product functions g^i have the following separable form:

(6) $$g^i(p, v) = (p \cdot B p)^{1/2} h^i(v), i = 1, \ldots, I,$$

where $p \cdot B p = \sum_{n=1}^{N} \sum_{k=1}^{N} b_{nk} \; p_n \; p_k, b_{nk} = b_{kn}$, and the function $h^i(v)$ is a nondecreasing function of v for $v \geq 0_M$. Recall the definitions of the output price indexes given in (2) and (3). Under the separability assumption (6), it can be seen that:

(7) $$P^i(p^j, p^i) \equiv g^i(p^i, v^i) / g^i(p^j, v^i) = (p^i \cdot B p^i / p^j \cdot B p^j)^{1/2} = P^j(p^j, p^i).$$

The output price indexes $P^i(p^j, p^i)$ and $P^j(p^j, p^i)$ coincide, and this common index equals $g^i(p^i, v) / g^i(p^j, v)$ for any reference input vector v.

18. Let us assume optimizing behavior on the part of producers in both countries (so that y^i is the solution to (1) given prices $p^i \gg 0_N$) and that the national output functions g^i have the separable form defined by (6). Then Diewert (1986) shows that the price indexes defined by (2) and (3) above are exactly equal to the Fisher price index defined as:

(8) $$P_F(p^j, p^i, y^j, y^i) = [P_L \cdot P_P]^{1/2}.$$

The special functional form defined by (6) can approximate any separable function of the form $f(p)h(v)$, where $f(p)$ is linearly homogenous, to the second order.[2] Thus, we have a strong justification for use of the Fisher price index in bilateral comparisons.

19. The direct application of (8) to the $I(I-1)/2$ possible pairs of countries yields a matrix of bilateral price indexes that may not satisfy the transitivity condition. To eliminate this problem,

we apply the multilateral Eltetö and Köves (1964) and Szulc (1964) method which defines the price index for country *i* relative to country *j* as the geometric mean of I ratios of bilateral Fisher price indexes:

$$(9) \qquad P_{EKS} = \left(\prod_{k=1}^{I} P_F(p^j, p^k, y^j, y^k) / P_F(p^i, p^k, y^i, y^k) \right)^{1/I}, i, j = 1, \ldots, I.$$

The multilateral Eltetö-Köves-Szulc price index defined by (9) satisfies transitivity while minimizing the deviations from the bilateral Fisher indexes.

20. The bilateral Fisher indexes, which are the building blocks of the multilateral Eltetö-Köves-Szulc indexes, are based on prices and quantities of commodities common to both countries. Even so, these bilateral indexes sometimes rely on a very small number of commodities. In this study, we construct direct bilateral Fisher indexes if the commodities common to both countries represent a minimum percentage of the value of production in both countries. Below this percentage, the Eltetö-Köves-Szulc indexes are constructed using indirect bilateral comparisons through other countries.[3]

21. The indirect bilateral indexes are calculated using a chain-link method. Adjacent countries are selected on the basis of the shortest possible path (*i.e.*, fewest number of countries) without falling below this predefined threshold. This method is similar to the chain-linked method used in intertemporal comparisons. The only difference is that there is no natural ordering of the data points (such as chronological ordering).

III. Production Accounts

22. The starting point for our comparison of levels of output, inputs, and productivity is the production account for each country in the comparison. We define output as gross production leaving the farm, as opposed to real value added. Inputs are not limited to capital and labor but include intermediate inputs as well. The text in this section provides an overview of the sources and methods used to construct the annual production accounts for the period 1973 to 1993.

Output and Intermediate Input

23. The development of a measure of output begins with disaggregated data for physical quantities and market prices of agricultural goods. Our principal data sources for the United States are the farm sector accounts originated by Ball (1985) and updated by Ball *et al.* (1997). For the European countries, these data are from the *Economic Accounts for Agriculture and Forestry* (Eurostat) and from *SPEL/EU* (Eurostat).[4]

24. For purposes of productivity measurement, output includes the quantities of goods sold off the farm plus additions to inventory and quantities consumed as part of final demand in farm households during the calendar year. The prices corresponding to each disaggregated output

reflects the value of that output to the producer; that is, subsidies are added and indirect taxes are subtracted from market values.

25. Intermediate input consists of goods used in production during the calendar year, whether purchased from outside the farm sector or withdrawn from beginning inventories. The inclusion and treatment of open market purchases requires little discussion. However, the treatment of withdrawals from producers' inventory requires elaboration.

26. Inventories enter the measurement of output, intermediate input, and capital input. Beginning inventories of agricultural goods represent capital input. Additions to these inventories represent deliveries to final demand and, therefore, are treated as part of output. Consumption of goods withdrawn from inventory symmetrically is defined as an intermediate input and, therefore, enters the farm input accounts.

Capital Input

Capital Stock. The measure of capital input begins with data on capital stock of each asset type in each country. We employ the perpetual inventory method to estimate capital stocks from data on investment in constant prices. In this method, we represent capital stock at the end of each period, say K_t, as the sum of past investments, each weighted by its relative efficiency d_t :

(10) $$K_t = \sum_{t=0}^{\infty} d_t \, I_{t-t} \, .$$

27. We assume that the relative efficiency of capital goods declines with age, giving rise to needs for replacement of productive capacity. The proportion of investment to be replaced at age t, say m_t, is equal to the decline in efficiency from age $t-1$ to age t :

(11) $$m_t = -(d_t - d_{t-1}), t = 1,\ldots,t.$$

These proportions represent mortality rates for capital goods of different ages. Replacement requirements at each point of time, say R_t, can be expressed as a weighted sum of past investments:

(12) $$R_t = \sum_{t=1}^{\infty} m_t \, I_{t-t} \, ,$$

where the weights are the mortality rates.

28. Taking the first difference of expression (10) and substituting from equations (11) and (12), we can write:

(13) $$K_t - K_{t-1} = I_t - R_t \, .$$

The change in capital stock in any period is equal to the acquisition of investment goods less replacement requirements.

29. To estimate replacement requirements, we must introduce an explicit description of the decline in efficiency. The relative efficiency of an asset t years of age is given by:

$$
(14) \qquad \begin{aligned} d_t &= (L - t)/(L - b t), 0 \leq t \leq L \\ d_t &= 0, t > L, \end{aligned}
$$

where L is the service life of the asset and b is a curvature or decay parameter.[5]

30. Little empirical evidence is available to suggest a precise value of b. However, two studies provide evidence that efficiency decay occurs more rapidly in the later years of service. Utilizing data on expenditures for repairs and maintenance of 745 farm tractors covering the period 1958-74, Penson, Hughes and Nelson (1977) found that the loss of efficiency was very small in the early years and increased rapidly as the end of the asset's service life approached. More recently, Romain, Penson and Lambert (1987) compared the explanatory power of alternative capacity depreciation patterns for farm tractors in a model of investment behavior. They found that the concave depreciation pattern better reflects actual investment decisions.

31. Taken together, these studies suggest that estimates of b should be restricted to the zero-one interval. Ultimately, the b values selected for this study are 0.75 for structures and 0.5 for equipment. It is assumed that the efficiency of a structure declines slowly over most of its service life until a point is reached where the cost of repairs exceeds the increased service flows derived from the repairs, at which point the structure is allowed to depreciate rapidly. The decay parameter for equipment assumes that the decline in efficiency is more uniformly distributed over the asset's service life.

32. Investment as used in this study is composed of different types of capital goods. Each type of capital good is a homogeneous group of assets for which the actual service life L is a random variable reflecting quality differences, maintenance schedules, *etc*. For each asset type, there exists some mean service life $\bar{L}$ around which there exists some distribution of actual service lives. In order to determine the amount of capital available for production the actual service lives and their frequency of occurrence must be determined. It is assumed that this distribution can accurately be depicted by the normal distribution truncated at points two standard deviations before and after the mean.

33. Once the frequency of occurrence of a particular service life is determined, the efficiency function for that service life is calculated using the assumed value of b. This process is repeated for all possible service lives. An aggregate efficiency function is then constructed as a weighted sum of the individual efficiency functions using as weights the frequency of occurrence. This function not only reflects changes in efficiency, but also the discard distribution around the mean service life of the asset.

Rental Prices. Firms add to capital stock so long as the present value of the net revenue generated by an additional unit of capital exceeds the purchase price of the asset. Following Coen (1975), this can be stated algebraically as:

$$(15) \qquad \sum_{t=1}^{\infty} \left(p \frac{\partial y}{\partial K} - w \frac{\partial R_t}{\partial K} \right) (1+r)^{-t} > w,$$

where p is the price of output, w is the price of investment goods, and r is the real discount rate.

34. To maximize net present value, firms add to capital stock until this equation holds as an equality. This requires that:

$$(16) \qquad p \frac{\partial y}{\partial K} = r\,w + r \sum_{t=1}^{\infty} w \frac{\partial R_t}{\partial K} (1+r)^{-t} = c.$$

The expression for c is the implicit rental price of capital corresponding to the mortality distribution m. The rental price consists of two components. The first term, $r\,w$, represents the opportunity cost of invested funds. The second term, $r \sum_{t=1}^{\infty} w \frac{\partial R_t}{\partial K} (1+r)^{-t}$, is the present value of all future replacements required to maintain the productive capacity of the capital stock.

35. Let F denote the present value of the stream of capacity depreciation on one unit of capital according to the mortality distribution m; that is:

$$(17) \qquad F = \sum_{t=1}^{\infty} m_t (1+r)^{-t}.$$

36. Since replacement at time t is equal to capacity depreciation at time t:

$$(18) \qquad \sum_{t=1}^{\infty} \frac{\partial R_t}{\partial K} (1+r)^{-t} = \sum_{t=1}^{\infty} F^t = \frac{F}{(1-F)}$$

and

$$(19) \qquad c = \frac{r\,w}{(1-F)}.$$

37. The real rate of return r in the above expression is calculated as the nominal yield on government bonds of all maturities less the rate of inflation as measured by the implicit deflator

for gross domestic product. An *ex ante* rate is obtained by expressing observed real rates as an ARIMA process.[6] We then calculate F holding the required real rate of return constant for that vintage of capital goods.

38. Although we estimate the decline in efficiency of capital goods for each component of capital input separately for all ten countries, we assume that the relative efficiency of new capital goods is the same in each country. Accordingly, the appropriate purchasing power parity for new capital goods is the purchasing power parity for the corresponding component of investment goods output. To obtain the purchasing power parity for capital input, we multiply the purchasing power parity for investment goods for any two countries by the ratio of the price of capital input for the two countries.

Land Input

39. To estimate the stock of land in each country, we construct intertemporal Fisher price indexes and implicit quantities of land in farms. Observations on land input in each country are differentiated by state and by land type (*i.e.*, arable and meadow). Land area idled from production by government programs is excluded from the stock of land.

40. Differences in the relative efficiencies of land across countries prevent the direct comparison of observed prices. Our estimates of the relative price of land in each country are based on hedonic regressions. For our cross section of countries, we estimate the following equation by least squares:

$$(20) \qquad \ln(w^i_j) = \sum_{i=1}^{I} \boldsymbol{d}_i D_i + \sum_{c=1}^{C} \boldsymbol{b}_c x^i_{jc} + \boldsymbol{e}_{ij},$$

where w^i_j is the price of land in region j of country i, x^i_j is a vector of land characteristics, and D_i is a dummy variable equal to unity for the corresponding country and zero otherwise, and $\boldsymbol{e}_{ij}$ is a stochastic error term.[7] When the log of price is related to linear country dummy variables as in (20), a hedonic price index can be calculated from the antilogs of the $\boldsymbol{d}_i$ coefficients.[8]

Labor Input

41. Data on labor input consist of hours worked disaggregated by hired and self-employed and unpaid family workers. Compensation of hired farm workers is defined as the average hourly wage plus social security taxes paid by employers.

42. Labor compensation data are not available for self-employed and unpaid family workers. As a result, for each country and year, self-employed and unpaid family workers are imputed the mean wage earned by hired farm workers. The appropriate purchasing power parity for labor is the relative wage rate.

43. Finally, all of the comparisons reported in this paper are base-country invariant, but they are not base-year invariant. We use 1990 as the base year for all of our time series comparisons.

The reason for this is that the detailed international price comparisons for the non-farm sector are available only for 1990 (OECD [1992]). This being the case, it is necessary to construct indexes for the other years by chain linking them to 1990. Thus, we did not have the option, recommended by Caves, Christensen, and Diewert (1982) of constructing comparisons that are both base-country and base-year invariant.

IV. Multilateral Comparisons for 1990

44. We proceed to compute relative levels of output and to allocate the differences in these levels among differences in levels of capital, land, labor, and intermediate inputs and differences in levels of total factor productivity. Table 1 presents multilateral Eltetö-Köves-Szulc indexes of output, and capital, land, labor, and intermediate inputs for the nine European countries relative to the United States for the year 1990.[9] We also present multilateral indexes of differences in total factor productivity between each country and the United States.

45. In 1990, the level of output for France relative to the United States was higher than for any other country at 0.243. Relative output for Italy was next highest at 0.177, with relative output for Germany, at 0.134. Ireland was found to have the lowest level of output relative to the United States 0.021.

46. Relative levels of output between any two countries can be expressed in terms of relative levels of capital, land, labor, and intermediate inputs and differences in levels of total factor productivity. Focusing attention on capital input, we find Italy had the highest level of capital input relative to the United States at 0.356, followed by Germany at 0.249, and France at 0.208. Belgium had the lowest level of capital input at 0.023. The relative level of capital input for Ireland was comparable to that for Belgium at 0.026.

47. No country approached the United States' level of land input. France had the highest input level among the nine European countries at 0.105. Italy was found to have the second highest input level at 0.086, followed by the United Kingdom at 0.063. The relative level of land input for Germany was 0.047. Belgium again had the lowest input level relative to the United States at 0.007.

48. The range of levels of relative labor input was much wider. Italy had the highest level of labor input relative to the United States at 0.845. Moreover, Italy had substantially higher labor intensity (relative to output) than the United States. Labor input for France relative to the United States was 0.506, followed by Germany at 0.299. Belgium had the lowest level of labor input among the nine European countries 0.037.

49. The relative levels of intermediate input were similar to those for output. France had the highest level of intermediate input relative to the United States at 0.269, followed by Germany at 0.181 and the United Kingdom at 0.116. The relative input level for Italy was 0.114. Ireland had the lowest level of intermediate input relative to the United States 0.021.

50. Our final comparison among the United States and nine European countries for 1990 is for relative levels of productivity. The level of productivity relative to the United States was

highest for the Netherlands at 1.36, followed by Belgium at 1.236 and Denmark at 1.148. In contrast, Ireland had the lowest relative productivity level among the nine countries at 0.679. Italy and Greece were closest to Ireland with relative productivity levels of 0.712 and 0.791, respectively. Germany at 0.838, the United Kingdom at 0.895, and France at 0.995 fell in the midrange of the countries in the comparison.

51. Our next objective is to examine the differences in factor intensities (relative to labor) among the ten countries. These are presented in table 2. Comparing capital input with labor input from table 1, we find that Denmark had a higher capital-labor ratio than the United States. The Netherlands, Germany, Belgium, and the United Kingdom had capital-labor ratios below Denmark and the United States, but substantially above the remaining four countries. The United States had the highest level of land input relative to labor. Belgium, the Netherlands, and Denmark had higher levels of intermediate input relative to labor input than the United States.

52. One promising line of inquiry in explaining relative productivity performance is the relationship between levels of capital and intermediate inputs and levels of total factor productivity. Tables 1 and 2 show high levels of capital and materials intensities associated with high levels of productivity, suggesting embodiment. The embodiment hypothesis will be taken up below.

V. Relative Levels of Output, Input, and Productivity, 1973-1993

53. In this section, our objective is to compare relative levels of output and capital, land, labor, and intermediate inputs and relative levels of productivity among the ten countries for the period 1973 to 1993. These comparisons are based on multilateral Eltetö-Köves-Szulc indexes of output, inputs, and productivity for 1990, which are extended forward and backward in time using intertemporal Fisher index numbers of output, inputs, and productivity for the individual countries.

54. We present levels of output relative to the United States for the 1973-93 period in table 3. Among the nine European countries, only the Netherlands and Ireland increased relative output levels over the full 1973-93 period. The most dramatic gain in output was for the Netherlands, with output relative to the United States increasing more than twenty percent between 1973 and 1993. By the end of the period in 1993, the Netherlands' level of output relative to the United States stood at 0.084 (obtained by dividing 0.085 by 1.016).

55. The Netherlands and Ireland were the only countries to have higher levels of real output relative to the United States in 1993 than they had in 1973. But for most countries, the differences in relative levels of output narrowed substantially in recent years. France, the Netherlands, Belgium, Ireland, and Denmark increased output levels relative to the United States between 1981 and 1993. Still, projection of this short-term trend in relative output levels beyond 1993 is probably not warranted, since the reforms of the Common Agricultural Policy (CAP) of the European Union adopted in 1993 put in place mechanisms designed to curb output growth.[10] The package of reforms lower support prices for agricultural goods. Producers are compensated for price reductions through direct payments based on historical yields and planted area. A land set-aside requirement applies to producers receiving compensatory payments. In contrast, the

United States, in 1996, dismantled acreage reduction programs that had been in effect for much of the postwar period.

56. Turning to capital input, we present levels of capital input relative to the United States in table 4. All nine European countries had substantially higher levels of capital input relative to the United States in 1993 than they had at the beginning of the period. The largest increase in capital input, as for output, was for the Netherlands with a doubling of capital input relative to the United States between 1973 to 1993.

57. Belgium began the period in 1973 with the lowest level of capital input relative to the United States at 0.017. Italy was closest to the United States in capital input at the beginning of the period at 0.281 in 1973 and has gained steadily since then, ending with a relative level of capital input in 1993 of 0.374.

58. Table 5 presents relative levels of land input. The patterns of change for relative land input were similar to those for relative capital input. Eight of the nine European countries increased relative levels of land input over the study period. Only Belgium had a lower level of land input relative to the United States in 1993 than she had in 1973. Relative levels of land input in 1993 ranged from 0.006 for Belgium to 0.108 for France.

59. Focusing on labor input relative to the United States, we present relative levels of labor input for all countries in table 6. The patterns bear little resemblance to those for relative levels of capital and land inputs. For Germany, France, Italy, and Denmark, labor input fell substantially relative to the United States. The largest decline was for Germany from 0.339 in 1973 to 0.278 in 1993. Belgium's relative labor input did not change much over this period. Although labor input declined in absolute terms, the Netherlands, the United Kingdom, Ireland, and Greece had dramatic increases in relative labor input.

60. In table 7, we present levels of intermediate input relative to the United States. The changes in relative levels of intermediate input were similar to those for relative levels of capital and land inputs. The range of levels of intermediate input narrowed substantially between 1973 and 1993. Ireland had the lowest input level relative to the United States in 1973 at 0.016. The relative input level increased to 0.021 in 1993. France had the highest input level among the nine European countries in 1993 at 0.233.

61. Finally, in table 8, we present relative levels of total factor productivity. Of the nine European countries, only Denmark and France increased productivity levels relative to the United States between 1973 and 1993. The largest gain in relative productivity was for France. France began the period in 1973 with a higher level of productivity than Germany, Italy, and Ireland. By the end of the period in 1993, she had surpassed the United Kingdom and Greece, but continued to trail the Netherlands, Belgium, and Denmark in relative productivity.

62. Belgium began the study period with the highest level of total factor productivity relative to the United States at 1.698. Ireland had the lowest relative level of productivity of any European country at 0.759. By 1993, the range of levels of total factor productivity relative to the United States had narrowed significantly--from 0.709 for Ireland to 1.392 for the Netherlands. Further evidence of convergence of productivity levels can be seen in figure 1, which plots for

each year the coefficient of variation (the ratio of the standard deviation to the mean) of relative productivity levels for all nine countries. Cross section dispersion declins steadily from 0.261 in 1973 to 0.227 in 1993.

VI. Analysis of Differences in Productivity

63. In the previous section, we saw that there has been a narrowing of the range of levels of productivity relative to the United States. We now turn to a regression framework to test two hypotheses concerning technology convergence. The first is the catch-up hypothesis, which states simply that those countries that lagged furthest behind the technology leaders benefit the most from the diffusion of technical knowledge and, hence, should exhibit the most rapid rates of productivity growth. Taking each country as an observation, this hypothesis implies that the rate of growth of productivity is inversely correlated with the level of productivity at the beginning of the period.

64. The second hypothesis is that technological innovation is embodied in capital and intermediate inputs. If the input measures do not correct for changes in input quality, then this hypothesis suggests that the rate of growth of productivity will be positively correlated with growth of capital and intermediate inputs. Again, we can treat each country as an observation to test this hypothesis.

65. To investigate both hypotheses, we employ the basic specification:

$$T\hat{F}P_t^i = \boldsymbol{b}_0 + \boldsymbol{b}_1 \ln TFP_t^i + \boldsymbol{b}_2 \left(\frac{\hat{K}}{L}\right)_t^i + \boldsymbol{b}_3 \left(\frac{\hat{M}}{L}\right)_t^i + \boldsymbol{e}_{it}, \qquad (21)$$

where TFP is the productivity level relative to the United States at the beginning of each period and $\left(\frac{K}{L}\right)$ and $\left(\frac{M}{L}\right)$ are relative factor intensities. The circumflexes (^) denote time derivatives or relative rates of change. Three-year and 5-year averages are used for the rates of change to reduce random noise. The United States is excluded from the regression equation, since the value of the dependent variable is always unity.

66. In a second regression, we include dummy variables, D_i, for each country (except Germany) to control for country-specific effects such as commitment to freedom of trade and government policy. In a third, we include a dummy variable, D_{7381}, defined as unity on or before 1981 and zero thereafter, which interacts with $\left(\frac{\hat{K}}{L}\right)$ to control for period effects.

67. The results, shown in table 9, confirm the catch-up hypothesis, showing a highly significant inverse relation between the rate of productivity convergence by country and its initial level relative to the United States (columns 1 and 4). The results for the embodiment hypothesis

are mixed. The variable $\left(\frac{\hat{K}}{L}\right)$ has a negative and significant coefficient (columns 2 and 5). This variable also has a negative coefficient when we include the period dummy, D_{7381}, but the coefficient for the interaction term, $\left(\frac{\hat{K}}{L}\right)\bullet D_{7381}$, is positive and significant (columns 3 and 6). These results suggest that embodiment of technology in capital was important during the period 1973 to 1981, but not important during the period 1982 to 1993. Indeed, net investment in fixed capital was negative for most countries during the latter period. The negative sign of the coefficient for capital intensity suggests that obsolescence of the capital stock, perhaps due to higher energy prices, may actually inhibit productivity growth.

68. The relation between productivity growth and growth of the materials-labor ratio was statistically insignificant. We conclude that the purchase price (and, hence, the implicit quantity) of intermediate input reflects fully the improvements in input quality.

69. Finally, an F test for the inclusion of the country dummy variables suggests that there are country-specific effects--economic and institutional--that play an important role in productivity growth. Dummy variables (relative to Germany) are not significant for the United Kingdom and Denmark, but are significant and positive for France, the Netherlands, Belgium, and Greece. In other words, once we account for the differences in the initial levels of productivity and the rates of growth of the relative factor intensities, we find that France, the Netherlands, Belgium, and Denmark have higher rates of growth of productivity than Germany. Italy and Ireland have lower rates of productivity growth.

VII. Summary and Conclusions

70. The purpose of this paper has been to provide a farm sector comparison of levels of output, inputs, and productivity for the United States and nine European countries. Our first objective was to compare levels of output in 1990 and to assess the relative importance of differences in levels of real factor input and in total factor productivity in accounting for differences in levels of output. Levels of output relative to the United States in 1990 varied from 0.243 for France to 0.021 for Ireland. Differences in relative levels of productivity were much smaller than differences in relative output. The level of productivity for France was 0.995. Ireland’s level of productivity relative to the United States was 0.679. We conclude that differences in levels of output were more closely associated with differences in levels of capital, land, labor, and intermediate inputs than with differences in levels of total factor productivity.

71. Our second objective was to compare relative levels of output, inputs, and productivity for the period 1973 to 1993. Among the nine European countries, only the Netherlands and Ireland increased output relative to the United States. In contrast, the differences in relative productivity levels narrowed significantly. We found evidence that those countries that lagged particularly far behind the technology leaders experienced the most rapid productivity convergence. This finding is consistent with Gerschenkron’s (1952) notion of the advantages of relative backwardness. The countries that were particularly far behind had the most to gain from the diffusion of technical knowledge and proceeded to grow most rapidly. Finally, the rate of

convergence was positively related to the rate of growth of the capital-labor ratio. This relation implies that at least some technological innovation is embodied in capital.

Appendix

(See pages 17 to 34)

Table 1. Output, Inputs, and Productivity Relative to the United States, 1990

	Germany	France	Italy	Netherlands	Belgium	United Kingdom	Ireland	Denmark	Greece
Output	0.134	0.243	0.177	0.082	0.032	0.095	0.021	0.035	0.040
Capital input	0.249	0.208	0.356	0.078	0.023	0.101	0.026	0.041	0.035
Land Input	0.047	0.105	0.086	0.010	0.007	0.063	0.013	0.011	0.012
Labor input	0.299	0.506	0.845	0.093	0.037	0.171	0.101	0.039	0.302
Intermediate inputs	0.181	0.269	0.114	0.100	0.042	0.116	0.021	0.040	0.029
Total factor productivity	0.838	0.995	0.712	1.360	1.236	0.875	0.679	1.148	0.791

Table 2. Factor Intensities Relative to the United States, 1990

	Germany	France	Italy	Netherlands	Belgium	United Kingdom	Ireland	Denmark	Greece
Capital input/labor input	0.8328	0.4111	0.4213	0.8387	0.6216	0.5906	0.2574	1.0513	0.1159
Land input/labor input	0.1572	0.2075	0.1018	0.1075	0.1892	0.3684	0.1287	0.2821	0.0397
Intermediate input/labor input	0.6054	0.5316	0.1349	1.0753	1.1351	0.6784	0.2079	1.0256	0.0960

Table 3. Output Relative to the 1990 Level for the United States

Year	Germany	France	Italy	Netherlands	Belgium	United Kingdom	Ireland	Denmark	Greece	United States
1973	0.111	0.174	0.143	0.048	0.027	0.080	0.014	0.024	0.033	0.677
1974	0.113	0.172	0.146	0.051	0.027	0.079	0.014	0.026	0.034	0.632
1975	0.112	0.164	0.151	0.050	0.025	0.074	0.014	0.023	0.037	0.680
1976	0.112	0.162	0.149	0.052	0.024	0.074	0.014	0.024	0.036	0.691
1977	0.119	0.170	0.151	0.055	0.025	0.080	0.016	0.026	0.035	0.746
1978	0.124	0.182	0.156	0.059	0.026	0.084	0.016	0.027	0.038	0.750
1979	0.124	0.196	0.166	0.061	0.027	0.084	0.016	0.028	0.037	0.809
1980	0.126	0.195	0.173	0.063	0.027	0.087	0.016	0.028	0.041	0.769
1981	0.125	0.193	0.171	0.066	0.027	0.086	0.016	0.029	0.041	0.860
1982	0.135	0.211	0.169	0.068	0.028	0.091	0.017	0.030	0.042	0.855
1983	0.132	0.206	0.180	0.070	0.027	0.090	0.018	0.029	0.040	0.732
1984	0.137	0.216	0.174	0.072	0.029	0.097	0.019	0.032	0.041	0.865
1985	0.132	0.224	0.175	0.073	0.029	0.094	0.019	0.033	0.043	0.903
1986	0.138	0.227	0.179	0.077	0.031	0.095	0.019	0.033	0.043	0.892
1987	0.131	0.233	0.186	0.075	0.030	0.094	0.019	0.031	0.042	0.920
1988	0.135	0.232	0.181	0.077	0.031	0.093	0.019	0.033	0.044	0.882
1989	0.135	0.238	0.183	0.079	0.032	0.094	0.019	0.034	0.046	0.970
1990	0.134	0.243	0.177	0.082	0.032	0.095	0.021	0.035	0.040	1.000
1991	0.134	0.237	0.189	0.083	0.034	0.095	0.021	0.034	0.045	1.017
1992	0.138	0.251	0.192	0.085	0.035	0.097	0.022	0.033	0.045	1.078
1993	0.134	0.239	0.189	0.085	0.036	0.093	0.022	0.036	0.045	1.016

Table 4. Capital Input Relative to the 1990 Level for the United States

Year	Germany	France	Italy	Netherlands	Belgium	United Kingdom	Ireland	Denmark	Greece	United States
1973	0.244	0.190	0.297	0.042	0.018	0.093	0.023	0.041	0.025	1.057
1974	0.246	0.197	0.305	0.043	0.018	0.097	0.023	0.043	0.027	1.109
1975	0.245	0.202	0.314	0.045	0.019	0.100	0.023	0.044	0.028	1.153
1976	0.246	0.205	0.321	0.046	0.019	0.102	0.023	0.045	0.030	1.181
1977	0.249	0.208	0.331	0.048	0.020	0.104	0.024	0.046	0.031	1.216
1978	0.255	0.210	0.340	0.051	0.021	0.107	0.024	0.048	0.032	1.244
1979	0.262	0.213	0.348	0.055	0.022	0.109	0.024	0.050	0.033	1.281
1980	0.268	0.216	0.355	0.058	0.022	0.110	0.024	0.051	0.035	1.322
1981	0.269	0.217	0.361	0.060	0.023	0.110	0.025	0.051	0.036	1.335
1982	0.266	0.218	0.365	0.061	0.023	0.109	0.025	0.050	0.037	1.326
1983	0.264	0.219	0.366	0.062	0.023	0.109	0.026	0.048	0.038	1.289
1984	0.264	0.219	0.364	0.063	0.023	0.110	0.026	0.047	0.038	1.249
1985	0.262	0.218	0.362	0.065	0.023	0.110	0.025	0.046	0.038	1.205
1986	0.258	0.215	0.360	0.067	0.023	0.110	0.025	0.045	0.039	1.147
1987	0.254	0.210	0.357	0.070	0.023	0.108	0.026	0.045	0.038	1.089
1988	0.251	0.206	0.354	0.073	0.023	0.105	0.026	0.044	0.037	1.051
1989	0.249	0.206	0.356	0.075	0.023	0.103	0.026	0.042	0.036	1.020
1990	0.249	0.208	0.356	0.078	0.023	0.101	0.026	0.041	0.035	1.000
1991	0.251	0.208	0.357	0.081	0.023	0.098	0.027	0.041	0.034	0.985
1992	0.256	0.205	0.355	0.083	0.022	0.094	0.027	0.039	0.033	0.964
1993	0.259	0.201	0.353	0.084	0.022	0.091	0.027	0.038	0.033	0.943

Table 5. Land Input Relative to the 1990 Level for the United States

Year	Germany	France	Italy	Netherlands	Belgium	United Kingdom	Ireland	Denmark	Greece	United States
1973	0.050	0.110	0.088	0.011	0.007	0.065	0.013	0.012	0.011	1.107
1974	0.050	0.110	0.088	0.011	0.007	0.065	0.013	0.012	0.011	1.102
1975	0.050	0.110	0.088	0.011	0.007	0.065	0.013	0.012	0.011	1.076
1976	0.049	0.110	0.088	0.011	0.007	0.065	0.013	0.012	0.011	1.071
1977	0.049	0.110	0.090	0.011	0.007	0.064	0.013	0.012	0.011	1.066
1978	0.049	0.110	0.088	0.011	0.007	0.064	0.013	0.012	0.011	1.063
1979	0.049	0.110	0.088	0.011	0.007	0.064	0.013	0.012	0.011	1.063
1980	0.049	0.108	0.088	0.011	0.007	0.064	0.013	0.012	0.011	1.061
1981	0.048	0.108	0.088	0.011	0.007	0.064	0.013	0.011	0.011	1.058
1982	0.048	0.108	0.088	0.011	0.007	0.064	0.013	0.011	0.011	1.054
1983	0.048	0.108	0.087	0.011	0.007	0.064	0.013	0.011	0.011	1.048
1984	0.047	0.107	0.086	0.011	0.007	0.064	0.013	0.011	0.011	1.041
1985	0.047	0.107	0.086	0.011	0.007	0.064	0.013	0.011	0.011	1.034
1986	0.047	0.107	0.085	0.011	0.007	0.064	0.013	0.011	0.011	1.024
1987	0.047	0.107	0.085	0.011	0.007	0.064	0.013	0.011	0.011	1.015
1988	0.047	0.106	0.086	0.011	0.007	0.064	0.013	0.011	0.011	1.010
1989	0.047	0.105	0.084	0.011	0.007	0.063	0.013	0.011	0.012	1.005
1990	0.047	0.105	0.086	0.011	0.007	0.063	0.013	0.011	0.012	1.000
1991	0.047	0.105	0.085	0.011	0.007	0.063	0.013	0.012	0.012	0.994
1992	0.047	0.106	0.085	0.011	0.006	0.063	0.013	0.012	0.012	0.990
1993	0.047	0.106	0.085	0.011	0.006	0.063	0.013	0.012	0.012	0.985

Table 6. Labor Input Relative to the 1990 Level for the United States

Year	Germany	France	Italy	Netherlands	Belgium	United Kingdom	Ireland	Denmark	Greece	United States
1973	0.518	0.843	1.337	0.112	0.058	0.229	0.137	0.072	0.413	1.529
1974	0.497	0.816	1.309	0.110	0.056	0.220	0.131	0.067	0.405	1.452
1975	0.484	0.788	1.259	0.109	0.054	0.205	0.128	0.064	0.397	1.436
1976	0.472	0.771	1.258	0.107	0.051	0.206	0.126	0.062	0.389	1.434
1977	0.453	0.756	1.214	0.104	0.049	0.213	0.125	0.059	0.381	1.384
1978	0.434	0.744	1.214	0.102	0.047	0.213	0.124	0.057	0.373	1.320
1979	0.413	0.733	1.194	0.101	0.047	0.209	0.123	0.055	0.366	1.287
1980	0.404	0.713	1.136	0.100	0.045	0.203	0.122	0.052	0.358	1.269
1981	0.399	0.694	1.079	0.098	0.044	0.199	0.117	0.050	0.351	1.263
1982	0.390	0.675	1.017	0.097	0.043	0.197	0.113	0.047	0.346	1.222
1983	0.371	0.656	1.041	0.097	0.043	0.195	0.108	0.046	0.342	1.192
1984	0.366	0.636	1.019	0.097	0.043	0.192	0.108	0.045	0.341	1.178
1985	0.361	0.614	0.978	0.096	0.042	0.191	0.108	0.044	0.343	1.093
1986	0.355	0.592	0.971	0.095	0.041	0.187	0.104	0.042	0.332	1.009
1987	0.334	0.571	0.950	0.094	0.040	0.183	0.100	0.040	0.312	1.005
1988	0.329	0.550	0.907	0.093	0.039	0.180	0.098	0.038	0.313	1.015
1989	0.309	0.527	0.861	0.093	0.038	0.175	0.103	0.039	0.303	1.032
1990	0.299	0.506	0.845	0.093	0.037	0.171	0.101	0.039	0.302	1.000
1991	0.282	0.485	0.846	0.093	0.036	0.166	0.100	0.038	0.267	1.014
1992	0.271	0.464	0.805	0.094	0.034	0.164	0.097	0.037	0.274	0.965
1993	0.258	0.440	0.746	0.092	0.034	0.163	0.095	0.036	0.276	0.927

Table 7. Intermediate Input Relative to the 1990 Level for the United States

Year	Germany	France	Italy	Netherlands	Belgium	United Kingdom	Ireland	Denmark	Greece	United States
1973	0.153	0.201	0.078	0.068	0.033	0.116	0.014	0.032	0.018	0.870
1974	0.149	0.207	0.080	0.070	0.033	0.110	0.012	0.030	0.018	0.896
1975	0.152	0.198	0.080	0.071	0.033	0.110	0.012	0.031	0.020	0.867
1976	0.164	0.208	0.085	0.076	0.033	0.113	0.013	0.035	0.021	0.927
1977	0.171	0.212	0.091	0.079	0.034	0.114	0.015	0.036	0.022	0.916
1978	0.180	0.224	0.097	0.084	0.034	0.115	0.017	0.039	0.023	1.038
1979	0.189	0.234	0.103	0.088	0.035	0.117	0.020	0.042	0.023	1.094
1980	0.190	0.237	0.107	0.093	0.034	0.114	0.017	0.040	0.025	1.105
1981	0.184	0.237	0.105	0.091	0.034	0.110	0.018	0.039	0.026	1.068
1982	0.185	0.238	0.105	0.091	0.035	0.118	0.018	0.039	0.026	0.979
1983	0.189	0.239	0.107	0.099	0.035	0.121	0.019	0.040	0.027	0.977
1984	0.189	0.243	0.107	0.095	0.035	0.118	0.019	0.039	0.027	1.003
1985	0.187	0.243	0.108	0.099	0.036	0.117	0.019	0.039	0.028	0.964
1986	0.185	0.248	0.111	0.099	0.038	0.121	0.021	0.039	0.026	0.956
1987	0.186	0.255	0.115	0.109	0.039	0.121	0.020	0.040	0.027	0.961
1988	0.185	0.259	0.115	0.107	0.040	0.121	0.020	0.039	0.028	0.913
1989	0.184	0.265	0.116	0.100	0.042	0.119	0.022	0.039	0.029	0.938
1990	0.181	0.269	0.114	0.100	0.042	0.116	0.021	0.040	0.029	1.000
1991	0.179	0.266	0.115	0.102	0.044	0.113	0.022	0.039	0.029	1.030
1992	0.174	0.264	0.114	0.102	0.045	0.112	0.022	0.040	0.029	1.052
1993	0.164	0.259	0.111	0.101	0.044	0.114	0.023	0.040	0.031	1.113

Table 8. Total Factor Productivity Relative to the 1990 Level for the United States

Year	Germany	France	Italy	Netherlands	Belgium	United Kingdom	Ireland	Denmark	Greece	United States
1973	0.624	0.644	0.516	0.980	1.080	0.702	0.483	0.750	0.660	0.636
1974	0.646	0.637	0.527	1.020	1.080	0.705	0.500	0.839	0.680	0.590
1975	0.644	0.624	0.553	1.000	1.042	0.667	0.500	0.719	0.740	0.645
1976	0.629	0.609	0.536	1.020	1.000	0.655	0.500	0.727	0.706	0.635
1977	0.669	0.639	0.539	1.058	1.042	0.702	0.552	0.788	0.686	0.692
1978	0.689	0.677	0.547	1.093	1.083	0.730	0.533	0.794	0.745	0.667
1979	0.681	0.721	0.576	1.109	1.125	0.724	0.516	0.800	0.725	0.704
1980	0.696	0.722	0.609	1.105	1.125	0.763	0.533	0.824	0.804	0.665
1981	0.698	0.723	0.615	1.179	1.125	0.768	0.533	0.879	0.804	0.753
1982	0.763	0.796	0.619	1.214	1.167	0.791	0.567	0.909	0.824	0.776
1983	0.750	0.783	0.652	1.186	1.125	0.776	0.600	0.879	0.769	0.673
1984	0.783	0.828	0.637	1.263	1.208	0.851	0.633	1.000	0.788	0.797
1985	0.763	0.872	0.653	1.237	1.208	0.825	0.633	1.031	0.827	0.862
1986	0.802	0.890	0.668	1.305	1.240	0.826	0.613	1.065	0.827	0.877
1987	0.780	0.921	0.699	1.210	1.200	0.825	0.633	1.000	0.824	0.916
1988	0.813	0.928	0.699	1.242	1.240	0.823	0.633	1.100	0.863	0.901
1989	0.828	0.964	0.726	1.317	1.231	0.855	0.613	1.133	0.902	0.984
1990	0.838	0.996	0.711	1.367	1.231	0.880	0.677	1.167	0.784	1.000
1991	0.854	0.992	0.756	1.361	1.308	0.896	0.677	1.133	0.918	1.005
1992	0.890	1.073	0.790	1.371	1.346	0.933	0.710	1.100	0.918	1.073
1993	0.893	1.058	0.815	1.393	1.385	0.894	0.710	1.200	0.900	1.001

Figure 1. Coefficients of Variation of Productivity Relative to the United States

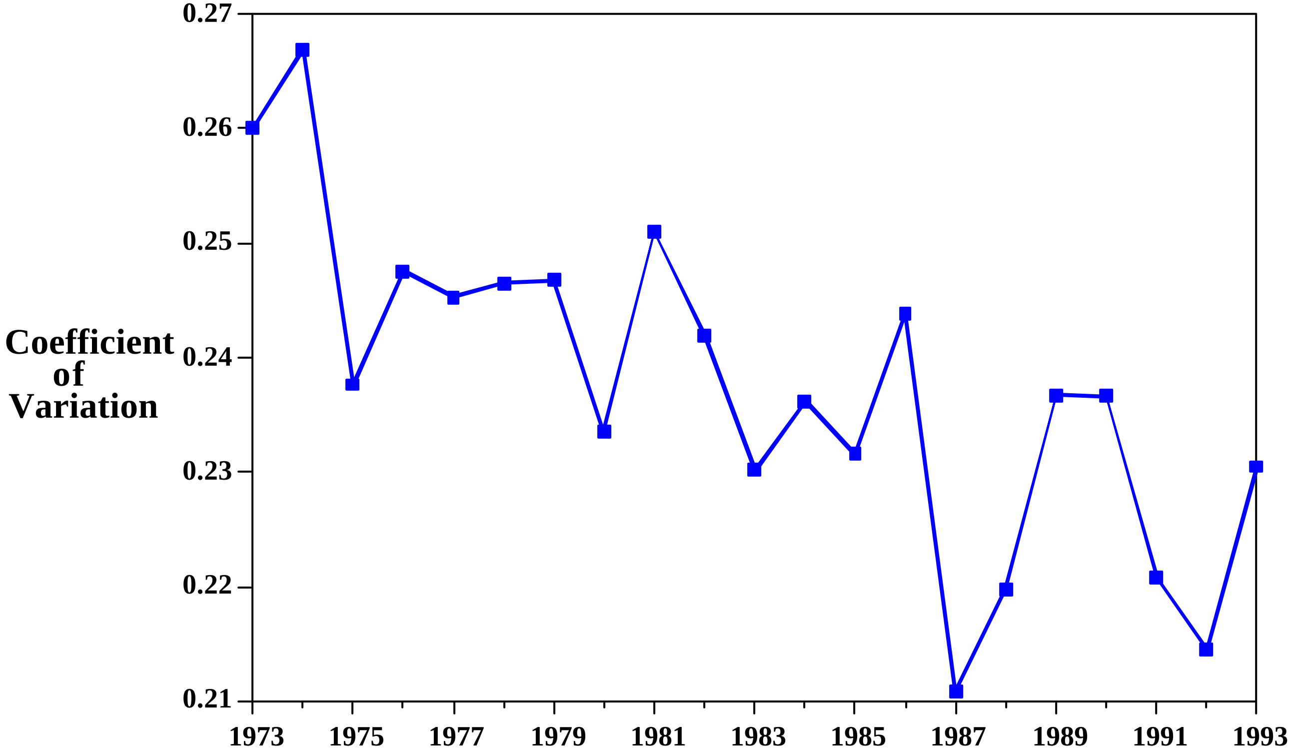

Table A1. Output, 1990

	France	Italy	Netherlands	Belgium	United Kingdom	Ireland	Denmark	Greece	United States
Value in national currency[1]	332,315	54,874	36,411	262,893	13,240	3,227	54,471	1,464	165,814
Purchasing power parities[2]	8.228	1.875	2.632	49.234	0.835	0.904	9.439	0.218	1.000
Value in dollars[3]	40,386	29,266	13,834	5,340	15,866	3,569	5,771	6,715	165,814
Implicit Quantity	0.243	0.177	0.083	0.032	0.095	0.021	0.035	0.040	1.000

[1]Value in millions of national currency, except Italy and Greece in billions of national currency.

[2]National currency per dollar, except Italy and Greece in thousands of national currency per dollar.

[3]Value in millions of dollars.

Table A2. Intertemporal Fisher Indexes, Output (1990 = 1.000)

Year	Germany	France	Italy	Netherlands	Belgium	United Kingdom	Ireland	Denmark	Greece	United States
1973	0.828	0.714	0.809	0.586	0.838	0.844	0.661	0.676	0.837	0.677
1974	0.838	0.708	0.823	0.620	0.856	0.839	0.661	0.739	0.850	0.632
1975	0.830	0.675	0.854	0.615	0.789	0.785	0.674	0.674	0.916	0.681
1976	0.837	0.665	0.840	0.640	0.770	0.787	0.671	0.682	0.914	0.691
1977	0.884	0.697	0.850	0.672	0.794	0.847	0.741	0.749	0.872	0.746
1978	0.922	0.750	0.880	0.717	0.827	0.886	0.778	0.773	0.955	0.750
1979	0.923	0.806	0.937	0.750	0.836	0.890	0.776	0.799	0.919	0.809
1980	0.936	0.802	0.977	0.769	0.840	0.918	0.767	0.804	1.018	0.769
1981	0.927	0.792	0.967	0.806	0.847	0.910	0.765	0.824	1.024	0.860
1982	1.005	0.867	0.952	0.834	0.873	0.965	0.814	0.870	1.043	0.855
1983	0.979	0.848	1.016	0.853	0.860	0.952	0.840	0.838	1.000	0.732
1984	1.019	0.887	0.983	0.883	0.908	1.029	0.911	0.931	1.033	0.865
1985	0.979	0.920	0.990	0.890	0.919	0.994	0.900	0.932	1.073	0.903
1986	1.025	0.932	1.011	0.935	0.967	1.003	0.889	0.943	1.071	0.892
1987	0.972	0.957	1.051	0.914	0.948	0.990	0.900	0.894	1.057	0.920
1988	1.005	0.953	1.023	0.934	0.983	0.988	0.916	0.935	1.105	0.882
1989	1.006	0.979	1.032	0.967	1.010	0.998	0.881	0.963	1.152	0.970
1990	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1991	0.997	0.973	1.064	1.019	1.061	1.008	1.003	0.976	1.137	1.017
1992	1.029	1.032	1.083	1.038	1.112	1.023	1.053	0.953	1.132	1.078
1993	1.001	0.981	1.064	1.042	1.127	0.984	1.019	1.033	1.123	1.016

Table A3. Capital Input, 1990

	Germany	France	Italy	Netherlands	Belgium	United Kingdom	Ireland	Denmark	Greece	United States
Value in national currency[1]	17,506	42,227	16,081	6,495	36,899	2,379	475	12,430	494	31,570
Purchasing power parities[2]	2.217	6.434	1.424	2.640	51.002	0.748	0.572	9.511	0.450	1.000
Value in dollars[3]	7,895	6,563	11,290	2,460	723	3,181	830	1,307	1,097	31,570
Implicit Quantity	0.249	0.208	0.356	0.078	0.023	0.101	0.026	0.041	0.035	1.000

[1]Value in millions of national currency, except Italy and Greece in billions of national currency.

[2]National currency per dollar, except Italy and Greece in thousands of national currency per dollar.

[3]Value in millions of dollars.

Table A4. Intertemporal Fisher Indexes, Capital Input (1990 = 1.000)

Year	Germany	France	Italy	Netherlands	Belgium	United Kingdom	Ireland	Denmark	Greece	United States
1973	0.976	0.913	0.834	0.535	0.768	0.925	0.852	1.002	0.723	1.057
1974	0.985	0.946	0.857	0.557	0.796	0.960	0.884	1.045	0.764	1.109
1975	0.984	0.972	0.880	0.580	0.823	0.990	0.871	1.070	0.795	1.153
1976	0.984	0.986	0.900	0.595	0.845	1.012	0.864	1.092	0.845	1.181
1977	0.997	1.003	0.928	0.618	0.877	1.034	0.901	1.125	0.885	1.216
1978	1.023	1.009	0.954	0.659	0.911	1.062	0.904	1.161	0.913	1.244
1979	1.050	1.024	0.977	0.704	0.955	1.082	0.912	1.201	0.952	1.281
1980	1.073	1.038	0.995	0.750	0.975	1.094	0.907	1.239	1.004	1.322
1981	1.077	1.043	1.014	0.772	0.980	1.090	0.929	1.241	1.030	1.335
1982	1.068	1.048	1.026	0.781	0.982	1.078	0.958	1.208	1.055	1.326
1983	1.059	1.056	1.027	0.794	0.991	1.078	0.971	1.172	1.076	1.289
1984	1.059	1.054	1.020	0.814	0.989	1.091	0.971	1.134	1.080	1.249
1985	1.049	1.048	1.015	0.837	0.986	1.096	0.965	1.110	1.089	1.205
1986	1.036	1.034	1.010	0.861	0.984	1.096	0.958	1.098	1.110	1.147
1987	1.020	1.009	1.002	0.903	0.989	1.074	0.987	1.086	1.083	1.089
1988	1.006	0.993	0.994	0.940	0.995	1.045	0.974	1.057	1.046	1.051
1989	0.997	0.992	0.999	0.969	0.999	1.025	0.973	1.021	1.020	1.020
1990	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1991	1.006	1.000	1.001	1.036	0.996	0.969	1.025	0.980	0.978	0.985
1992	1.027	0.989	0.997	1.061	0.976	0.935	1.026	0.952	0.958	0.964
1993	1.038	0.966	0.992	1.081	0.957	0.901	1.013	0.924	0.945	0.943

Table A5. Land Input, 1990

	Germany	France	Italy	Netherlands	Belgium	United Kingdom	Ireland	Denmark	Greece	United States
Value in national currency[1]	21,013	22,659	3,552	3,860	34,970	2,986	512	6,029	1,642	28,136
Purchasing power parities[2]	15.881	7.670	1.469	12.639	189.294	1.682	1.452	19.313	5.048	1.000
Value in dollars[3]	1,323	2,954	2,418	305	185	1,775	352	312	325	28,136
Implicit Quantity	0.047	0.105	0.086	0.011	0.007	0.063	0.013	0.011	0.012	1.000

[1]Value in millions of national currency, except Italy and Greece in billions of national currency.

[2]National currency per dollar, except Italy and Greece in thousands of national currency per dollar.

[3]Value in millions of dollars.

Table A6. Intertemporal Fisher Indexes, Land Input (1990 = 1.000)

Year	Germany	France	Italy	Netherlands	Belgium	United Kingdom	Ireland	Denmark	Greece	United States
1973	1.062	1.051	1.020	1.052	1.135	1.030	1.011	1.064	0.918	1.161
1974	1.058	1.050	1.019	1.048	1.125	1.027	1.011	1.046	0.911	1.176
1975	1.054	1.049	1.024	1.042	1.112	1.026	1.012	1.049	0.918	1.148
1976	1.046	1.049	1.022	1.038	1.104	1.026	1.011	1.047	0.950	1.143
1977	1.038	1.048	1.046	1.031	1.091	1.020	1.016	1.045	0.933	1.137
1978	1.038	1.047	1.030	1.024	1.079	1.021	1.017	1.044	0.946	1.113
1979	1.038	1.046	1.026	1.017	1.062	1.019	1.019	1.042	0.946	1.121
1980	1.038	1.030	1.025	1.010	1.052	1.020	1.010	1.037	0.950	1.132
1981	1.029	1.030	1.026	1.005	1.045	1.013	1.011	1.034	0.954	1.128
1982	1.021	1.027	1.022	1.002	1.042	1.012	1.011	1.029	0.955	1.113
1983	1.013	1.029	1.016	1.004	1.039	1.010	1.010	1.022	0.963	1.009
1984	1.010	1.023	1.005	1.007	1.037	1.010	1.010	1.024	0.963	1.080
1985	1.006	1.023	0.998	1.010	1.032	1.009	1.011	1.012	0.976	1.067
1986	1.006	1.023	0.993	1.007	1.028	1.008	1.005	1.008	0.982	1.036
1987	1.006	1.022	0.988	1.005	1.025	1.008	1.009	1.007	0.989	0.989
1988	1.004	1.007	0.995	1.003	1.017	1.006	1.009	1.002	0.993	0.984
1989	1.002	1.002	0.980	0.999	0.992	1.003	1.003	0.995	0.999	1.006
1990	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1991	0.998	1.001	0.994	0.994	0.991	0.999	1.005	1.069	0.999	0.994
1992	0.997	1.006	0.993	0.993	0.982	1.000	1.005	1.063	1.010	0.999
1993	0.995	1.009	0.991	0.997	0.973	1.001	1.004	1.069	1.019	0.981

Table A7. Labor Input, 1990

	Germany	France	Italy	Netherlands	Belgium	United Kingdom	Ireland	Denmark	Greece	United States
Value in national currency[1]	23,735	157,326	40,500	10,558	62,887	4,272	1,833	12,950	942	42,642
Purchasing power parities[2]	1.867	7.300	1.125	2.676	39.904	0.585	0.425	7.832	0.073	1.000
Value in dollars[3]	12,715	21,553	35,991	3,946	1,576	7,297	4,311	1,653	12,864	42,642
Implicit Quantity	0.298	0.505	0.844	0.093	0.037	0.171	0.101	0.039	0.302	1.000

[1] Value in millions of national currency, except Italy and Greece in billions of national currency.

[2] National currency per dollar, except Italy and Greece in thousands of national currency per dollar.

[3] Value in millions of dollars.

Table A8. Intertemporal Fisher Indexes, Labor Input (1990 = 1.000)

Year	Germany	France	Italy	Netherlands	Belgium	United Kingdom	Ireland	Denmark	Greece	United States
1973	1.737	1.666	1.582	1.212	1.582	1.339	1.352	1.848	1.369	1.529
1974	1.665	1.613	1.550	1.191	1.521	1.287	1.294	1.720	1.341	1.452
1975	1.623	1.558	1.490	1.176	1.456	1.197	1.260	1.642	1.314	1.436
1976	1.583	1.525	1.490	1.160	1.385	1.205	1.249	1.590	1.288	1.434
1977	1.517	1.495	1.437	1.127	1.326	1.245	1.238	1.527	1.262	1.384
1978	1.454	1.471	1.437	1.101	1.282	1.245	1.227	1.468	1.235	1.320
1979	1.386	1.449	1.414	1.087	1.277	1.219	1.216	1.409	1.211	1.287
1980	1.355	1.410	1.345	1.078	1.227	1.187	1.205	1.343	1.186	1.269
1981	1.337	1.372	1.278	1.056	1.193	1.160	1.160	1.282	1.162	1.263
1982	1.305	1.335	1.204	1.051	1.170	1.148	1.116	1.207	1.145	1.223
1983	1.245	1.297	1.233	1.052	1.161	1.138	1.072	1.194	1.132	1.192
1984	1.225	1.257	1.207	1.045	1.154	1.120	1.071	1.163	1.130	1.179
1985	1.208	1.214	1.158	1.040	1.126	1.114	1.071	1.120	1.136	1.093
1986	1.190	1.171	1.150	1.028	1.113	1.094	1.029	1.081	1.100	1.009
1987	1.119	1.129	1.125	1.019	1.079	1.067	0.988	1.039	1.035	1.005
1988	1.101	1.087	1.074	1.006	1.044	1.048	0.973	0.980	1.038	1.015
1989	1.035	1.043	1.019	1.006	1.019	1.021	1.015	1.003	1.002	1.032
1990	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1991	0.945	0.959	1.001	1.001	0.976	0.972	0.985	0.966	0.885	1.015
1992	0.907	0.918	0.952	1.010	0.934	0.957	0.959	0.946	0.907	0.965
1993	0.866	0.870	0.883	0.999	0.911	0.949	0.940	0.937	0.914	0.927

Table A9. Intermediate Input, 1990

	Germany	France	Italy	Netherlands	Belgium	United Kingdom	Ireland	Denmark	Greece	United States
Value in national currency[1]	29,496	145,551	16,111	16,947	147,270	6,879	1,351	26,303	391	73,275
Purchasing power parities[2]	2.225	7.394	1.937	2.324	48.093	0.809	0.863	8.910	0.184	1.000
Value in dollars[3]	13,255	19,686	8,319	7,292	3,062	8,499	1,566	2,952	2,130	73,275
Implicit Quantity	0.181	0.269	0.114	0.100	0.042	0.116	0.021	0.040	0.029	1.000

[1]Value in millions of national currency, except Italy and Greece in billions of national currency.

[2]National currency per dollar, except Italy and Greece in thousands of national currency per dollar.

[3]Value in millions of dollars.

Table A10. Intertemporal Fisher Indexes, Intermediate Input (1990 = 1.000)

Year	Germany	France	Italy	Netherlands	Belgium	United Kingdom	Ireland	Denmark	Greece	United States
1973	0.843	0.747	0.689	0.685	0.795	0.998	0.657	0.796	0.615	0.870
1974	0.821	0.769	0.704	0.703	0.795	0.951	0.582	0.742	0.638	0.896
1975	0.841	0.735	0.705	0.715	0.797	0.955	0.554	0.781	0.700	0.867
1976	0.906	0.775	0.750	0.763	0.796	0.973	0.627	0.863	0.726	0.927
1977	0.945	0.790	0.799	0.790	0.809	0.986	0.692	0.885	0.771	0.916
1978	0.993	0.834	0.857	0.842	0.815	0.992	0.793	0.960	0.793	1.038
1979	1.044	0.872	0.909	0.886	0.831	1.007	0.919	1.032	0.810	1.094
1980	1.048	0.884	0.945	0.932	0.824	0.983	0.816	0.984	0.848	1.105
1981	1.015	0.881	0.922	0.917	0.813	0.955	0.861	0.961	0.882	1.068
1982	1.023	0.884	0.924	0.914	0.830	1.021	0.857	0.971	0.900	0.979
1983	1.044	0.890	0.938	0.992	0.826	1.044	0.902	0.993	0.928	0.977
1984	1.042	0.904	0.942	0.948	0.845	1.021	0.897	0.965	0.926	1.004
1985	1.032	0.904	0.951	0.991	0.868	1.014	0.908	0.977	0.956	0.964
1986	1.022	0.922	0.973	0.995	0.911	1.044	0.966	0.957	0.903	0.956
1987	1.025	0.948	1.013	1.088	0.938	1.045	0.926	0.989	0.948	0.961
1988	1.020	0.965	1.014	1.070	0.956	1.044	0.942	0.973	0.961	0.913
1989	1.015	0.988	1.018	1.003	0.992	1.025	1.015	0.967	0.997	0.938
1990	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1991	0.989	0.989	1.017	1.019	1.057	0.980	1.009	0.979	0.997	1.030
1992	0.963	0.984	1.002	1.024	1.070	0.967	1.025	0.986	1.007	1.052
1993	0.904	0.964	0.976	1.015	1.060	0.983	1.068	0.994	1.070	1.113

NOTES

1. An analogous input price index can be defined by replacing the assumption of revenue maximizing behavior with that of cost minimizing behavior.

2. Diewert (1976) has used the term “superlative” to characterize index numbers which are exact for functional forms having this approximation feature.

3. For example, the bilateral index of output prices between Greece and Ireland, which enters the Eltetö-Köves-Szulc index number formula, is constructed using comparisons between Italy and France.

4. SPEL/EU Data 73-97 is available on CD-ROM from the Office of Publications of the European Communities, L-2985, Luxembourg.

5. The decay function defined by (17) incorporates many of the commonly used forms of depreciation as special cases. The upper limit of b is unity. This corresponds to the "one-hoss shay" form of depreciation. As the value of b approaches zero, decay occurs at an increasing rate over time. If b equals zero, the function corresponds to the formula for straight-line depreciation. Finally, if b is negative, decay occurs most rapidly in the early years of service, corresponding to accelerated forms of depreciation such as geometric decay.

6. Observed real rates are expressed as an AR(1) process. We use this specification after examining the correlation coefficients for autocorrelation, partial and inverse autocorrelation, and performing the unit root and white noise tests. We centered each time series by subtracting its sample mean. The analysis was performed on the centered data.

7. The observations on w_j^i in (20) consist of average prices. When average data are used rather than actual observations on prices, the disturbance terms are likely to be heteroskedastic. Efficient parameter estimates are obtained by applying weighted least squares, where the weights are land area.

8. For the semilogarithmic specification used here, a consistent estimate of the parameter d_i is given by $\exp(\hat{d}_i) - 1$ (Halverson and Palmquist [1980]).

9. Recall that the quantity indexes are constructed implicitly. The multilateral Eltetö-Köves-Szulc price indexes or purchasing power parities for aggregate output and for capital, land, labor, and intermediate inputs and their nominal values for 1990 are contained in the Appendix. The Appendix also contains the intertemporal Fisher quantity indexes which are used to extend these comparisons backward and forward in time.

10. For a discussion of the package of reforms and their likely impact, see Ball *et al* (1997).

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