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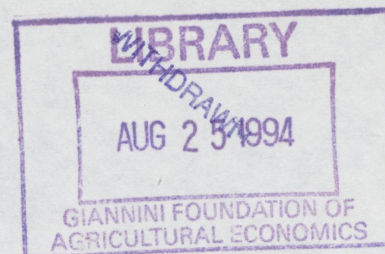
A Comparison of Three Nonparametric Measures of Productivity Growth in European and United States Agriculture

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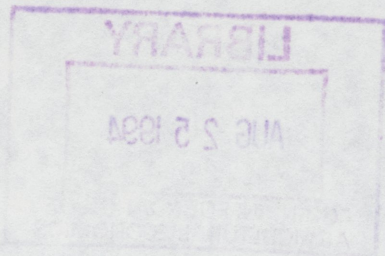# A Comparison of Three Nonparametric Measures of Productivity Growth in European and United States Agriculture

1. Introduction

The fundamental contributions by Diewert have shed light on the assumptions on the technology that are made when choosing a particular index formula for measuring total factor productivity (TFP). Most economists tend to favor the Törnqvist index in empirical applications, since this index is consistent with a very general structure of the technology Diewert (1992), Färe and Grosskopf (1992), Balk (1993) have shown that the Fisher index also imposes very few restrictions on the technology, providing justification for the use of the Fisher productivity index. Recently, Färe, Grosskopf, Lindgren and Roos (1989) (hereafter FGLR) have shown that the Malmquist index, originally proposed by Caves, Christensen and Diewert as a theoretical index (1982), may also be computed. Since it is constructed from perfect aggregator functions, it too has desirable properties as an index number formula. The goal of this paper is to compare the performance of the Malmquist index to other index numbers, using data on the agricultural sector of European Community (EC) countries and the United States over the period from 1973 to 1989.

The paper also addresses alternative treatments of fixed factors and their influence on calculated productivity. Typically, TFP indices are very dependent on the conventions adopted in the measurement of service flows and user costs of fixed factors. Some theoretical advances have provided conceptual guidelines in measuring fixed factors: Hulten (1980) and Jorgenson (1989), Hulten and Wykoff (1981) provide a framework for constructing capital stocks and measuring economic depreciation; and Jorgenson (1963) and Coen's (1975) definitions of user cost are important steps in the construction of prices for
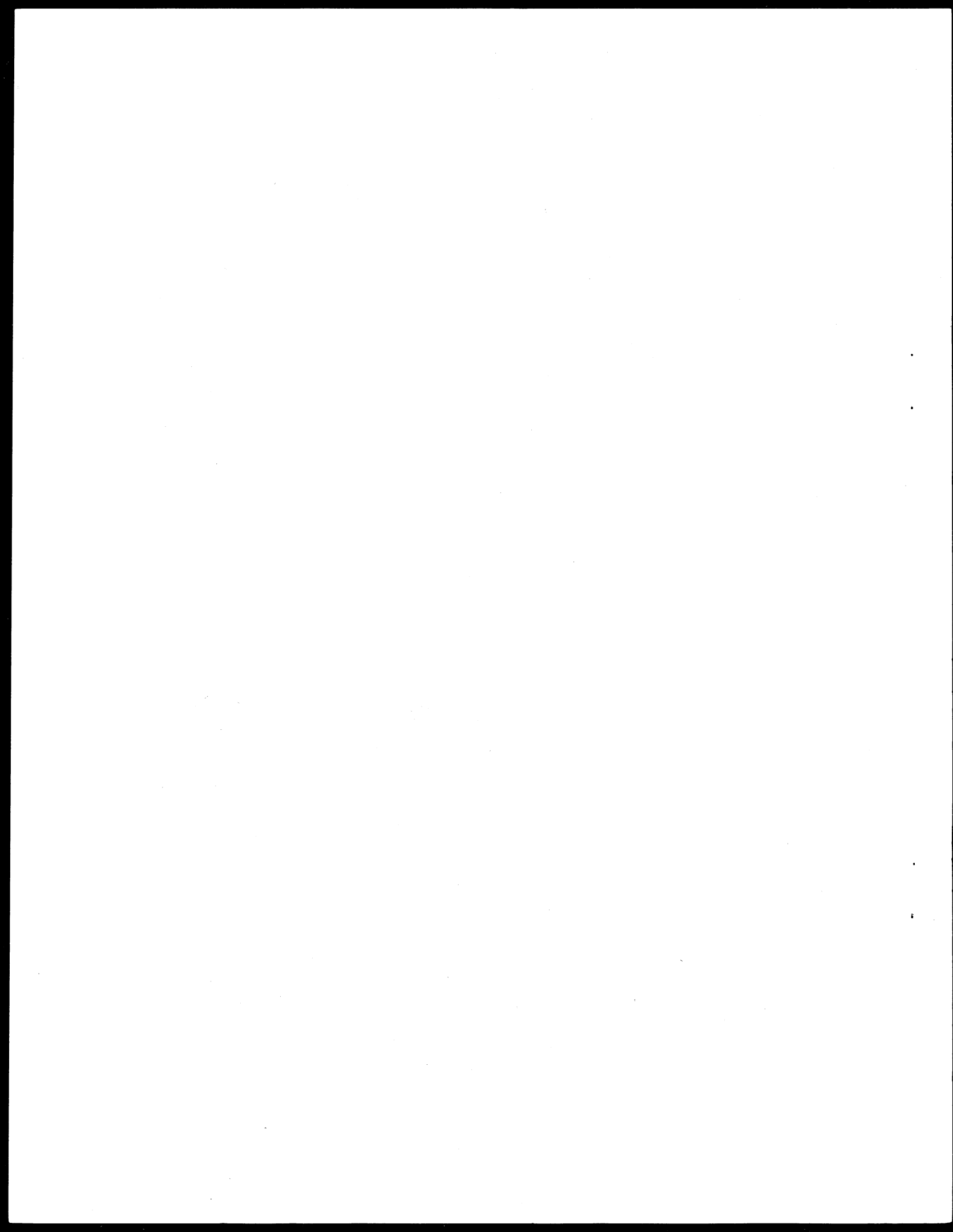
capital. More recently, Berndt and Fuss (1986) suggest that quasi-rents (i.e., shadow prices) are the most satisfactory way to value factors fixed in the short run in productivity measurement.

In spite of these theoretical improvements in the treatment of capital empirical implementation is still fraught with problems: the choice of lifetimes, as well as rates and patterns of depreciation for structures and equipment is still highly subjective (and not always supported by empirical evidence); in addition, the discount factor, which is part of the expression of user cost, must be approximated by expected interest rates which are unobservable. Moreover, even satisfactory solutions suggested by the theory run into data problems in a very critical way: for example, Gollop and Jorgenson's method for pricing agricultural family labor requires data which did not exist in Europe. Nor are the necessary data on land prices generally available to construct a satisfactory user cost (these data are not comparable across countries).

Since the measurement of service flows and user costs for fixed factors remains a major problem in computing most TFP indexes, we include in our comparison one index which relies only on data on quantities for these factors.[1] The index number which allows us to avoid computation of service flows and user cost is the Malmquist index. This index is constructed from (ratios of) distance functions, which provide a very general description of the technology, especially when technology involves many inputs and many outputs (Cornes (1992)).[2] Until recently (see FLGR), this index was considered to be solely theoretical. As formulated by FGLR, the computational form of the Malmquist index has several advantages over traditional TFP indexes:

-       in principle it only requires data on quantities and contributes to solving the

   difficult problem of service flow measurement for fixed factors.

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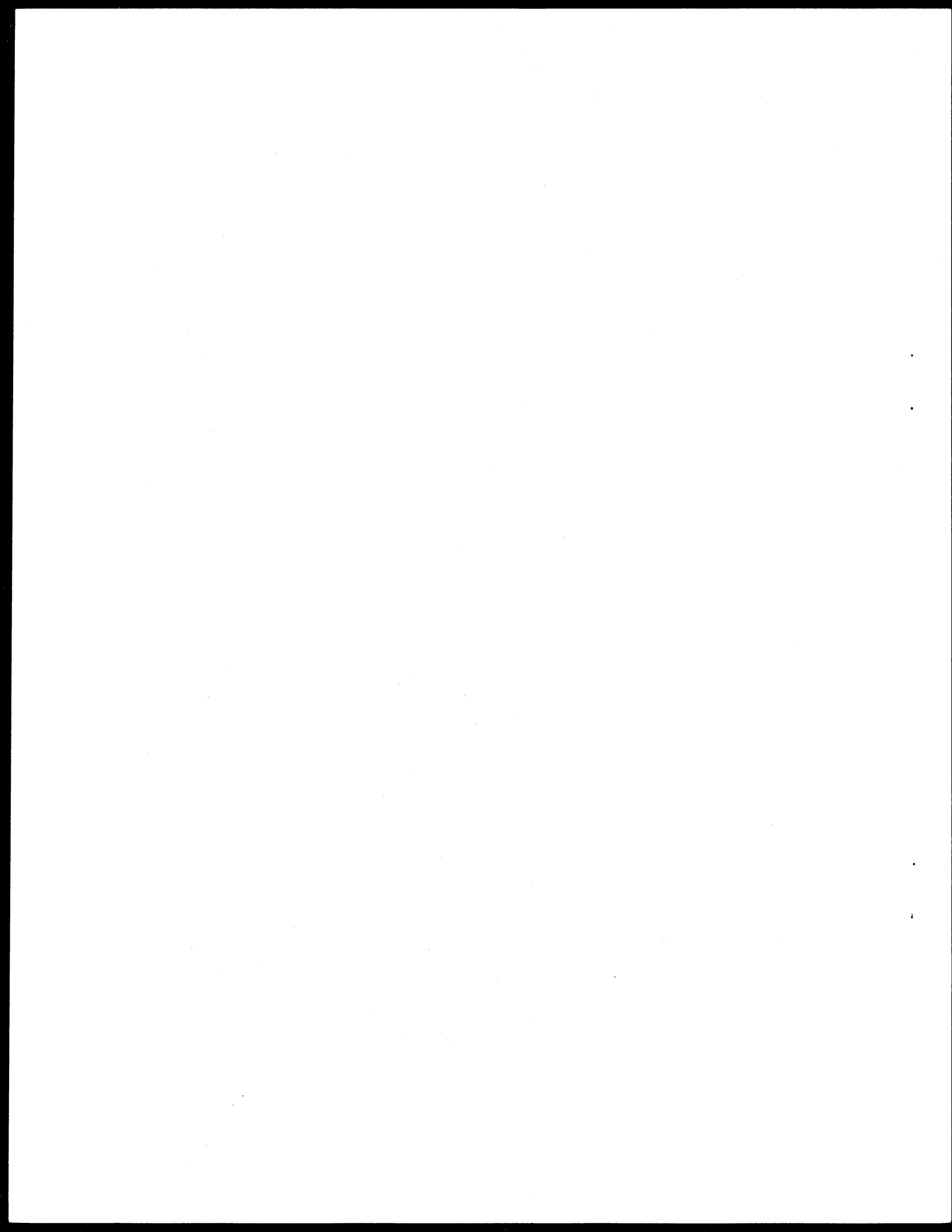
- it corresponds to very general structures of technology since the Malmquist index requires less restrictive assumptions than other commonly used indexes.

- no assumption on the optimizing behavior of the producer is necessary, in contrast to traditional index numbers.

- it allows for inefficiency.

- it does not require econometric estimation, but can be implemented with a simple data envelopment technique.[3]

We compare the Malmquist approach to more traditional measures of TFP. In particular, we compare it to two versions of the Fisher index. The first version is presented in section 2 and is based on an assumption of long term equilibrium. Factor and output shares are used to aggregate inputs and outputs and to approximate elasticities in the Divisia formula (see Jorgenson and Griliches (1967), or Diewert (1976 or 1983)). In the second version of the Fisher index (section 3), we assume that some quasi-fixed factors are not used at their long term equilibrium level. In this case, quasi-rents of these fixed factors can be used in the computation of the factor shares à la Berndt and Fuss. However, we employ Hulten's (1986) ex-post approach rather than econometrically estimating quasi-rents.

2. A traditional measure of TFP in long term equilibrium: The Fisher Index.

The method used in constructing our traditional TFP index number in long term equilibrium is a chain-linked version of the Fisher index. This Fisher index is consistent with a general representation of the technology and can be derived from a flexible aggregator function as described in Diewert (1992), under the assumption of nonincreasing returns to scale and profit maximizing behavior of the producer.
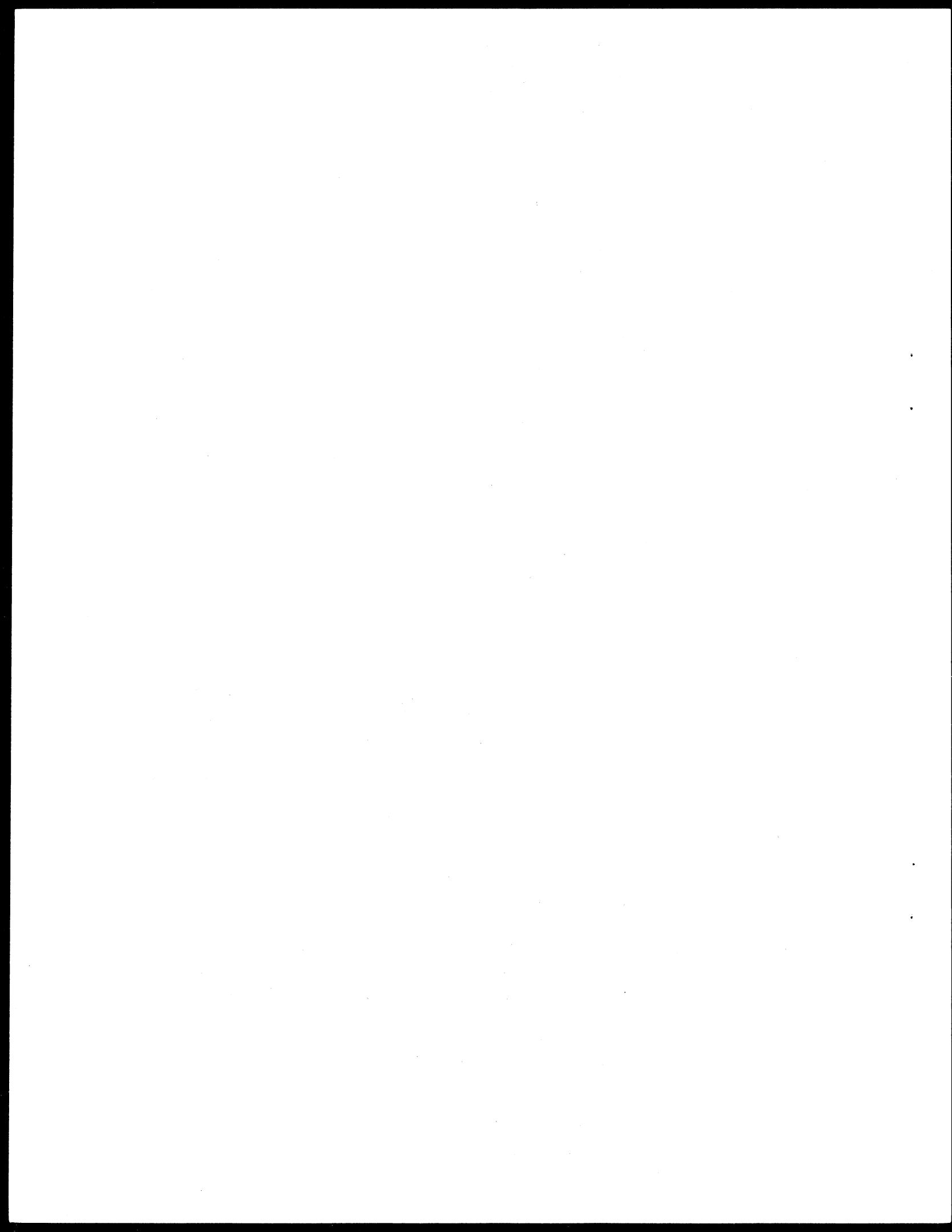
The Fisher index is defined as the geometric mean of the Paasche and Laspeyres index. Here the Fisher TFP index between year t and year t+1 is constructed in each country using nominal values and values in 1985 national currency at the basic heading level of the national accounts of agriculture. Let $x^t - (x_1^t,...,x_n^t,...,x_N^t)\epsilon R_+^N$ denote a vector of inputs at time t=1,...,T and let $y^t - (y_1^t,...,y_m^t,...,y_M^t)\epsilon R_+^M$ denote a vector of outputs. Let $w^T - (w_1^t,...,w_n^t,...,w_N^t)'\epsilon R_+^N$ denote a vector of positive input prices and let $p^t - (p_1^t,...,p_m^t,...,p_M^t)'\epsilon R_+^M$ denote the vector of positive output prices. The Fisher TFP index (TFP_F) is constructed as:

$$(2.1) \qquad TFP_F(x^t,x^{t+1},y^t,y^{t+1},w^t,w^{t+1},p^t,p^{t+1}) = \frac{Q_F^{out}(y^t,y^{t+1},p^t,p^{t+1})}{Q_F^{inp}(x^t,x^{t+1},w^t,w^{t+1})}$$

$$\text{where} \qquad Q_F^{out}(y^t,y^{t+1},p^t,p^{t+1}) - \left[\frac{p^t y^{t+1}}{p^t y^t} \cdot \frac{p^{t+1} y^{t+1}}{p^{t+1} y^t}\right]^{\frac{1}{2}}$$

$$Q_F^{inp}(x^t,x^{t+1},w^t,w^{t+1}) - \left[\frac{w^t x^{t+1}}{w^t x^t} \cdot \frac{w^{t+1} x^{t+1}}{w^{t+1} x^t}\right]^{\frac{1}{2}}.$$

A description of the data used to compute (2.1) is included in section 5.

3. A measure of TFP in short term equilibrium: The Hulten Index.

For the Fisher index discussed in the previous section, we assume that all inputs can adjust to their long term equilibrium level, i.e., the flow of services is assumed to be proportional to the stock of quasi fixed factors. If, however, under-utilization of capacity occurs in the short term, the above approach can lead to interpreting short term variations of capacity as long term decreases in productivity growth (see Morrisson (1986)). In the presence of quasi-fixed inputs, Berndt and Fuss (1986) suggest that the flow of services should not be assumed to be proportional to the stock of quasi-fixed input; they suggest
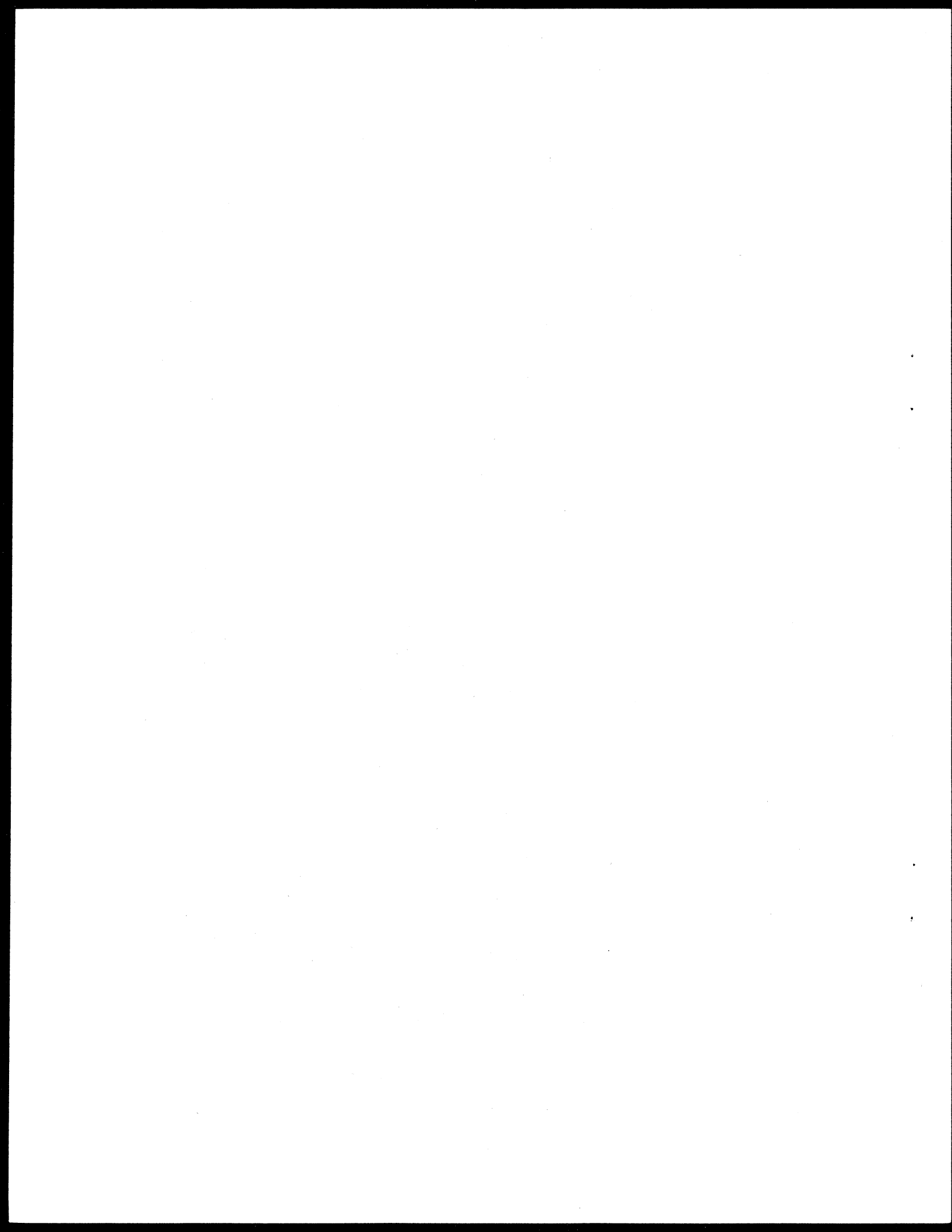
altering the value of the input by pricing quasi-fixed inputs using their shadow values, not their market transaction prices.

Our second index, which is a short-run TFP index follows Hulten (1986), who suggests expanding Berndt and Fuss' idea, by proposing an alternative to directly computing shadow price. With one quasi-fixed input, an estimate of the quasi-rent to the quasi-fixed input (i.e., the shadow price) can be obtained as residual income per unit of quasi-fixed input if constant returns to scale hold. This makes it possible to avoid econometric estimation of the quasi-rent. However, if more than one input is quasi-fixed, this "ex-post" procedure only leads to the quasi-rent of the aggregate.

In constructing our ex-post Hulten index, we disaggregate the ex-post quasi-rent to subaggregates of land, capital and family labor. We assume that the user costs of capital and land give a reasonable estimate of the quasi-rent to these two inputs. Therefore the quasi-rent of the aggregated fixed input is decomposed between the user cost for land, the user cost for capital and a residual which is interpreted as the quasi-rent for the family labor.[4] With these assumptions, our Hulten index is computed as a modified Fisher index as in section 2. The price of family labor is modified, since the quantity of family labor is not priced using the wage rates in agriculture, but using the residual net income per family labor.

4. The Malmquist measure of TFP.

Both "Fisher" and "Hulten" measures of TFP rely on measures of service flows and user costs which are problematic due to data limitations and conventions necessary to aggregate quasi-fixed inputs. We next present a possible alternative using an output-based Malmquist index. This index is expressed in terms of output distance functions. These distance functions are defined relative to a common EC-US reference technology constructed

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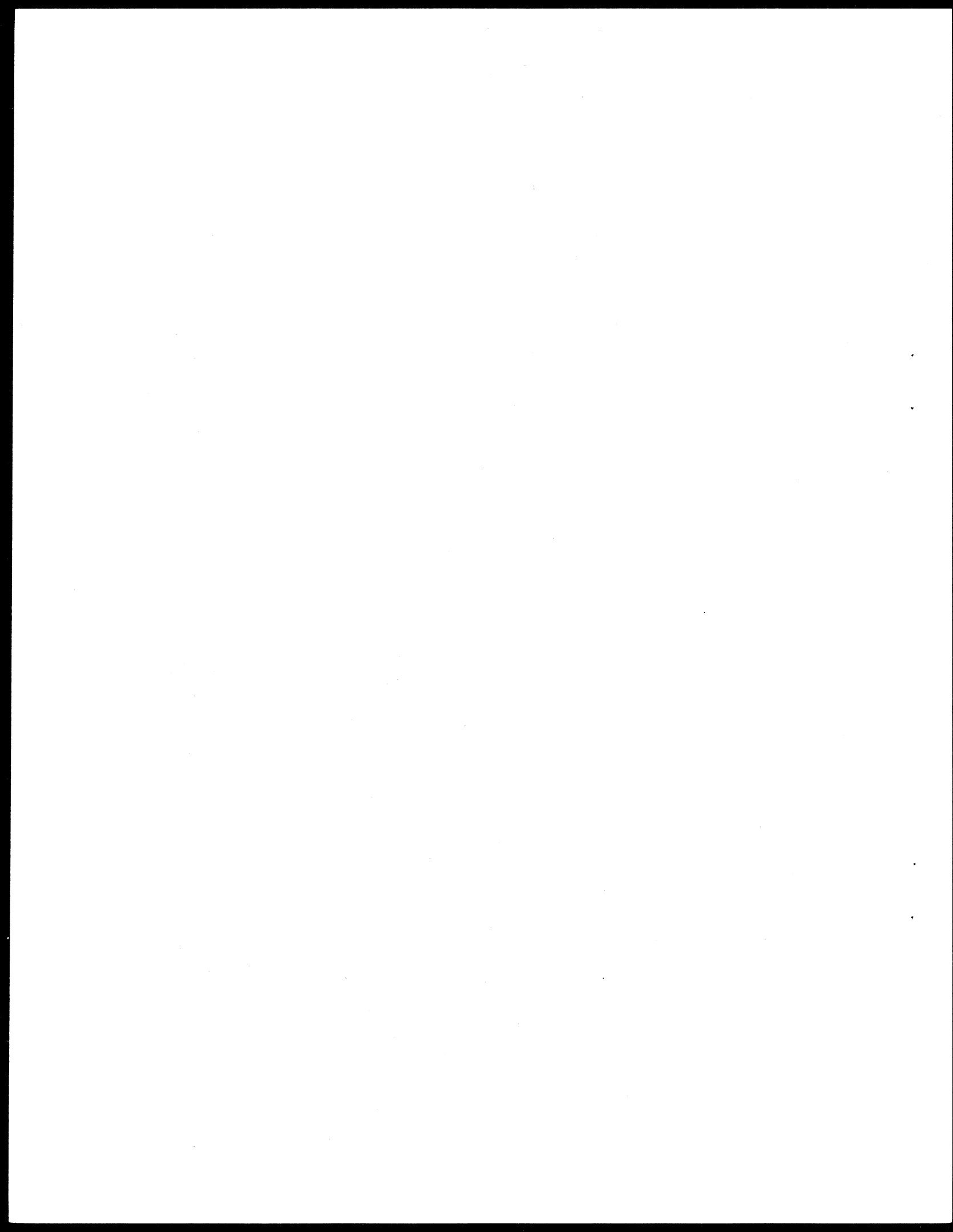
from observed inputs and outputs, thus (in principle) no prices are required. The index used here was developed by FGLR (1989); it is the geometric mean of two (theoretical) Malmquist productivity indexes as defined by Caves, Christensen and Diewert (1982). Since the computational form of the Malmquist index is fairly new (the first published paper to appear using this index was FGLR (1992)), we provide a brief description below.

In order to formalize the Malmquist index, we start by defining an output distance function, which was introduced into economics by Shephard (1970). Let $x^t = (x_1^t,...,x_n^t,...,x_N^t) \epsilon R_+^N$ denote a vector of inputs at time $t=1,...,T$ and let $y^t = (y_1^t,...,y_m^t,...,y_M^t) \epsilon R_+^M$ denote a vector of outputs. The technology S^t denotes the set of all pairs (x^t,y^t) such that x^t can produce y^t. Following Shephard the output distance function is defined as (see also Färe (1988))

$$(4.1) \qquad D_o^t = \inf\{\theta : (x^t,y^t/\theta) \epsilon S^t\}.$$

In words, for a given pair of inputs and outputs (x^t,y^t), and given technology S^t, the output distance function is defined as the "maximum" proportional expansion of outputs, keeping $(x^t,y^t/\theta)$ feasible. The fact that the output distance function is the reciprocal of the output-based Farrell measure of technical efficiency can be exploited to easily compute the distance function.

Suppose we are given a panel of inputs and outputs $(x^{k,t},y^{k,t})k=1,...,K$ and $t=1,...,T$, then using this data as coefficients, our reference technology is:

$$(4.2) \qquad S^t = \{(x^t,y^t) : y^t \le \sum_{k-1}^{K} z^{k,t}y_m^{k,t} \qquad m=1,...,M$$

$$x_n^t \ge \sum_{k-1}^{K} z^{k,t}x_n^{k,t} \qquad n=1,...,N$$
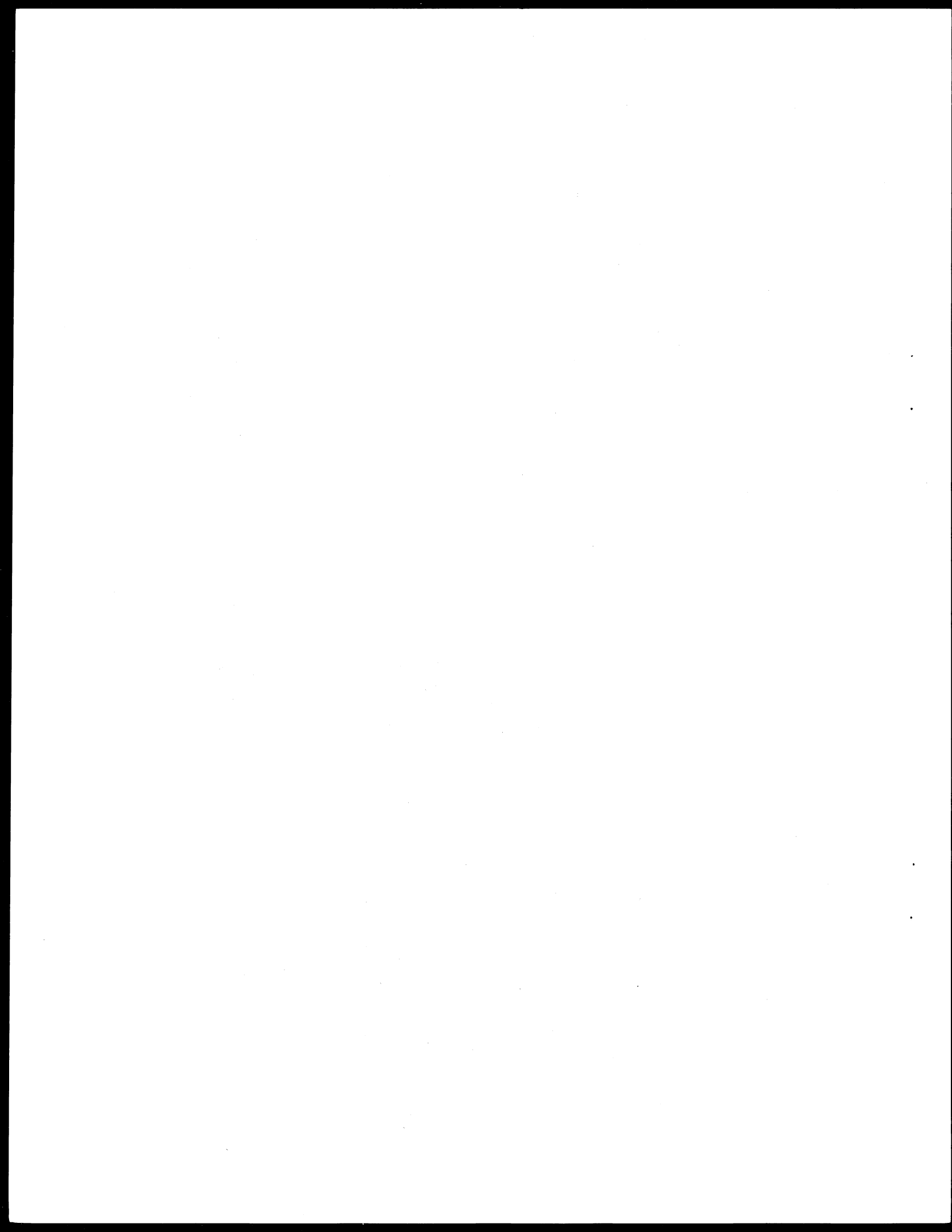
$$z^{k,t} \geq 0 \qquad k=1,\ldots,K\},$$

where $z^{k,t}$ denotes the intensity variables familiar from activity analysis. One can show (Färe, Grosskopf and Lovell 1985, 1994) that the reference technology S^t exhibits strong disposability of inputs and outputs[5] as well as constant returns to scale.[6]

The distance function (4.1) is computed relative to the technology S^t for each observation k', at each t, as the solution to the linear programming problem

$$(4.3) \qquad 1/D_o^t(x^{k',t},y^{k',t}) = \text{Max}\{\theta y^{k',t} : \theta y^{k't} \epsilon S^t\},$$

where S^t is specified as in (4.2), with $\theta y^{k't}$ replacing y^t in the first constraint. In fact, (4.3) calculates the output-based Farrell measure of technical efficiency relative to the common EC-US reference technology. However, since the Farrell measure is the reciprocal of the distance function, the latter is obtained by inverting the solution. We note that since observation k' is feasible, the distance function (4.3) is less than or equal to one, where one indicates Farrell efficiency.

The above distance function $D_o^t(x^{k',t},y^{k',t})$ must be computed for each $k'=1,\ldots,K$ and $t=1,\ldots,T$. In addition, distance functions of mixed periods are needed to obtain the Malmquist productivity change index. In particular, we define

$$(4.4) \qquad D_o^{t+1}(x^t,y^t) = \text{inf}\{\theta : (x^t,y^t/\theta)\epsilon S^{t+1}\}$$

We note that the input-output vector (x^t,y^t) is from period t while the technology S^{t+1} is of period $t+1$. The computation of (4.4) for observation k' is similar to (4.3) except that the first M and N restrictions have different time periods on the left and right hand sides of the inequalities. Also note that observation $(x^{k't},y^{k't})$ need not be an element of S^{t+1}, thus the corresponding distance function may achieve values larger than one. The last distance function required to define the Malmquist productivity index is similar to (4.4) but the t and
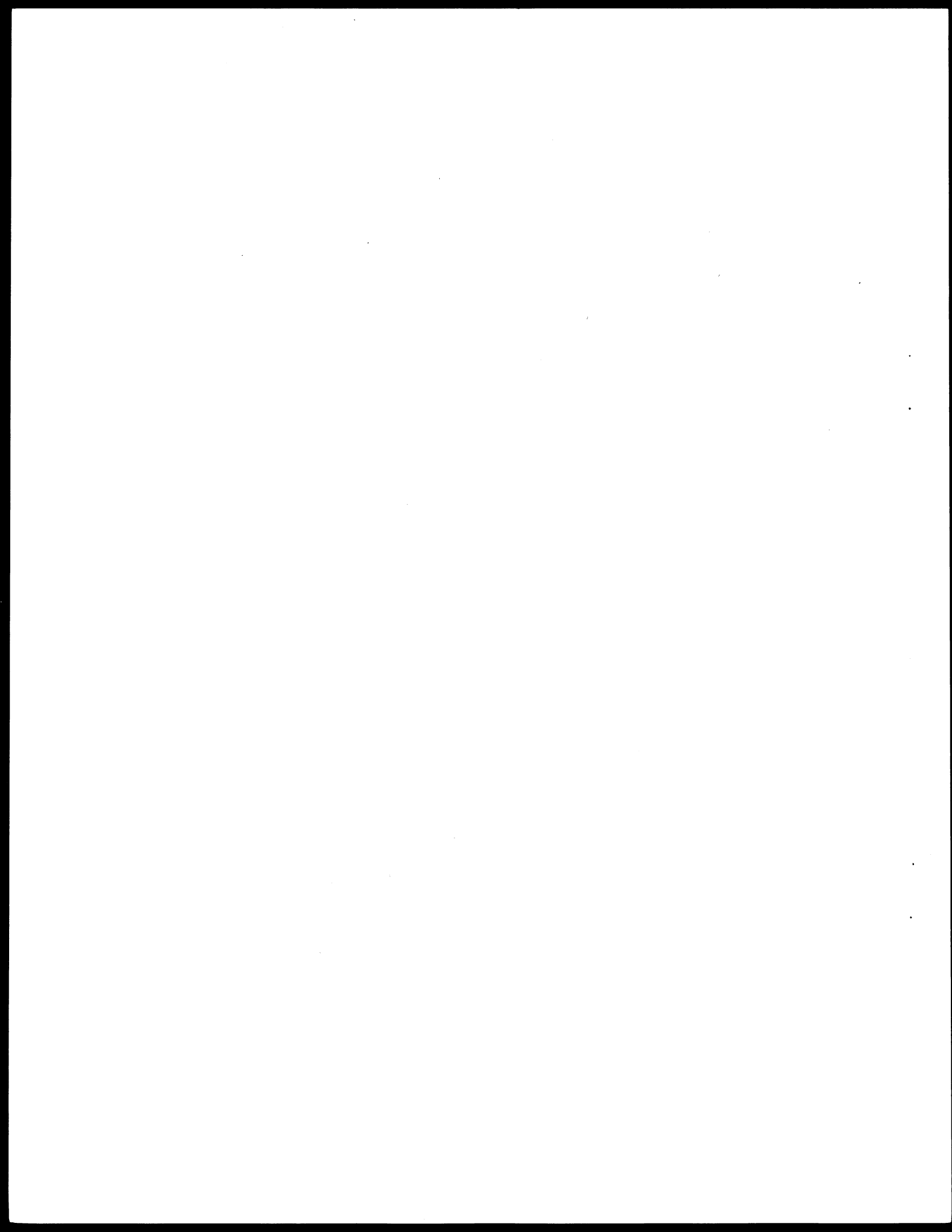
t+1 superscripts are interchanged. (For a more detailed discussion of the computations of the distance functions and Malmquist index see FGLR (1989) or Färe, Grosskopf, Norris and Zhang (1994).)

Following FGLR (1989) we define the Malmquist productivity change index as the geometric mean of two Malmquist productivity indexes as defined by Caves, Christensen and Diewert (1982).

$$(4.5) \qquad M_o^{t+1} = \left(\frac{D_o^t(x^{t+1}, y^{t+1}) D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t) D_o^{t+1}(x^t, y^t)} \right)^{\frac{1}{2}}$$

Note that this index requires only data on (x,y), i.e., quantity data on inputs and outputs. The distance function itself aggregates these inputs and outputs.[7] By computing the above four distance functions for each k=1,...,K and each t=1,...,T, we obtain the Malmquist productivity change index for each country for all periods.

5. Data

The data used in the empirical application which follows is described in Ball, Barkaoui, Bureau and Butault (1994) (hereafter BBBB). The basic sample consists of the agricultural sectors of nine EC countries and the US over the period 1973 to 1989.

The data is constructed on the basis of a list of 64 outputs and 30 inputs. The source of values in national currency and of the time-series price indices for variable inputs and outputs is the COSA data base compiled by Eurostat and the data base of Economic Research Service (ERS) of the US Department of Agriculture. The matching of the European and US accounts is made on the basis of European definitions and rules of accounting, described in Eurostat (1987).
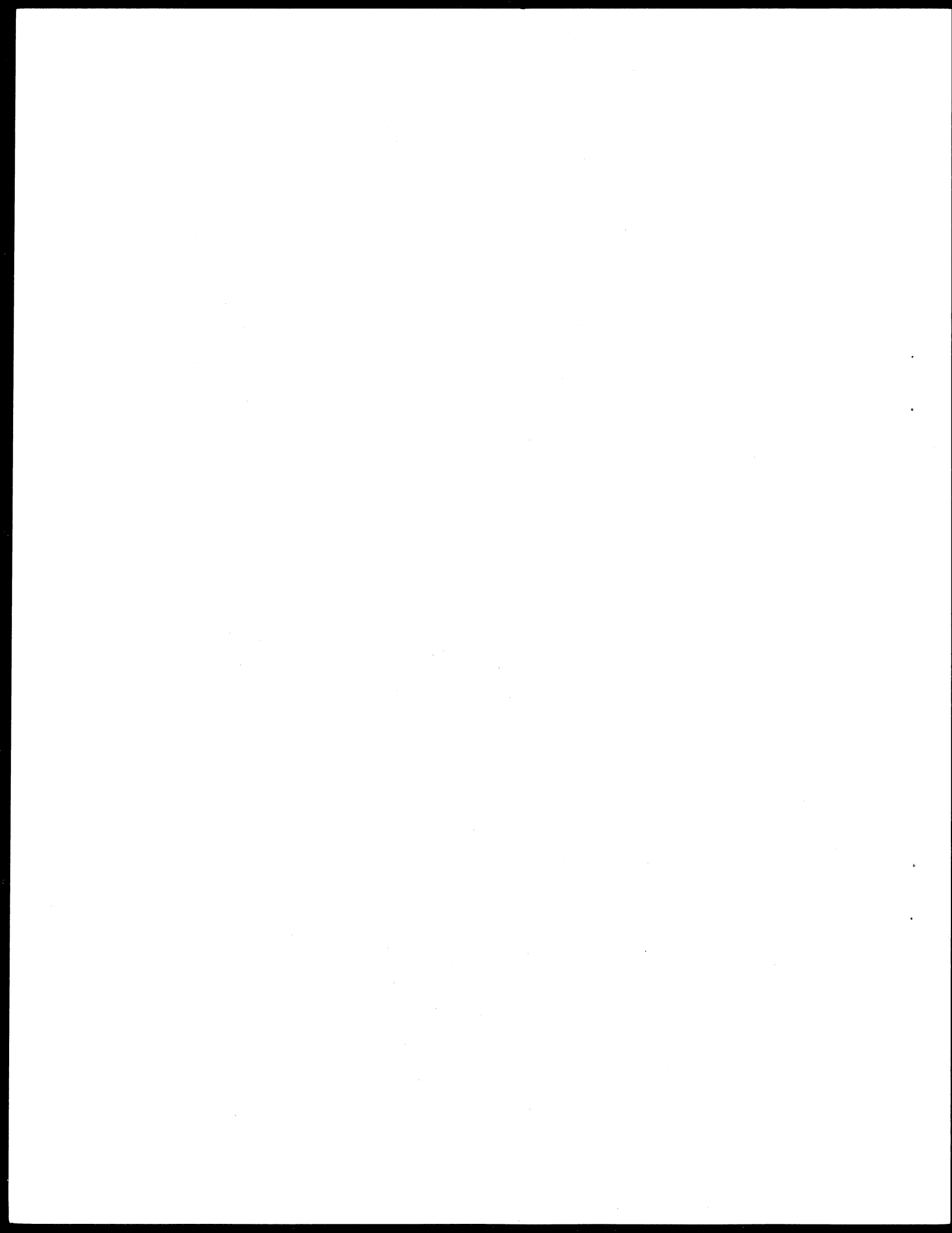
The quantity of service flows is assumed to be proportional to "productive" stocks of capital, i.e. stocks taking into account physical depreciation of assets (these stocks should not be confused with the stocks at replacement value, since economic depreciation only corresponds to physical depreciation if depreciation follows a geometric rate). The perpetual inventory method is used to accumulate past investment for machinery, transportation vehicles, and buildings. The function relating efficiency to the age of assets is approximated by a rectangular hyperbola. Decay parameters, age distributions and service lives are identical in all countries. These parameters as well as a detailed description of the construction of productive stocks, can be found in Ball, Bureau, Butault, Von Witzke (1993).

The user cost of capital is constructed as the sum of economic depreciation and returns to the stock of capital (at replacement value). The expected real rate of return is measured as the nominal interest rate relative to the price of capital and is forecasted using an ARIMA. The construction of user costs follows the methodology perferred by Coen and is described in BBBB.

Stocks of animals are constructed using annual censuses on the number of animals (Eurostat and National Agricultural Statistical Service, NASS) and unit values from Farm Accounting Data Network in Europe and from NASS and ERS in the US. Only adult reproducers are considered as capital. Service flows are assumed to be proportional to the stock at the replacement value due to the lack of data for constructing a productive stock in the EC (Ball and Harper (1990)).

The quantity of land is the acreage used by farmers. The user cost is constructed as the sum of interest on the debt share of owned land (i.e., cash interest charges for land) plus land taxes and land rents.
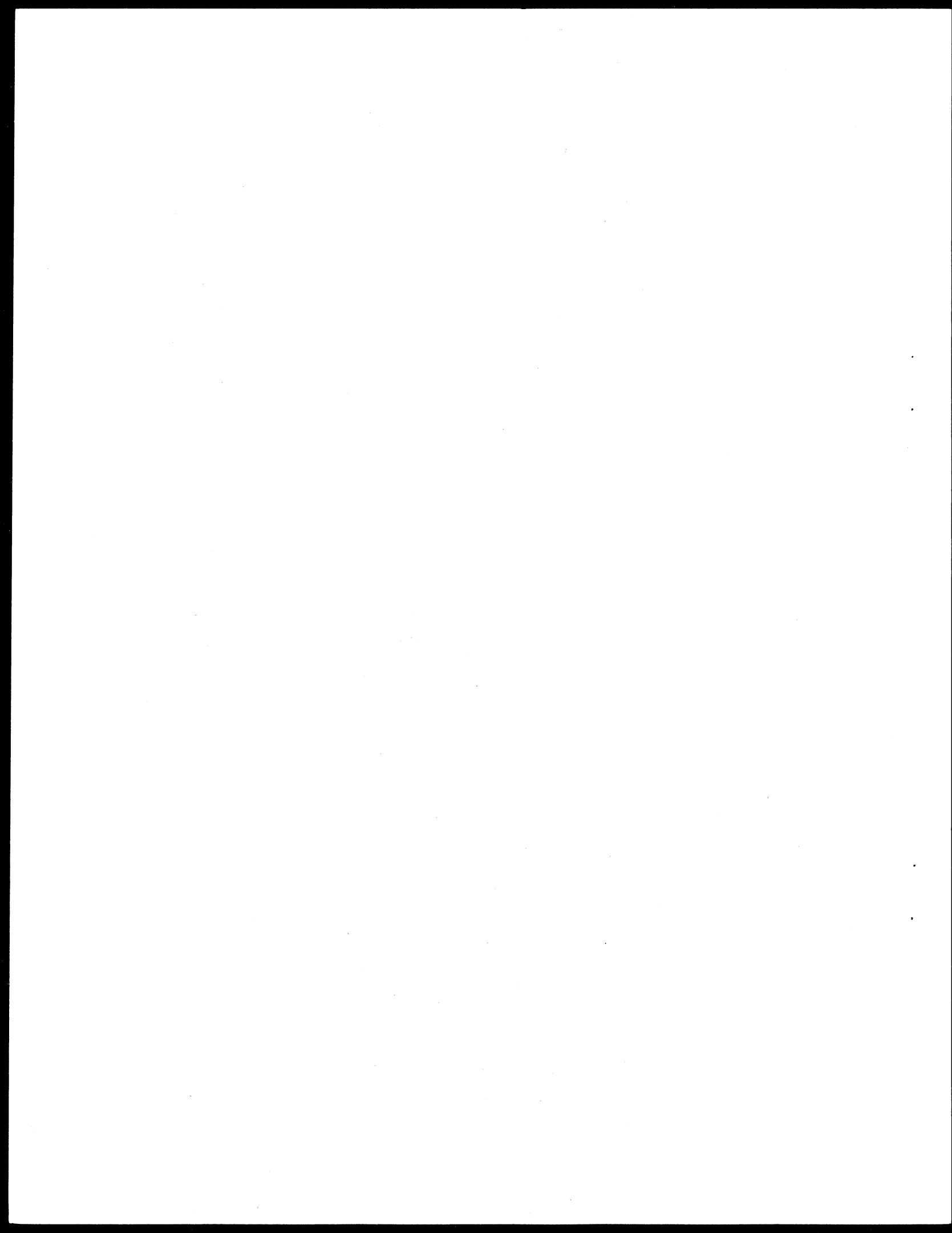
For the European community, the quantity of labor is an estimate of the number of hours worked, expressed in Annual Worker Units (AWU). This crude measure does not correct for quality differences. Although more refined data has been developed by Gollop and Jorgenson (1980) for the United States, AWUs have also been used in order to be consistent across countries. The labor price is the average wage rate in the agricultural sector.

The same data sources are used for the Hulten version of the Fisher index and for the Malmquist index. As discussed earlier, the Hulten index differs from the long-term equilibrium Fisher index in that the price of family labor is imputed as a residual quasi-rent rather than wage rates.

The Malmquist index does not (in principle) require data on input or output prices. For computational purposes, we would like to restrict the number of goods used in constructing the distance function to be less than the number of observations, thus we aggregate all intermediate inputs and all outputs into two quantity indexes. Machinery, buildings and animal stocks are kept separate in order to avoid making restrictive assumptions on user costs. Therefore, the Malmquist productivity index is constructed with one output and six inputs (intermediate inputs, land, labor, machinery, buildings and animal capital).[8] For land and labor, physical quantities are used directly (hectares for land, AWUs for labor, see above). For the other goods, these quantities are quantity indexes that are obtained by deflating nominal values in two dimensions, space and time.[9]

6. Results

The purpose of this paper is to compare the Fisher, Hulten and Malmquist indexes based on computed productivity in the agricultural sectors of nine EC countries and the US over the period 1973-1989. Before turning to our results and analyzing the differences

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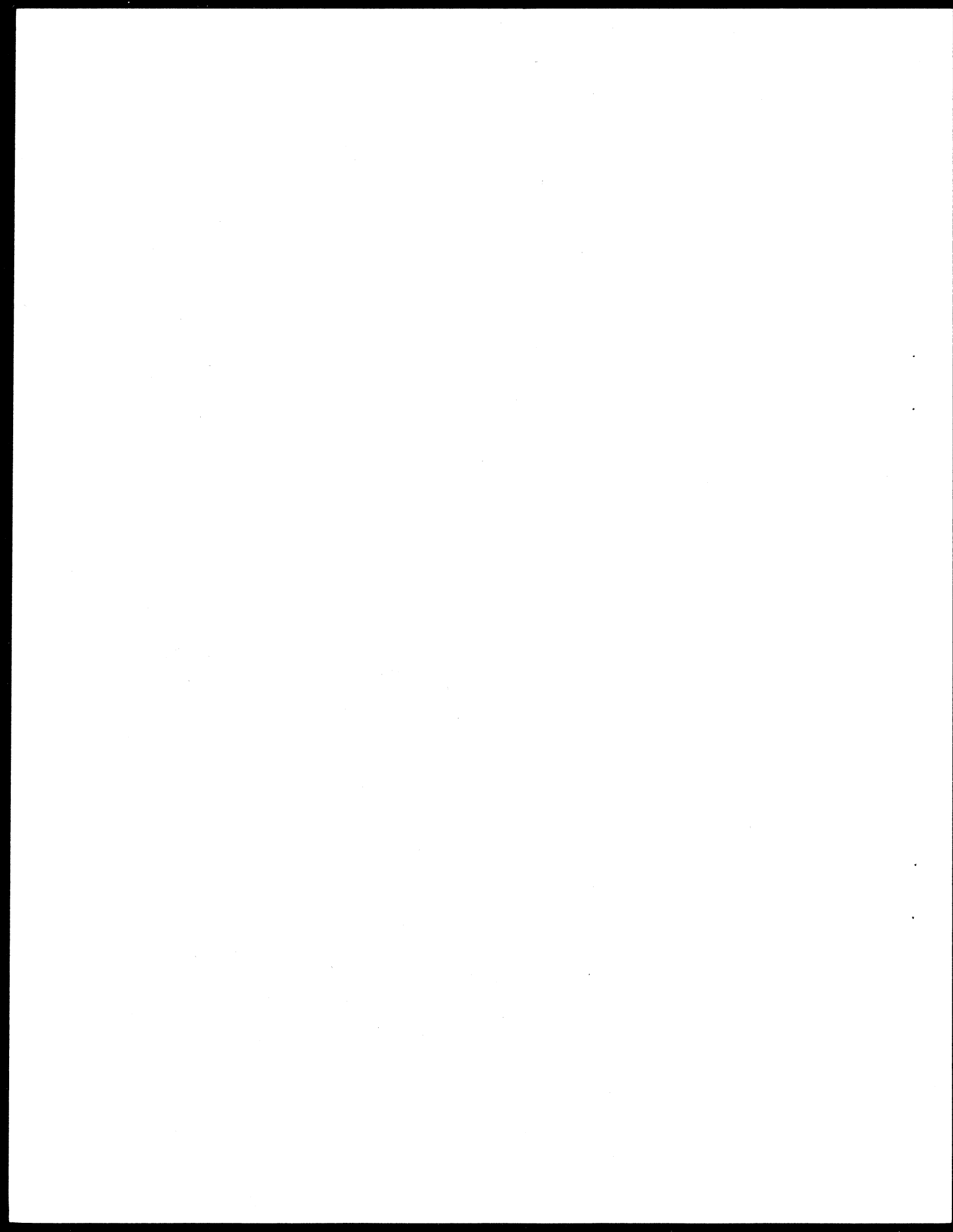
among the three measures, we summarize which assumptions are consistent with each type of measure.

The "Fisher" index as calculated here is consistent with the following assumptions: i) technology can be approximated by a twice differentiable flexible form as shown in Diewert (1992); ii) competitive profit maximizing behavior on the part of the firm in each period; iii) nonincreasing returns to scale; iv) all inputs and outputs can be adjusted to the market price or user cost defined in section 5; and v) user costs defined in section 5 are an appropriate representation of the value of service flows of the quasi-fixed inputs. This implies that anticipated discount rates in the presence of uncertainty are correctly approximated, that depreciation is also correctly measured.[10]

The "Hulten" index is consistent with the following assumptions: i) short run competitive profit maximization for the variable input and freely adjustable output in each period; ii) constant returns to scale; and iii) expected (ex-ante) output and variable input prices are realized.[11]

The "Malmquist" index as computed here is consistent with the following assumptions: i) constant returns to scale; ii) short run competitive profit maximization for the variable input and the freely adjustable outputs. This latter assumption is not part of the construction of the Malmquist index, but is necessary to construct subaggregates for the variable inputs and outputs in order to restrict the number of goods when estimating the frontier.

Based on these assumptions, we would expect the Malmquist index to be least likely to be ' biased', since it does not require input shares to be computed, at least in theory. In practice, shares are computed to aggregate inputs and outputs to subaggregates. The Fisher and Hulten indexes rely on further aggregation using factor shares, however. We would

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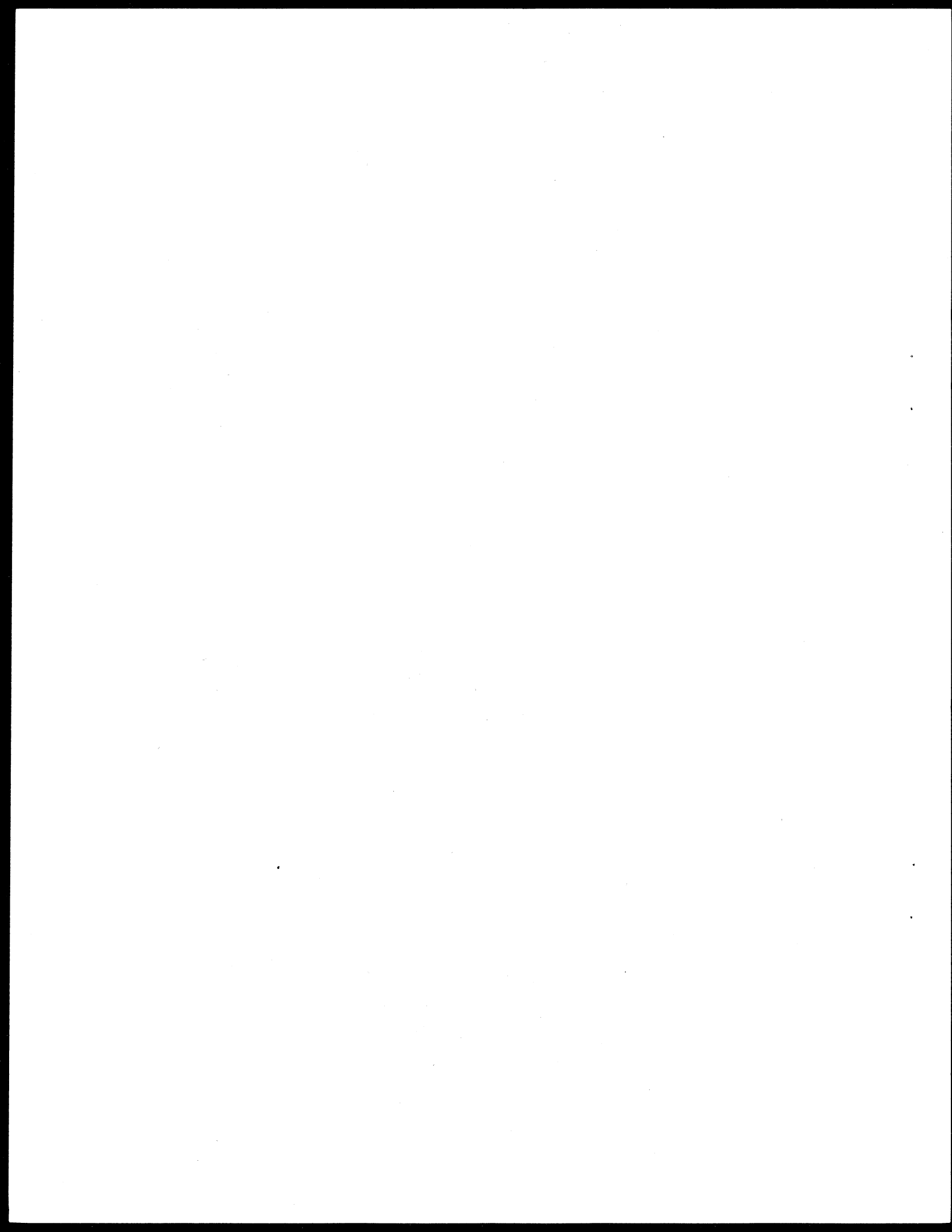
expect the Hulten index to be more flexible (and closer to the truth) than the Fisher index since it adjusts for capacity utilization of quasi-fixed factors. That conclusion is conditional on that adjustment being correct, however.

Before turning to the comparison of our three indexes, we first include a few remarks concerning the general patterns we observe in terms of productivity growth across countries and time in our sample. We note that our indexes all are normalized to unity in our first year, 1972-73, and that the figures depict cumulated productivity.

The three indexes are displayed in Figures 1-10 for the period 1973-1989. The EC countries in our sample (Germany, France, Italy, the Netherlands, Belgium-Luxembourg, UK, Ireland, Denmark and Greece) are displayed in Figures 1-9, the US is in Figure 10. The index labeled "Fisher" is our long-run equilibrium index (see Section 2), the index labelled "Hulten" is our short-run index (see Section 3), and the index labeled "Malmquist" is our distance function index (see Section 4). A quick glance at Figures 1-10 highlights the remarkable similarity in productivity growth patterns across our three indexes for every country in our sample. Although there are differences in the absolute magnitudes of growth rates (which we discuss later), the similarity in patterns is striking. This is all the more remarkable given the very different computational techniques (linear programming) employed to calculate the Malmquist index. Thus we begin our discussion of our results by focusing on the patterns of productivity growth by country before discussing differences across the indexes.

Almost all of the countries in our sample show a decline in productivity toward the beginning of the time period (1972-1973 is our starting point), perhaps reflecting effects of the early oil shocks. Almost all also show a dip in productivity in 1983, especially in the U.S. which experienced a severe drought. Otherwise, the general pattern is one of
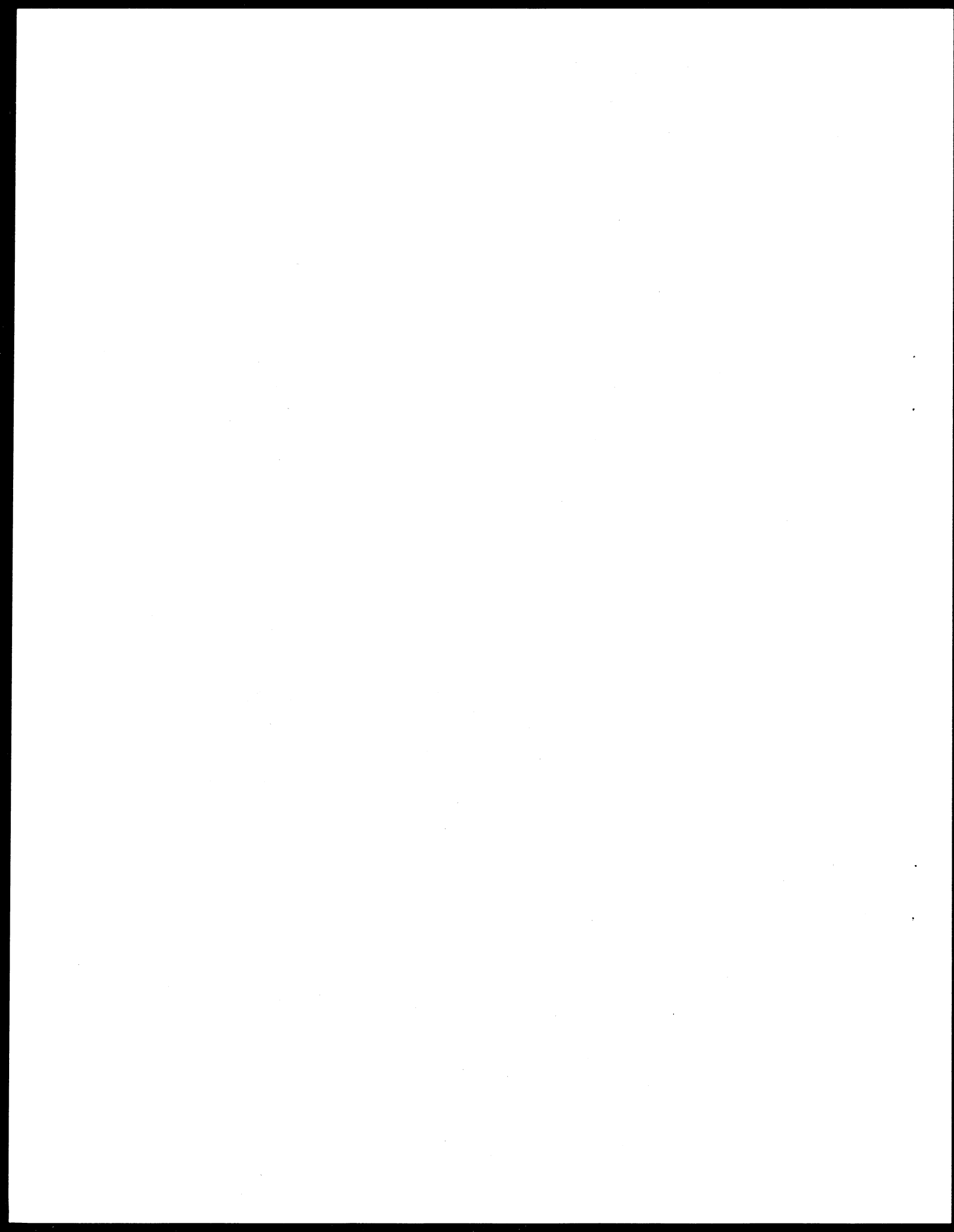
productivity growth (Germany shows a seesaw pattern from about 1981 onward, but the average trend is increasing). Cumulated growth by 1989 ranges from a low of around 2% (Belgium and Luxembourg) to a high of about 7% (Denmark). The U.S. falls toward the bottom of this range with cumulated growth of about 3%. For a more detailed discussion of the cross-country differences based on the Fisher index (using this data), see BBBB.

We now turn to the main focus of this paper, the comparison of the three indexes for our sample. We being by focusing on the relationship between the Fisher and the Hulten index. Empirically, the most obvious reason for observing differences is that the two use different prices for family labor in computing labor shares: the Fisher uses the wage rate and the Hulten uses ex-post returns (where the latter is intended to adjust for capacity).

In Germany, Denmark and France, where wage rates are high and agricultural incomes are low, the share of labor in total output is larger when family labor is priced using the wage rates (Fisher index) than using the ex-post returns (Hulten index). Therefore, in giving a higher weight to an input which is "shrinking", the Fisher index yields a higher rate of growth in productivity than the Hulten index. This is confirmed by referring to Figures 1, 8 and 2, respectively.

In countries where wage rates are low (e.g. Greece, or Ireland at the beginning of the period), or in which agricultural income per self employed worker is relatively high (e.g. the Netherlands, the United States), the Hulten index gives higher rates of productivity than the Fisher index. The magnitude of the discrepancies between these two indexes depends on the importance of labor in the input combination (high in Greece, but low in the US). It also depends on the rate of decrease in the labor input relative to the other inputs (high in Germany and France, but low in the Netherlands).
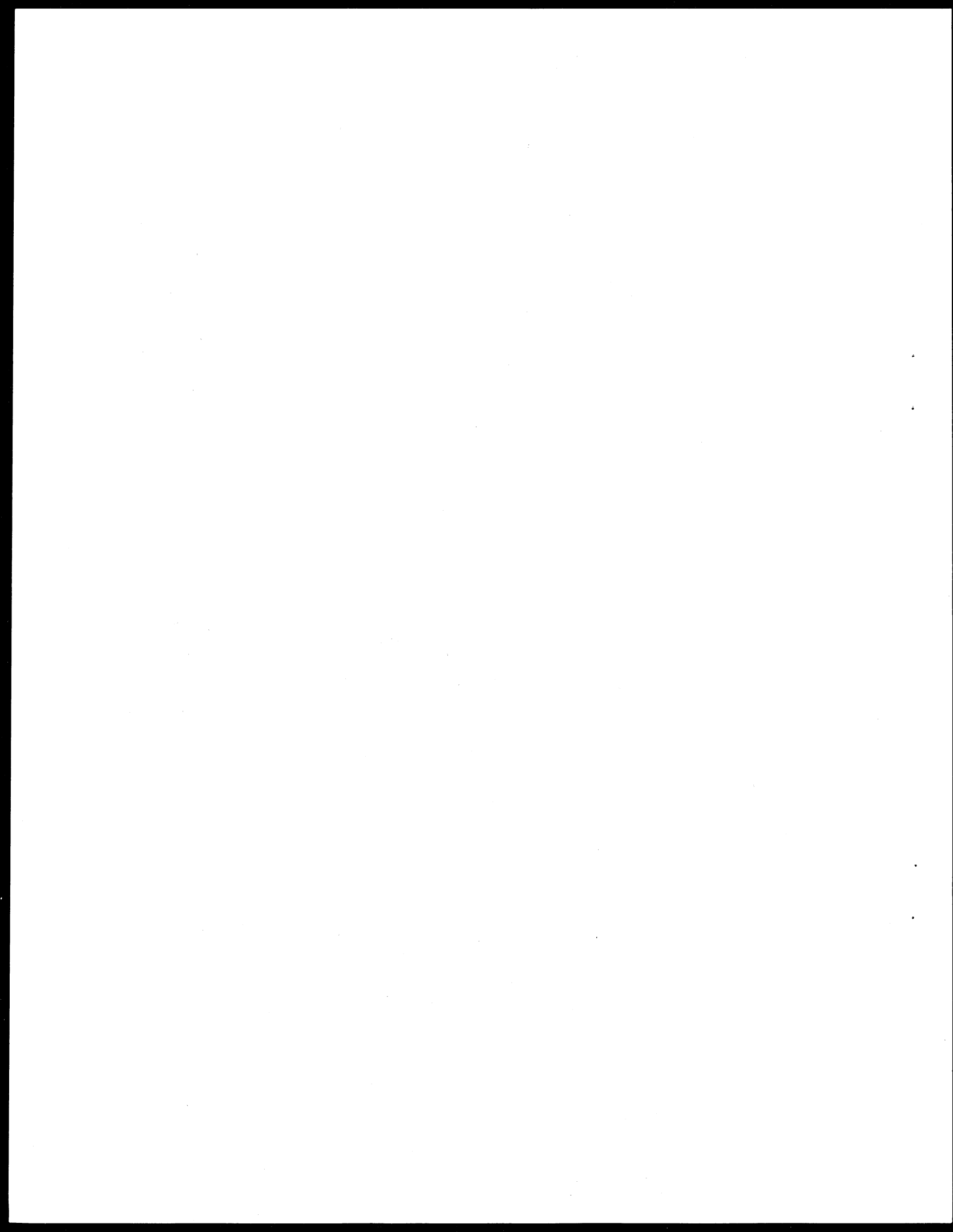
Before concluding that the divergence between Fisher and Hulten indexes is due to the fact that the Hulten index corrects for capacity utilization of labor, whereas the Fisher does not (Hulten (1986), Morrison (1986)), we remind the reader that this depends on the assumption that the ex-post returns to family labor are a correct approximation of the quasi-rents. Climatic variations in agriculture not only involve differences between ex-post prices and ex-ante expectations, but also uncertainty about the production level itself. Due to specific aspects of agricultural production, the Hulten measure may not always provide a satisfactory correction for capacity utilization in this sector.

Turning to the Malmquist index, no factor share is computed, and no weight is given a priori to the change in the level of each input. The implicit weight given by the Malmquist index reflects the contribution of each input to the production process which may not be the market value of the input. Thus we interpret the Malmquist as "correct" with respect to the contribution of quasi-fixed inputs. In the case of Germany, the Malmquist index is close to the Hulten index. This suggests that using the ex-post returns for the family labor corrects for short-run disequilibrium and provides a better measure than using the wage rates. In France, the use of the ex-post returns still leads to an overestimate of the marginal contribution of labor to production. In the case of Greece and Ireland, it seems that the use of ex-post returns increases the bias of the Fisher index, which occurs in approximating elasticities of production with factor shares at the market value.

The differences between the Fisher and Malmquist indexes may also reflect the changes in capital stocks. In Greece and Ireland, the divergence between the Malmquist and the Fisher index occurs in a period when the stock of capital is growing rapidly, and output is constant. Over this period, the average productivity of capital is decreasing. The Malmquist index shows growth rates of total factor productivity that are lower than the
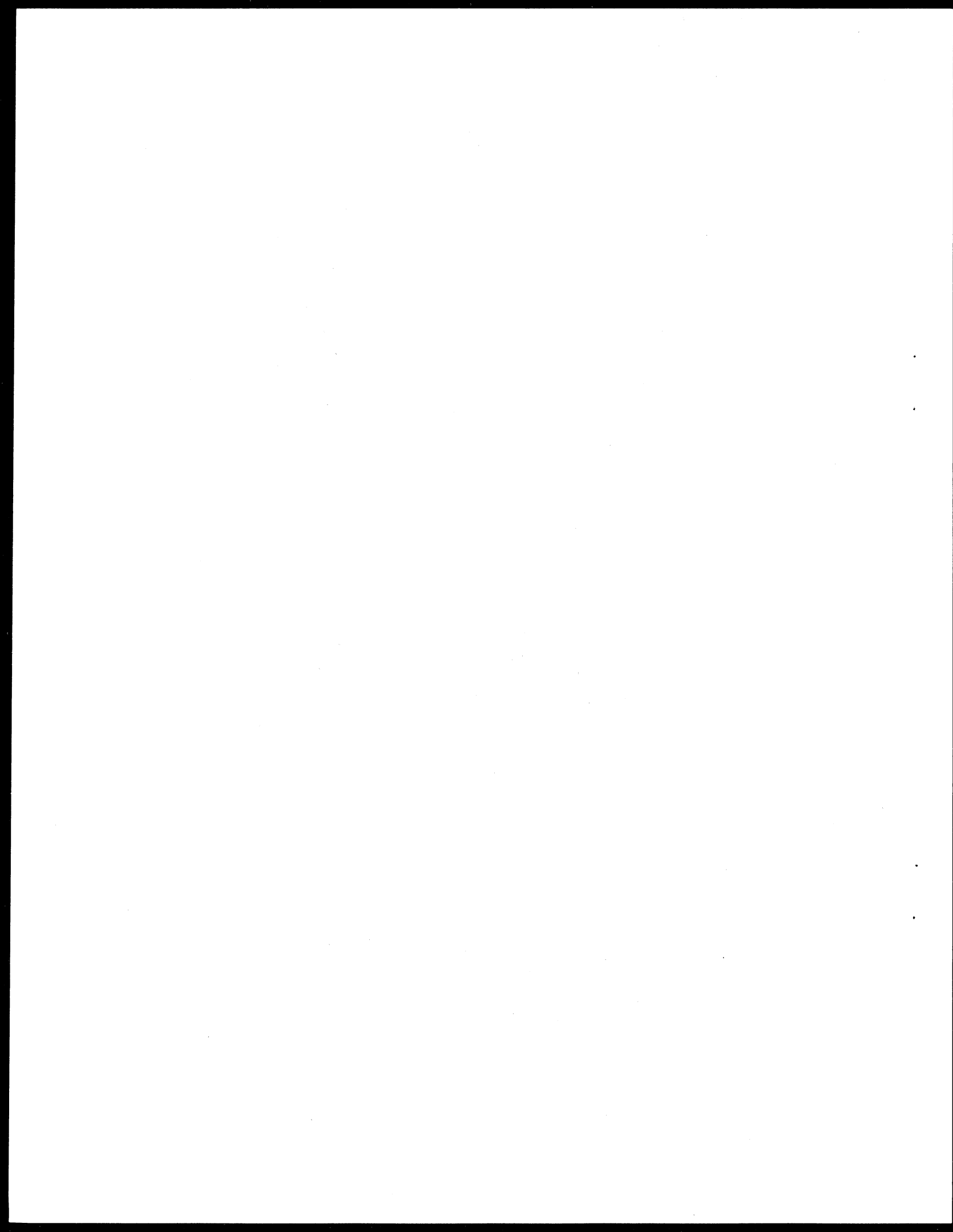
Fisher index. This suggests that the factor shares computed using the user costs (used in the Fisher and Hulten indexes) do not accurately reflect the marginal contribution of capital to production. In France, Italy, Denmark and the United States, the divergence between the Fisher and Malmquist indexes occurs when the stock of capital is decreasing. In these cases, the rate of growth measured by the Fisher index exceeds the rate measured by the Malmquist index for France and Italy, and is lower for Denmark and the US. Although no general conclusion holds on the direction of differences, these results also suggest that the implicit weight given to capital in the Malmquist index is different from the factor shares used in the Fisher index.

The divergence between the Malmquist index and the two other indexes observed in Figures 1 to 10 should not be attributed solely to flaws in the Fisher and Hulten indexes. In spite of the theoretical advantages of the Malmquist index over the Fisher and Hulten, specific problems may arise in the empirical estimation. This may also contribute to observed discrepancies among the indexes. Among the possible explanations for the differences between the Malmquist measure and the others, the sensitivity of the deterministic frontier to data cannot be ruled out. The non-parametric technique used in the construction of the Malmquist index is sensitive to outliers. Because of the data envelopment technique, annual changes in the frontier may be affected by measurement errors, which may have a considerable influence on TFP growth rates. This is emphasized by the chaining of the annual indexes since the chained version of an index is known for accentuating annual shocks. Our results, at least in terms of the pattern of productivity growth suggest that this was probably not a problem for our data given the consistency of these patterns across the three indexes. However, the general problem suggests a direction for future research: comparisons based on a Monte Carlo study.
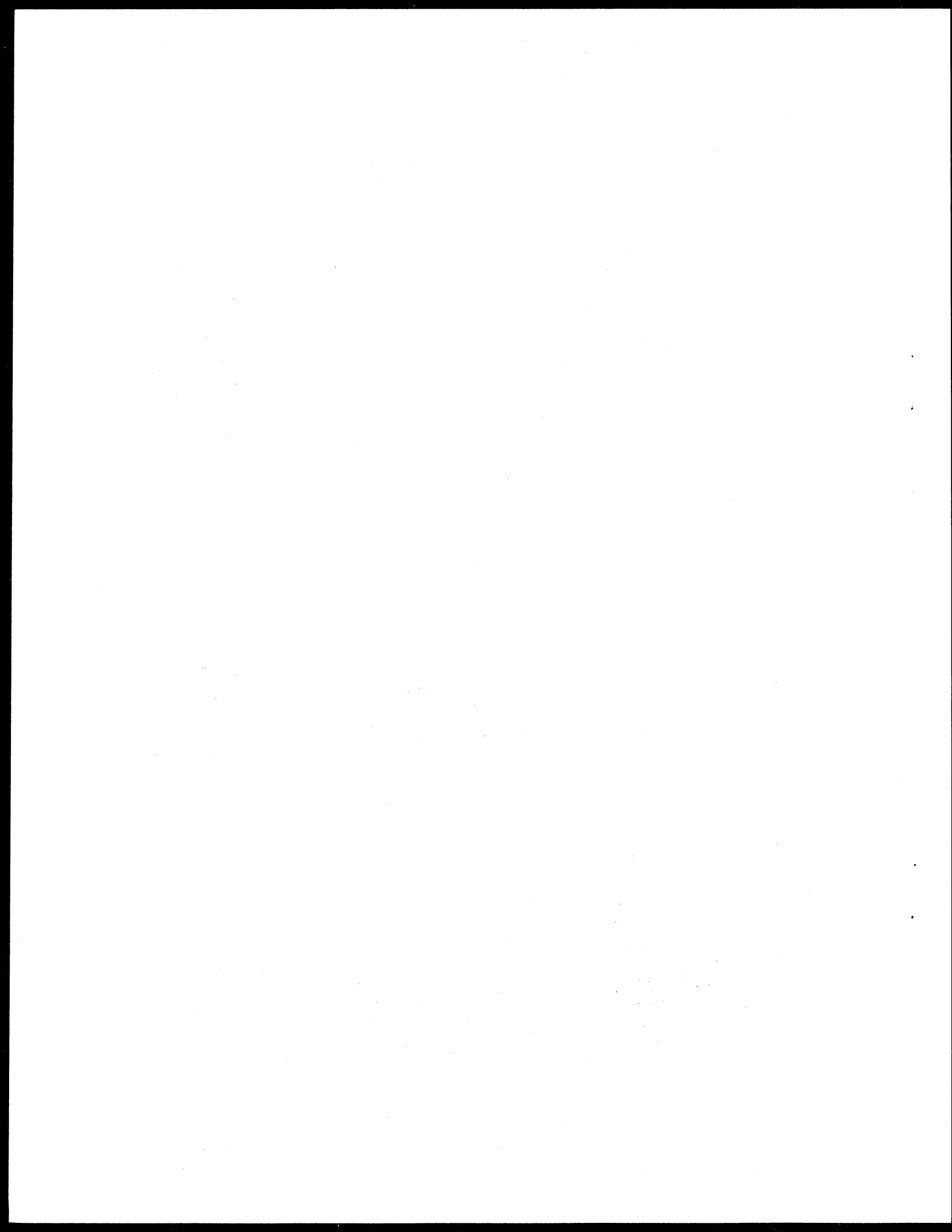
7. Conclusion

In the years between Diewert's 1980 paper and his 1992 paper, the theory of index numbers has progressed dramatically. However, in these two papers, the conclusions about difficulties when dealing with empirical data are very similar: formidable problems remain. Although theory now provides satisfactory grounds for choosing an index number, empirical measures of TFP still run into sensitivity to assumptions regarding quasi-fixed inputs and data availability, while empirical evidence seldom supports a particular choice. Measures of TFP usually differ more between two different conventions on capital using one index than they do between a Fisher and a Törnqvist index, and even between a Fisher and Laspeyres index, using the same data.

A major advantage of the direct estimation of Malmquist index numbers is to avoid empirical problems in the definition of user costs for the quasi-fixed factors. The ability of this method to measure productivity using only data on quantities is a definite advantage. Moreover this approach is consistent with underlying assumptions which are less restrictive than traditional index numbers. Nonparametric estimation of Malmquist indexes is very easily implemented and does not require econometric estimation.

In the empirical application to European and US agriculture, the Malmquist index yields TFP measurements which are remarkably consistent with the two versions of the Fisher index calculated here. The pattern of productivity growth is very similar to that obtained with a Fisher index, despite the very different computational techniques (the Malmquist index computed here employs linear programming). However, absolute magnitudes of cumulated growth rates differ. Theory suggests that the growth rates measured by the Fisher index may suffer from bias due to the equilibrium assumptions when using user costs for the fixed factors. They may also suffer from inaccurate assumptions
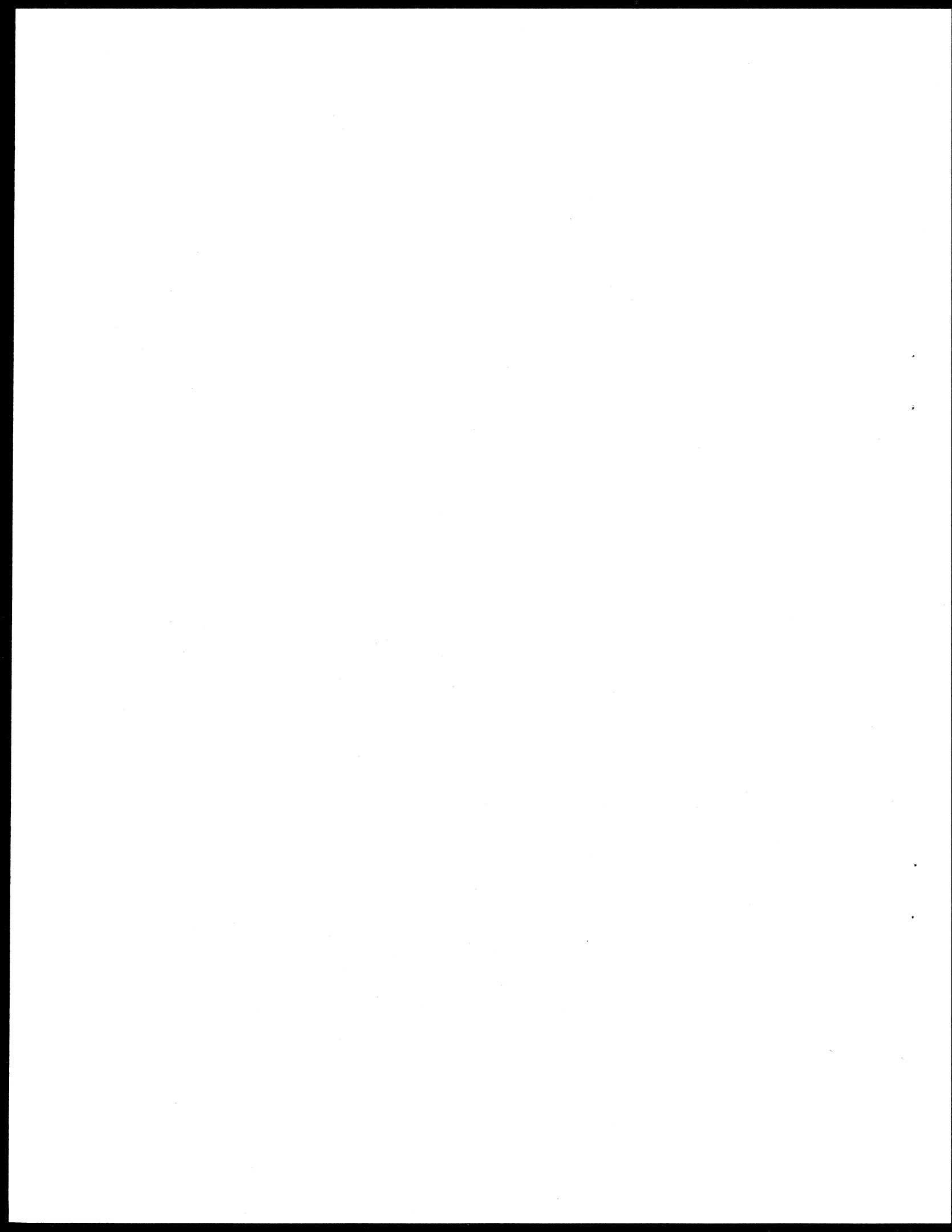
made when computing these user costs. The main limitation of the Malmquist index is that the construction of deterministic frontiers makes the method proposed in this paper sensitive to outliers (again, the consistency of the indexes with each other suggests that this was not a problem for our data set). However, the use of a Malmquist index should be restricted to high quality data. Another flaw of the nonparametric estimation of the Malmquist index (as well as the Fisher and Hulten index) is that the classical tools of statistical inference cannot be used, and few indicators of the quality of the estimation are available. Although it is always possible to construct Malmquist indexes using econometric methods instead of nonparametric methods, one of the main advantages of the index number approach, which is to avoid econometric estimation, would disappear.
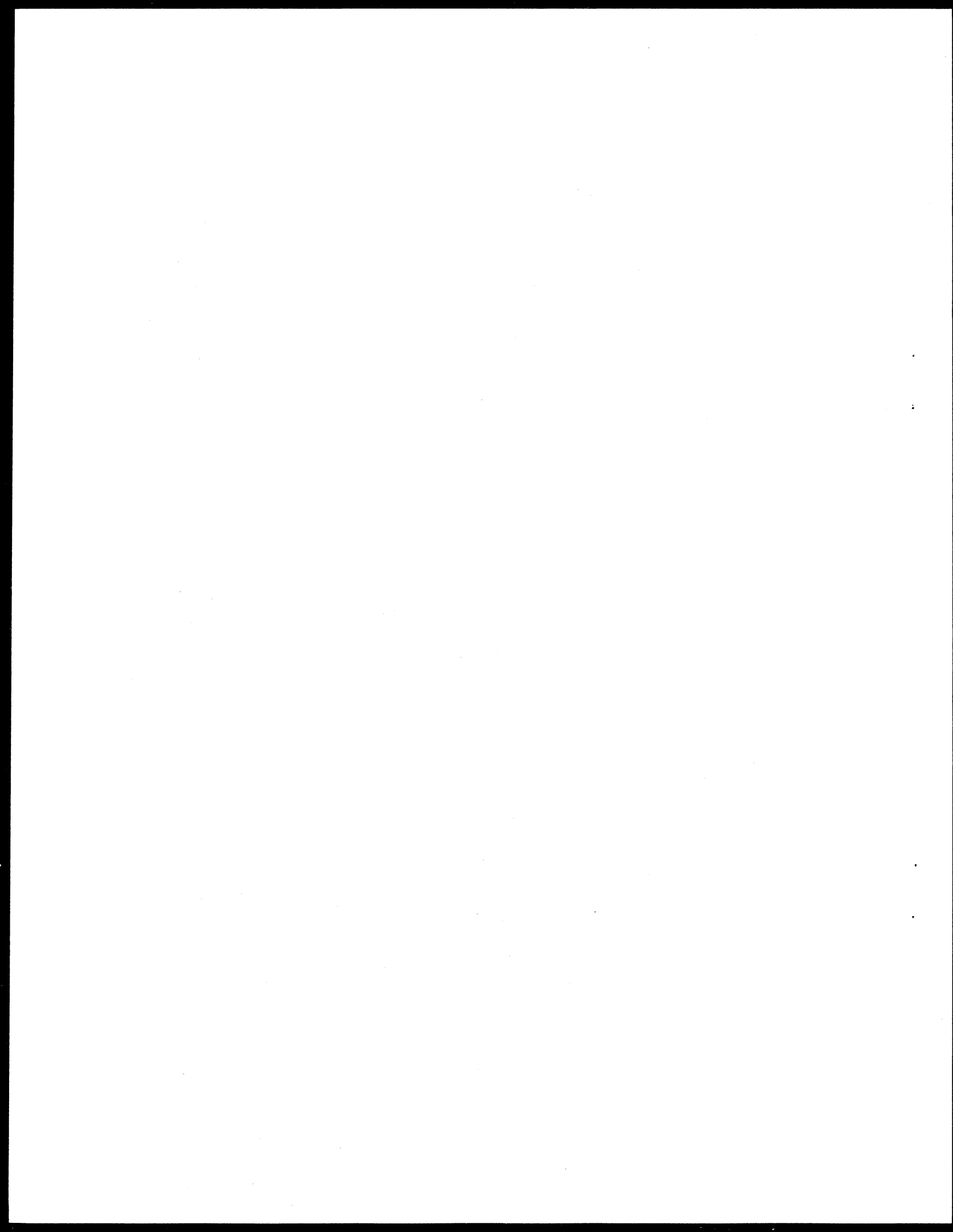
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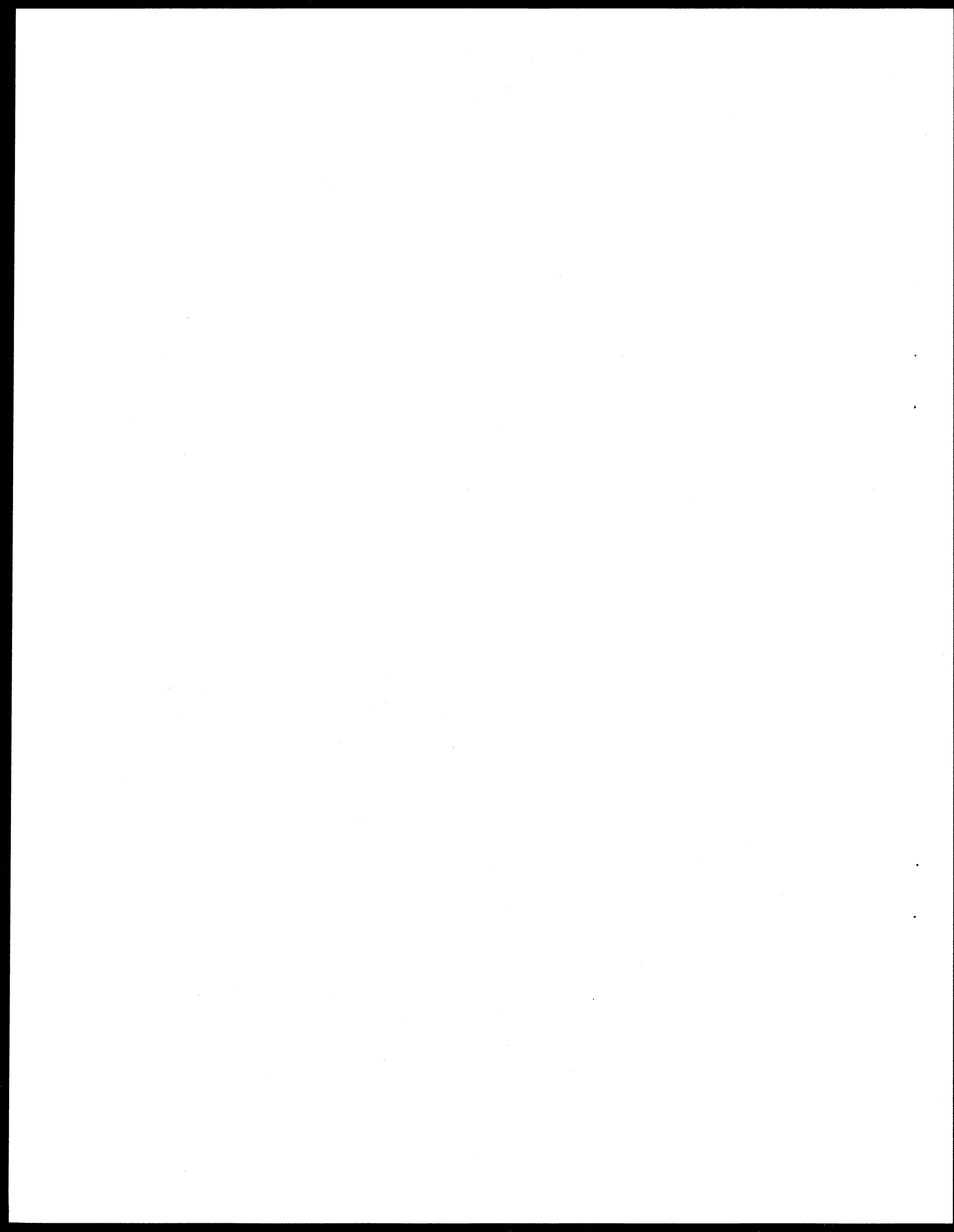
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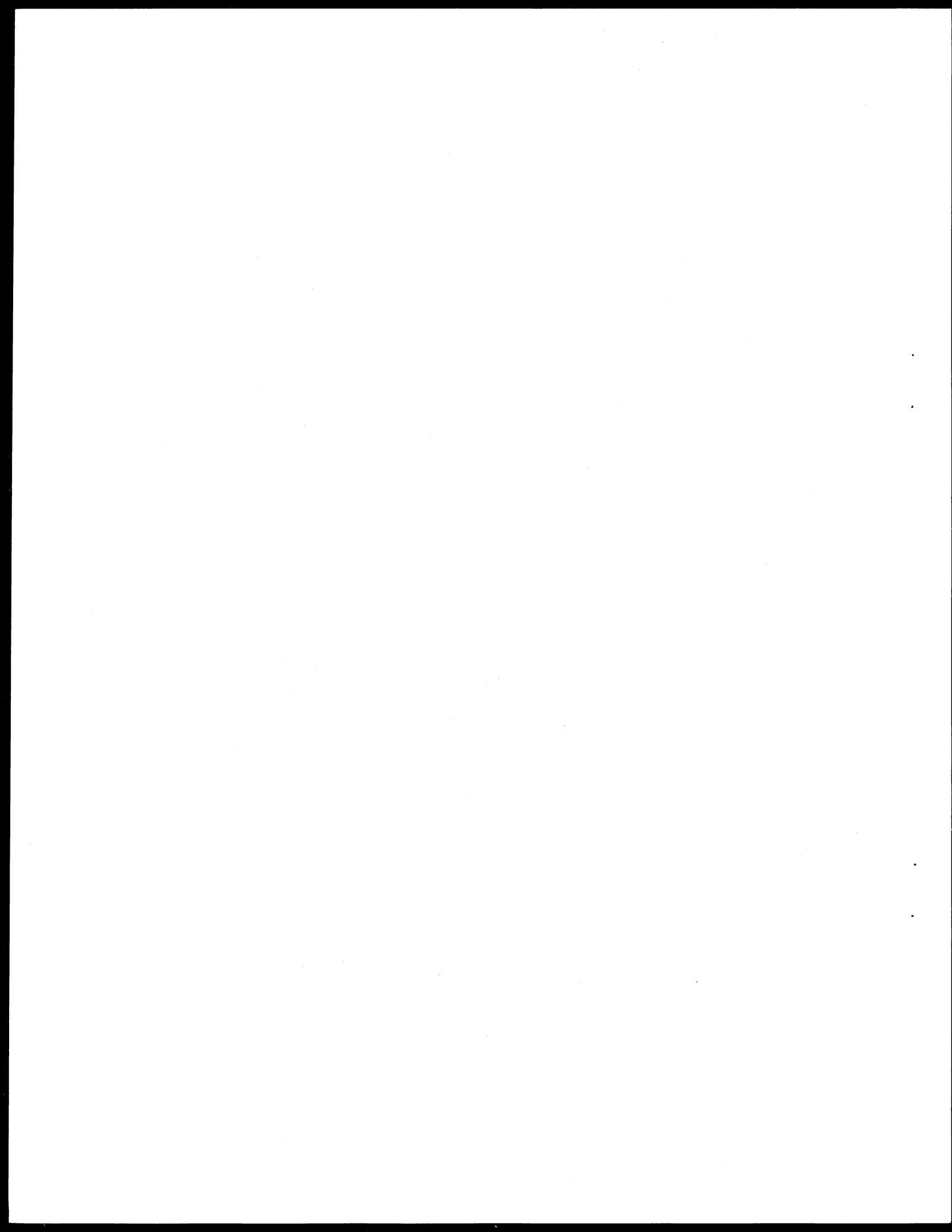
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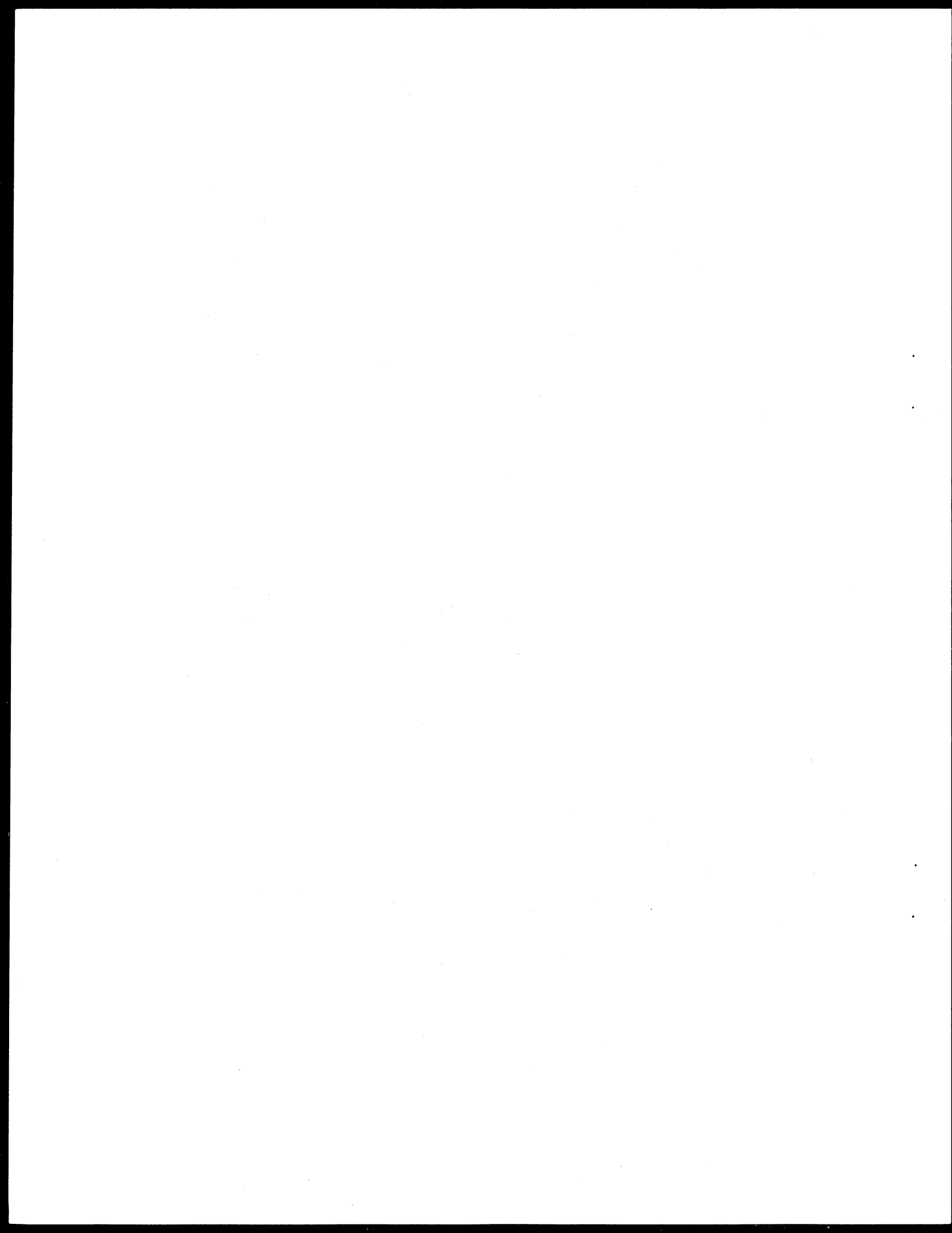
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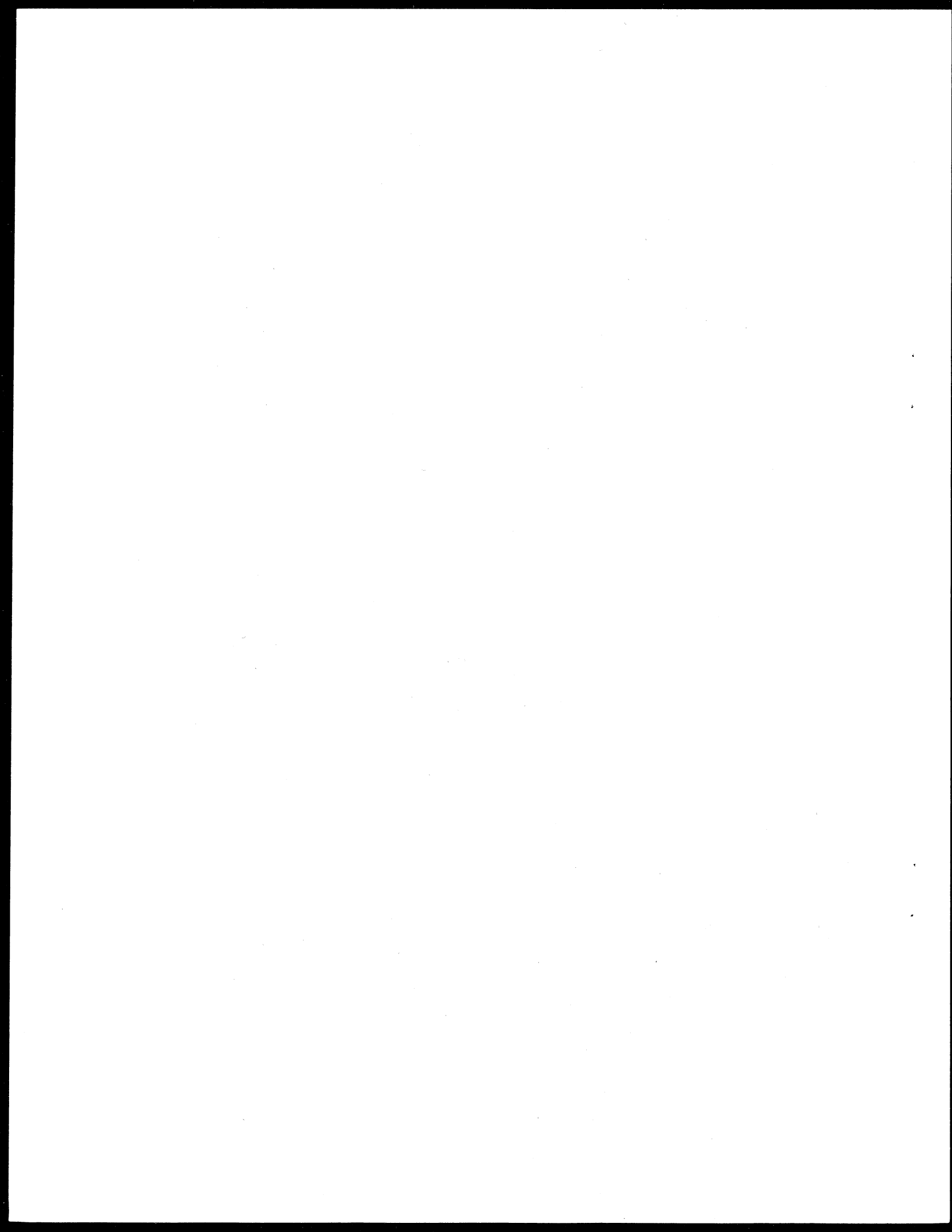
Footnotes

1. For capital, it is still necessary to aggregate different assets according to their productive ability, i.e., to construct a productive stock, but the problem of user costs can be avoided.

2. Caves, Christensen and Diewert (1982) used distance functions to define a "theoretical" productivity index which they approximated by an empirical formula (the Törnqvist index), which requires data on shares to aggregate inputs and outputs (the distance function does not require share data).

3. However, this approach requires panel data in order to construct (meaningful) frontiers of the possibility set. In addition it is desirable to limit the number of inputs and outputs to a dimension less than the number of observations in the set. This requires the construction of time series quantity indexes, but also of "spatial" quantity indexes. In international comparisons, these spatial (i.e., cross countries) quantity indexes can be constructed from input and output values (in national currencies) using international price indices, called "Purchasing Power Parities" or PPPs. These PPPs must be specific to each of the aggregates considered. They should not be confused with the PPPs used by international organizations which are constructed for the National Accounts.

4. This assumption of a residual remuneration of family labor is supported by several empirical studies which show that family labor is the less mobile of the quasi-fixed inputs (Vasavada and Ball (1988)).

5. Inputs are strongly disposable if $(x,y) \epsilon S$ and $x^* \geq x$ imply that $(x^*,y) \epsilon S$. Outputs are strongly disposable if $(x,y) \epsilon X$ and $y^* \leq y$ imply that $(x,y^*) \epsilon S$. Strong disposability
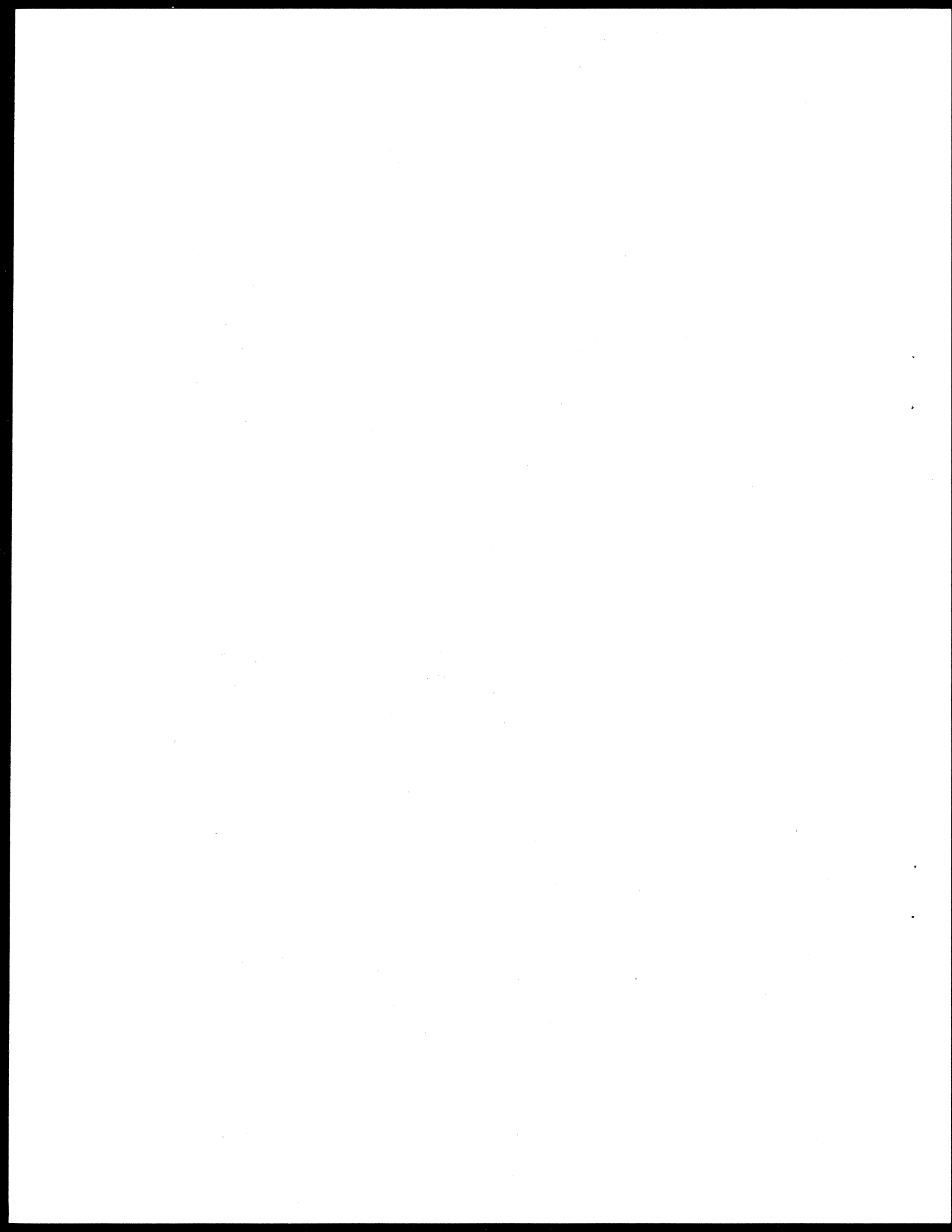
may be relaxed to weak disposability if desired. See Färe, Grosskopf and Lovell (1985, 1994).

6. The technology S exhibits constant returns to scale if it is a cone, i.e., if $\alpha S = S$, $\alpha > 0$. Constant returns to scale may be relaxed, see Färe, Grosskopf and Lovell (1985, 1994).

7. This index can be decomposed into two components, one measuring technical change and one measuring change in efficiency, namely:

$$M_o^{t+1} = \frac{D_o^{t+1}(x^{t+1},y^{t+1})}{D_o^{t}(x^{t},y^{t})} \left(\frac{D_o^{t}(x^{t+1},y^{t+1})D_o^{t}(x^{t+1},y^{t+1})}{D_o^{t+1}(x^{t},y^{t})D_o^{t+1}(x^{t},y^{t})} \right)^{\frac{1}{2}}.$$

The first ratio on the right hand side measures the change in efficiency between t and t+1. The second expression is the measure of technical change. In particular, it takes the geometric mean of the change in technology at t and t+1.

8. Färe and Grosskopf (1992) have demonstrated that when convexity, constant returns and profit maximization hold, the Malmquist productivity index corresponds to the Fisher index. The two indexes are related through the duality between distance and support functions. Balk (1993) generalized their result and shows that under rather weak assumptions the two indexes are approximately equal. Therefore, whenever inputs and outputs can be reasonably assumed to correspond to the profit maximizing levels, they can be aggregated into a single good using a Fisher index and be included in the Malmquist index.

9. In the space dimension, i.e., across countries in a given year, real values are constructed by deflating nominal values (in national currency) with a spatial price
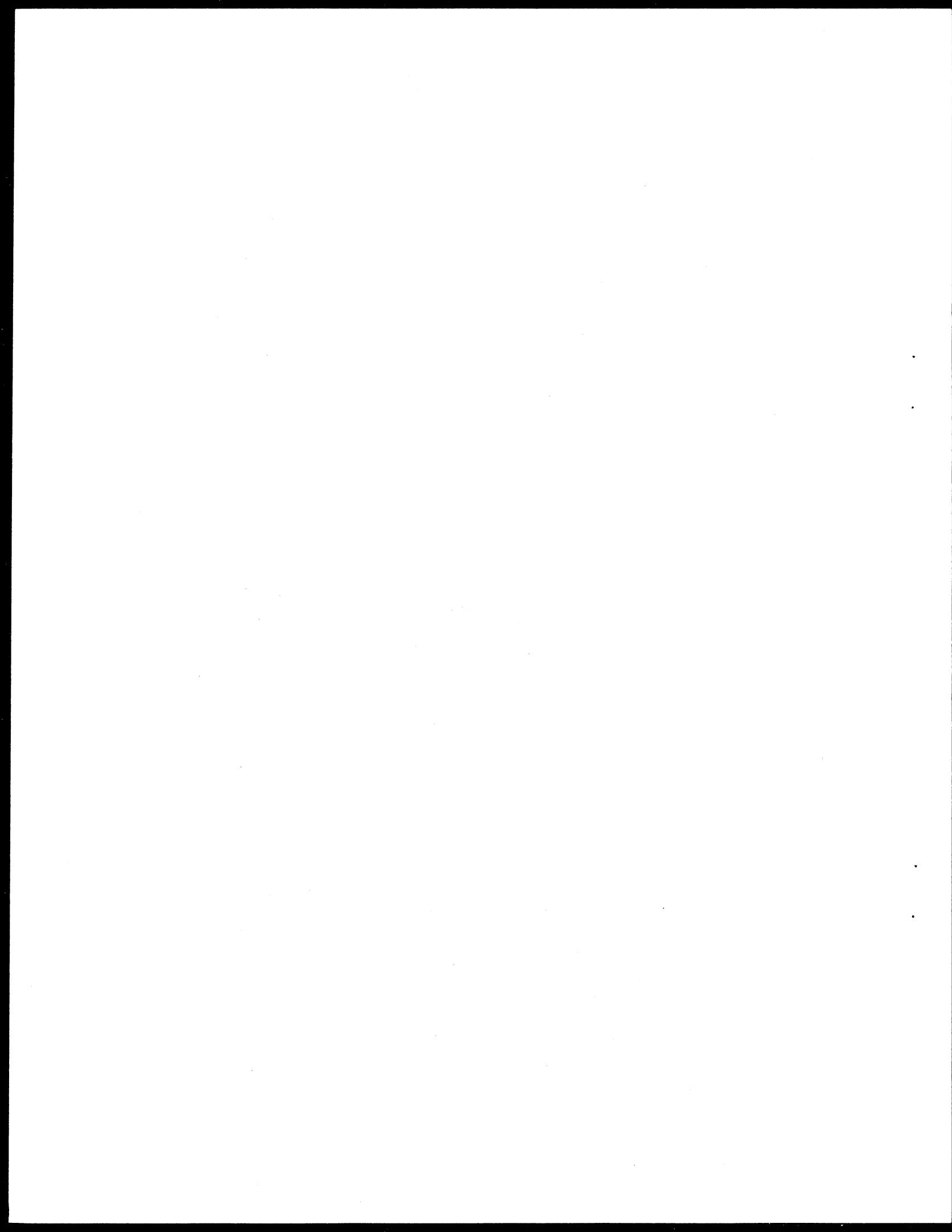
index. This spatial price index is an index of the rate of PPP for the considered aggregate, with a base 1 for the aggregate Community. Therefore, real values in 1985 are constructed in converting nominal values into a common currency with an exchange rate which corrects for difference in the level or prices between countries. In the time dimension, Fisher quantity indexes base 1 in 1985, are used to extrapolate the 1985 real values between 1973 and 1989. PPPs are constructed using an EKS (Eltetö and Köves, Szulc) index number. The source of nominal values and of the time series deflator is the national accounts, as stated in section 5. The PPPs used for the spatial deflation come from BBBB. These PPPs are computed for the specific list of inputs and outputs used in constructing the Malmquist index. Productive stocks of capital are used as a measure of physical quantity. Productive stocks of machinery, buildings, animals stocks are converted into a common currency using the PPPs for the particular item, as described in Conrad and Jorgenson (1985). The source of PPPs for gross formation of capital in the agricultural sector is unpublished data provided by Eurostat for buildings and machinery. The EKS index is presented in a more accessible literature in Eurostat (1983) and Gerardi.

10. If the technology is not putty-putty, i.e., factor combinations cannot be freely adjusted after quasi-fixed inputs are purchased (for example that ex-post complementarity exists between factors), the user cost of capital is not independent of the price of other inputs. The assumption of a putty-putty technology is necessary for the derivation of Jorgenson's (1963) expression of user cost.

11. If iii) does not hold, the ex-post unit residual remuneration of quasi-fixed factors does not correspond to the quasi rent, since decisions about output and variable inputs are made prior to the start of production.
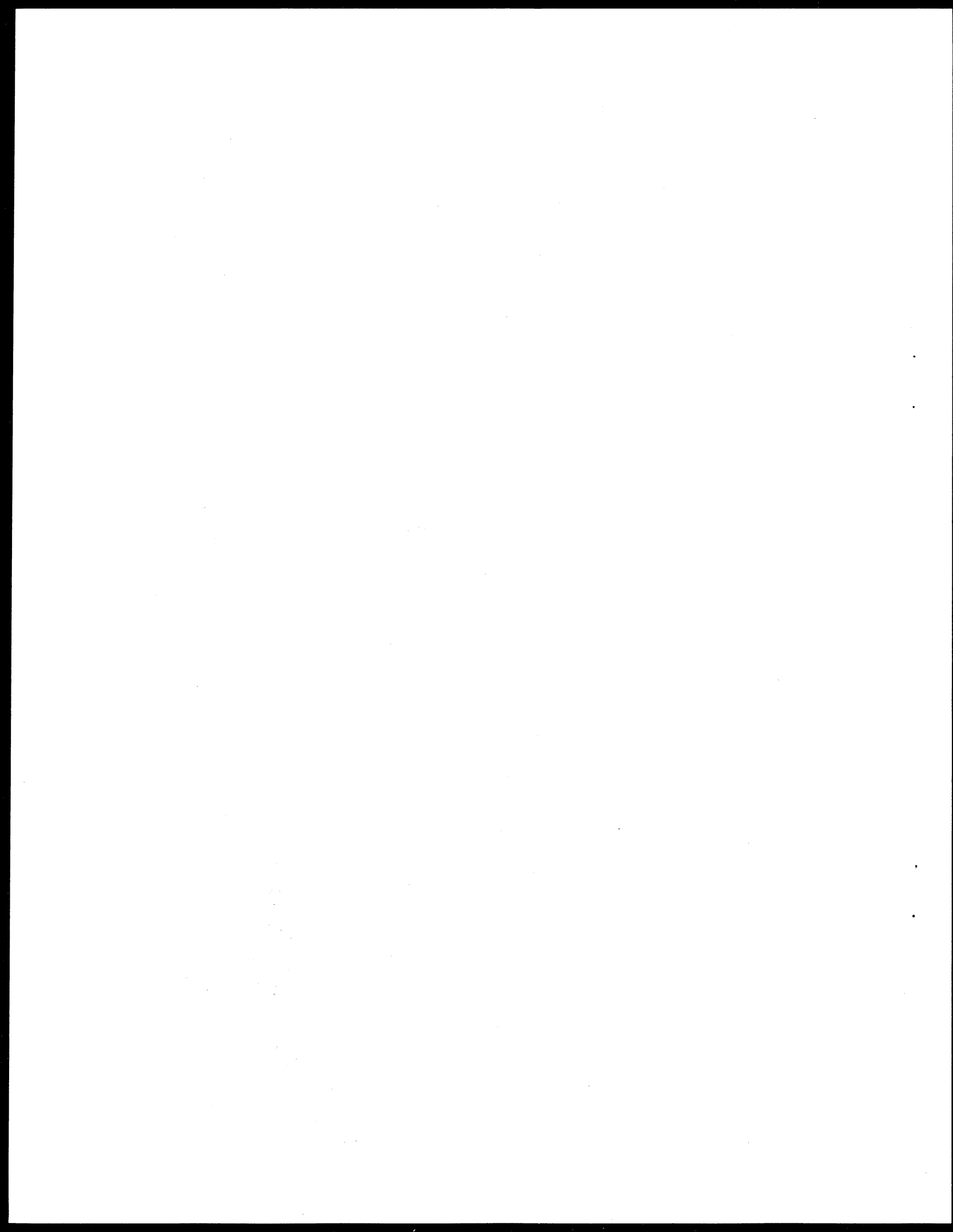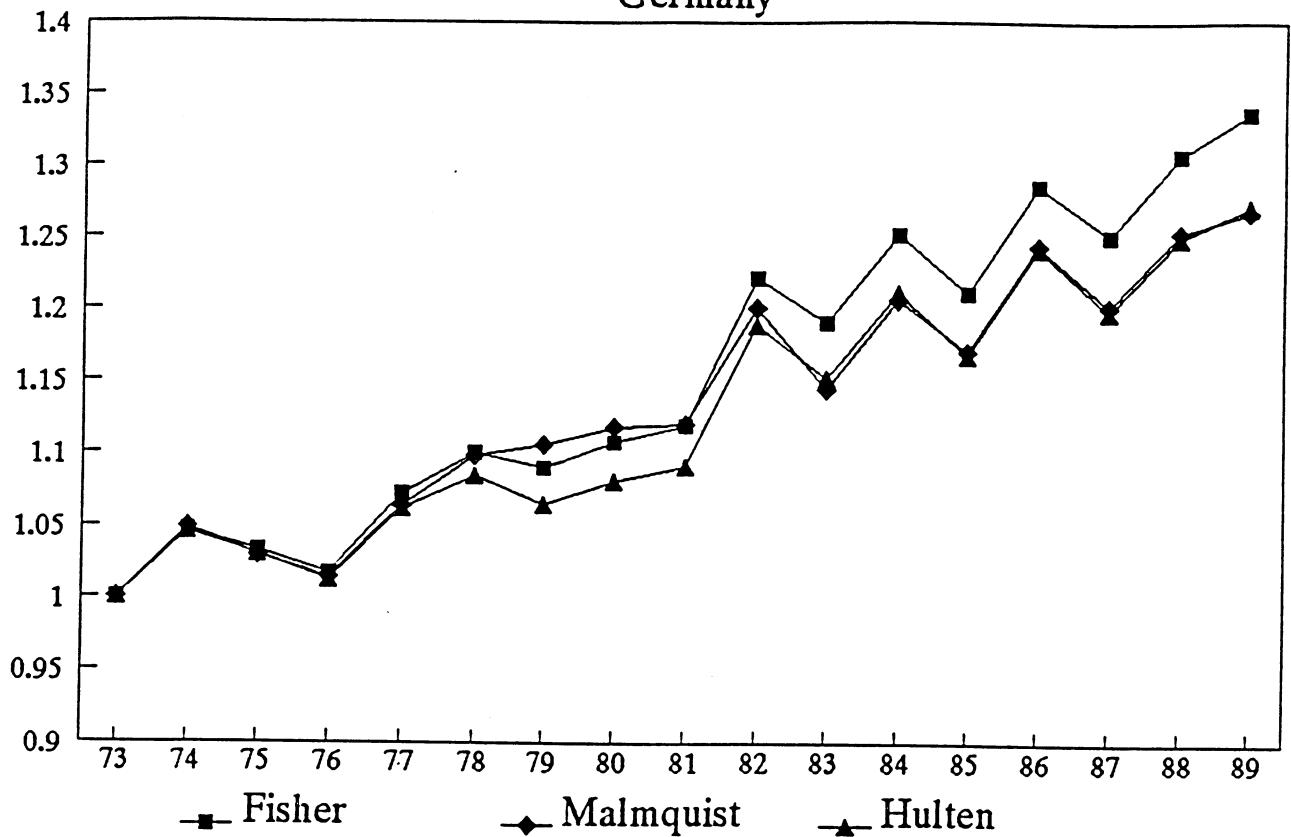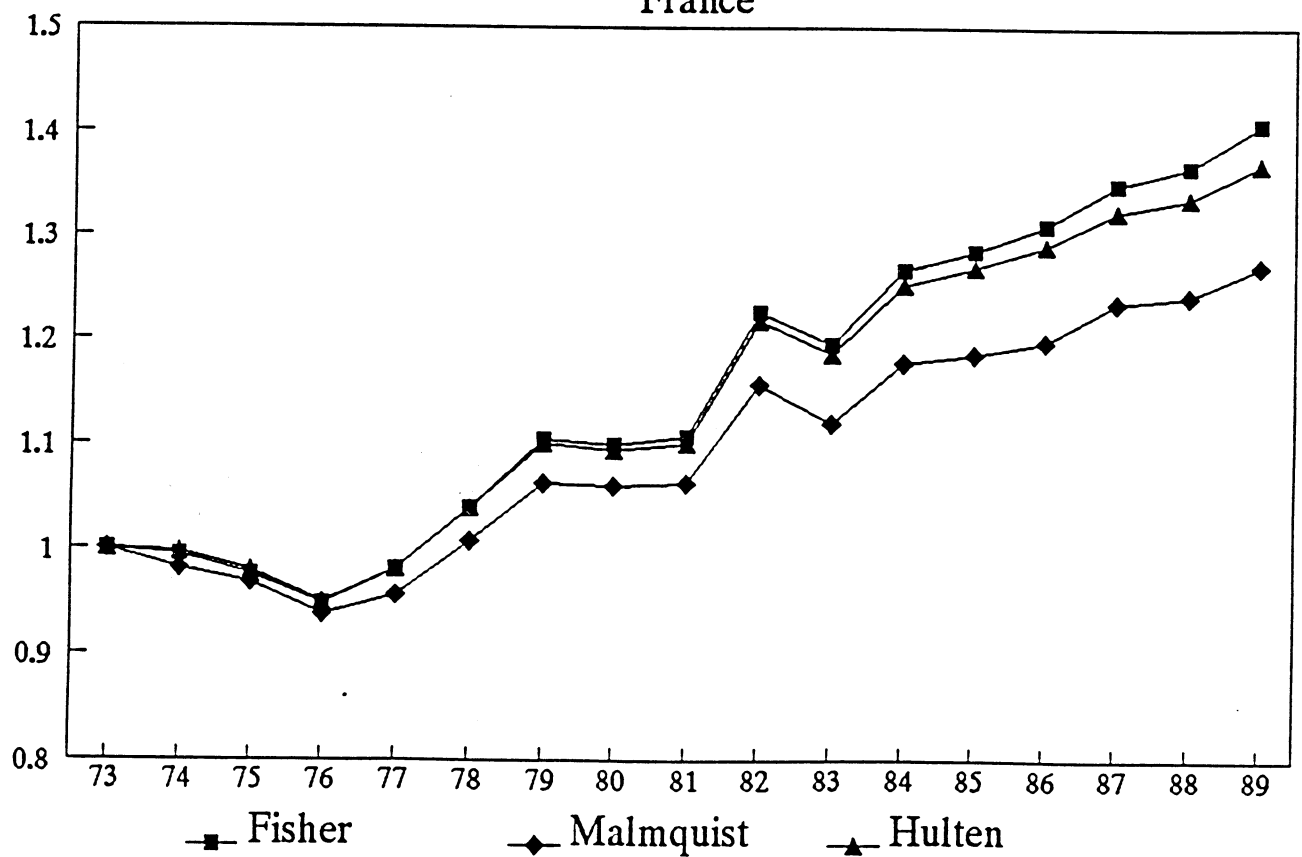
Figure 1: Total Factor Productivity
Germany

Fisher ■ Malmquist ◆ Hulten ▲

Figure 2: Total Factor Productivity
France

Fisher ■ Malmquist ◆ Hulten ▲
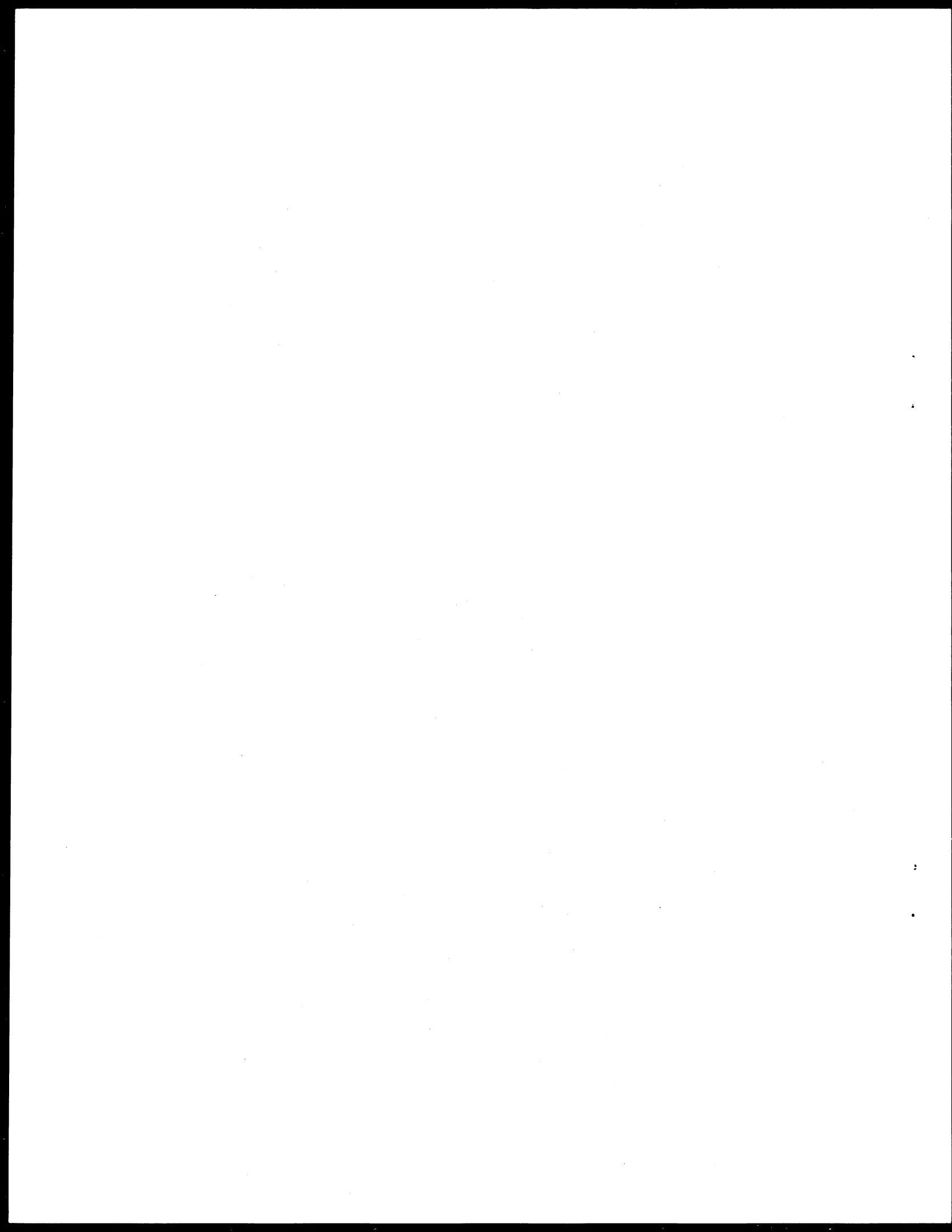
Figure 3: Total Factor Productivity
Italy

Fisher   Malmquist   Hulten
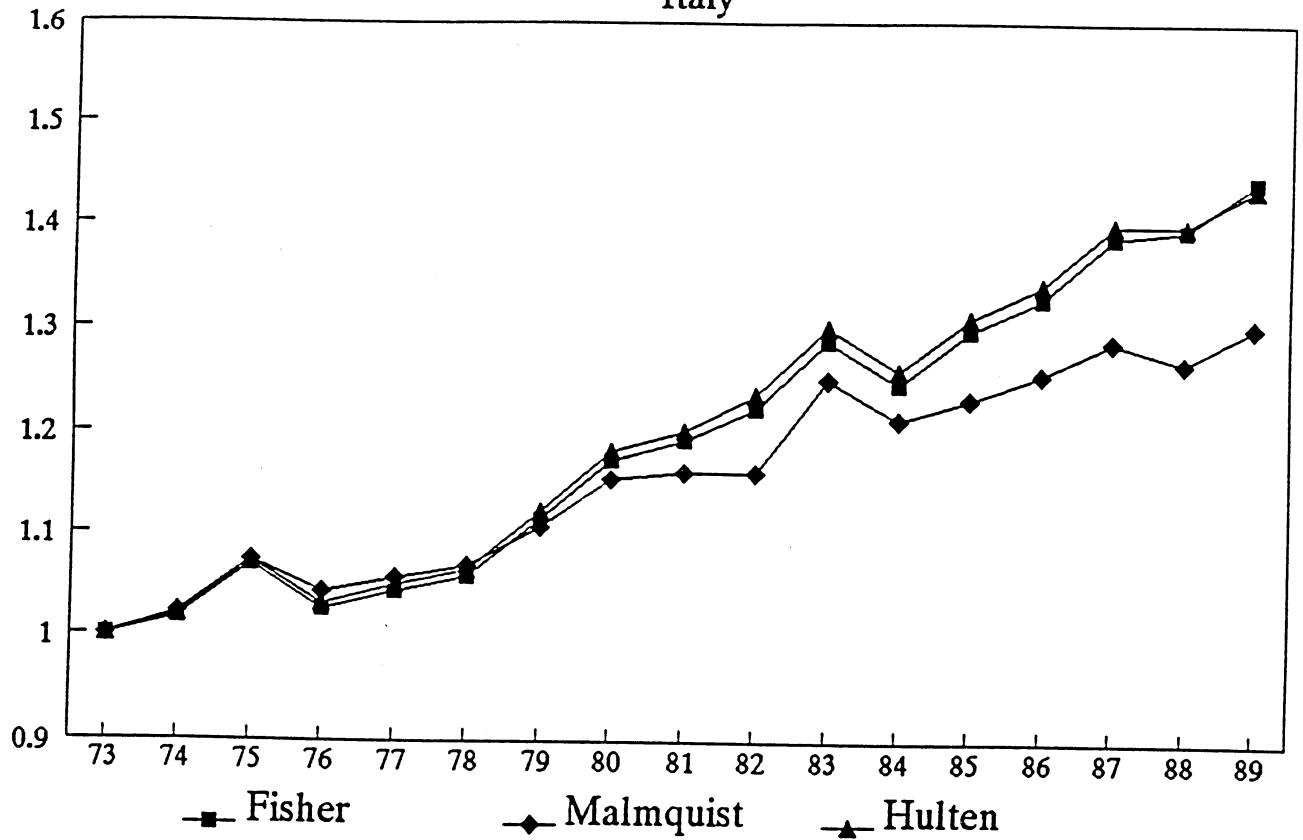
Figure 4: Total Factor Productivity
The Netherlands

Fisher   Malmquist   Hulten
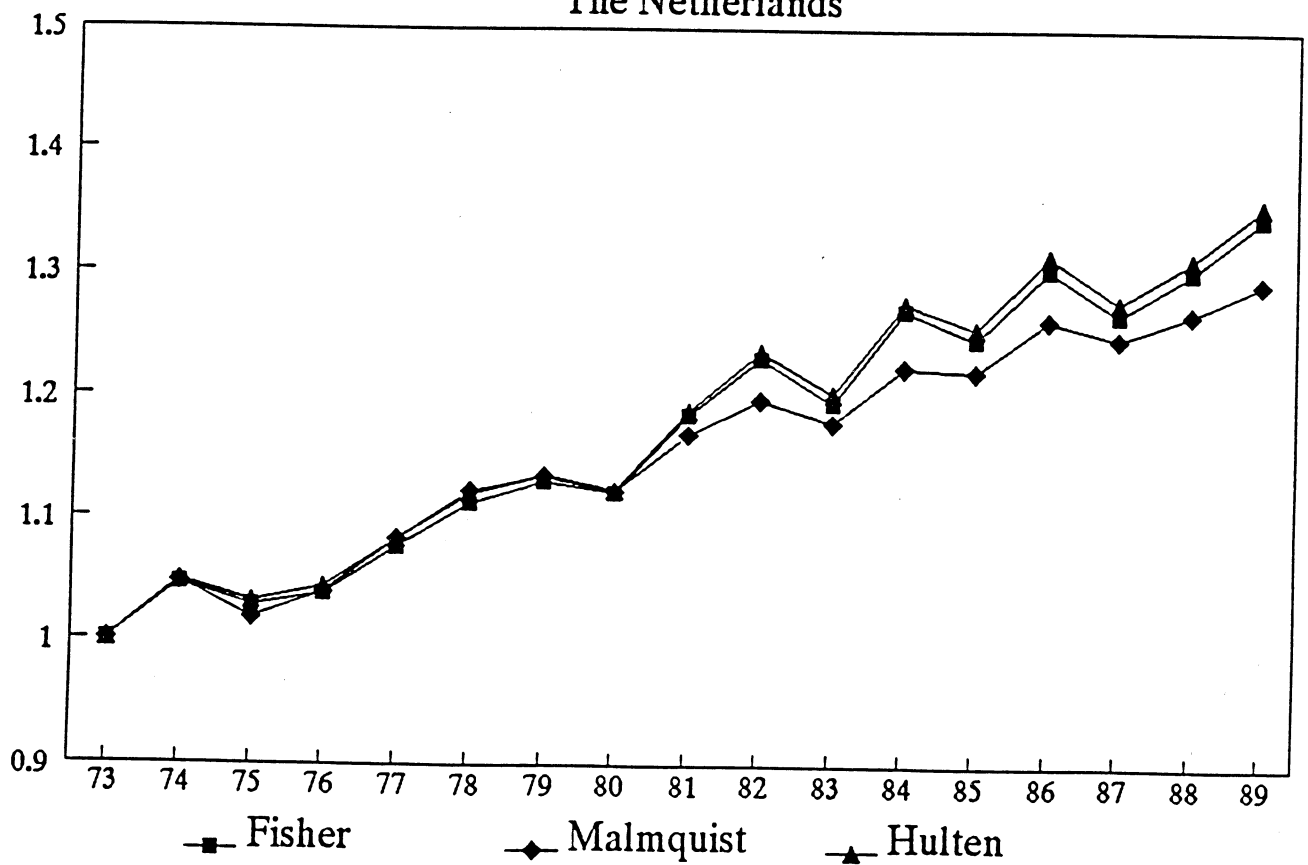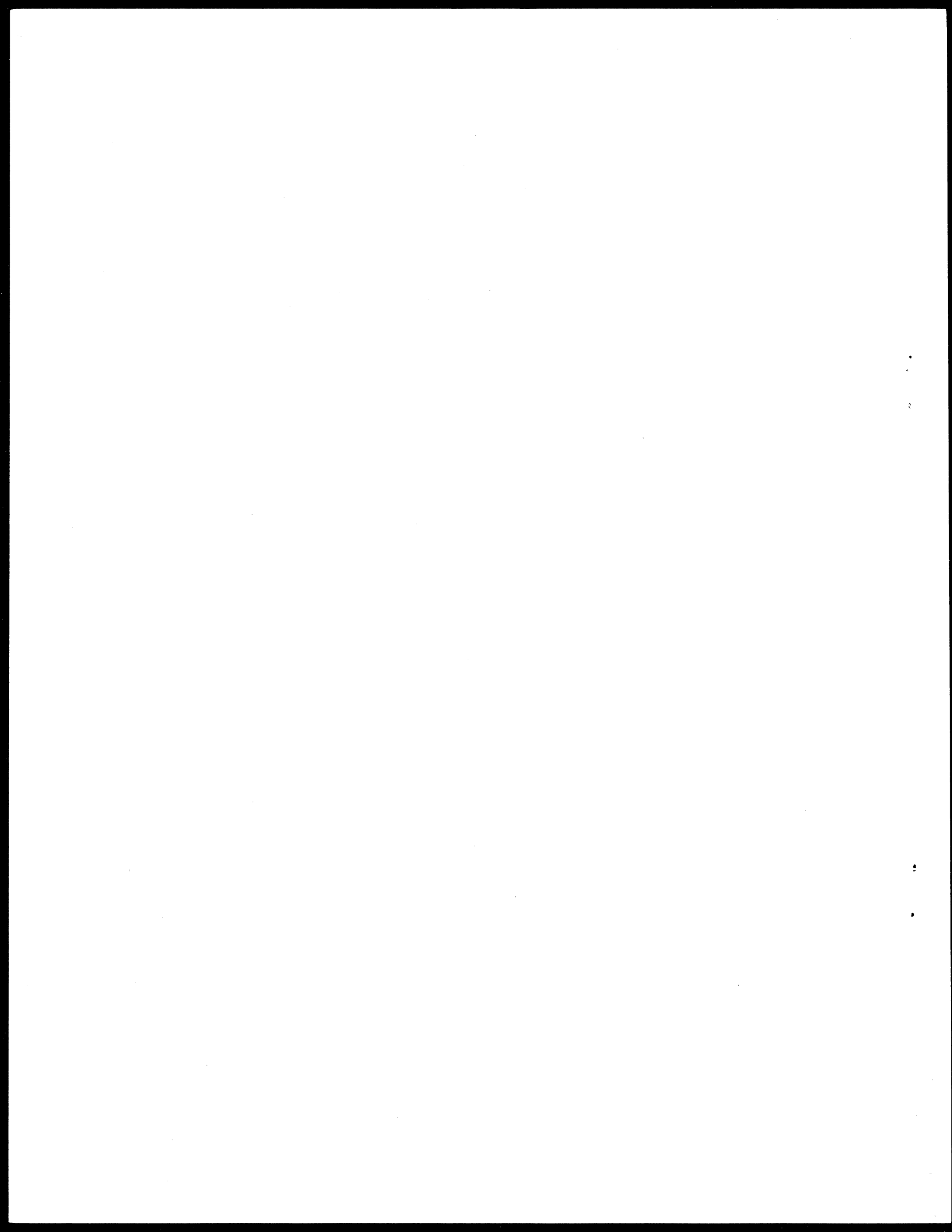
Figure 5: Total Factor Productivity
Belgium−Luxemburg

Fisher ■   Malmquist ◆   Hulten ▲
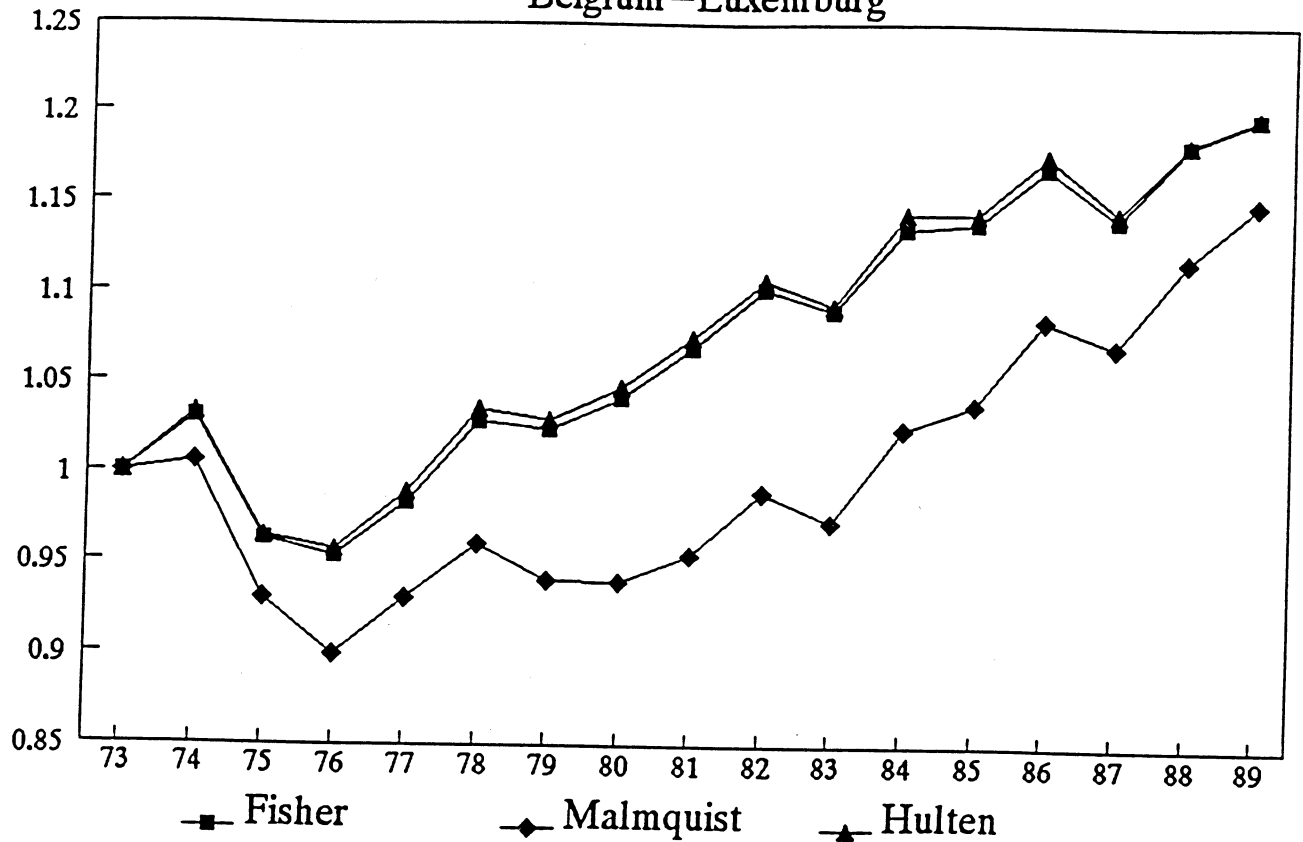
Figure 6: Total Factor Productivity
United Kingdom

Fisher ■   Malmquist ◆   Hulten ▲
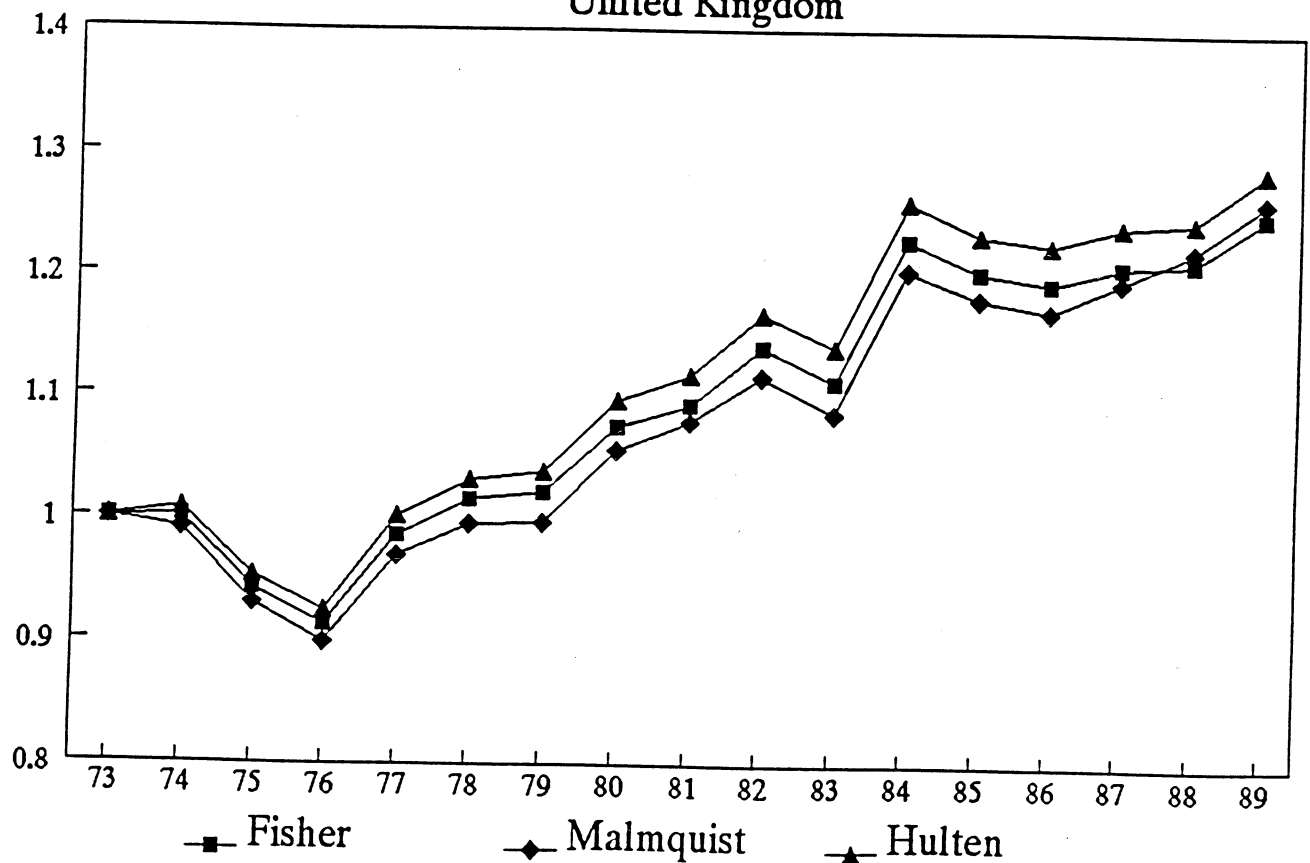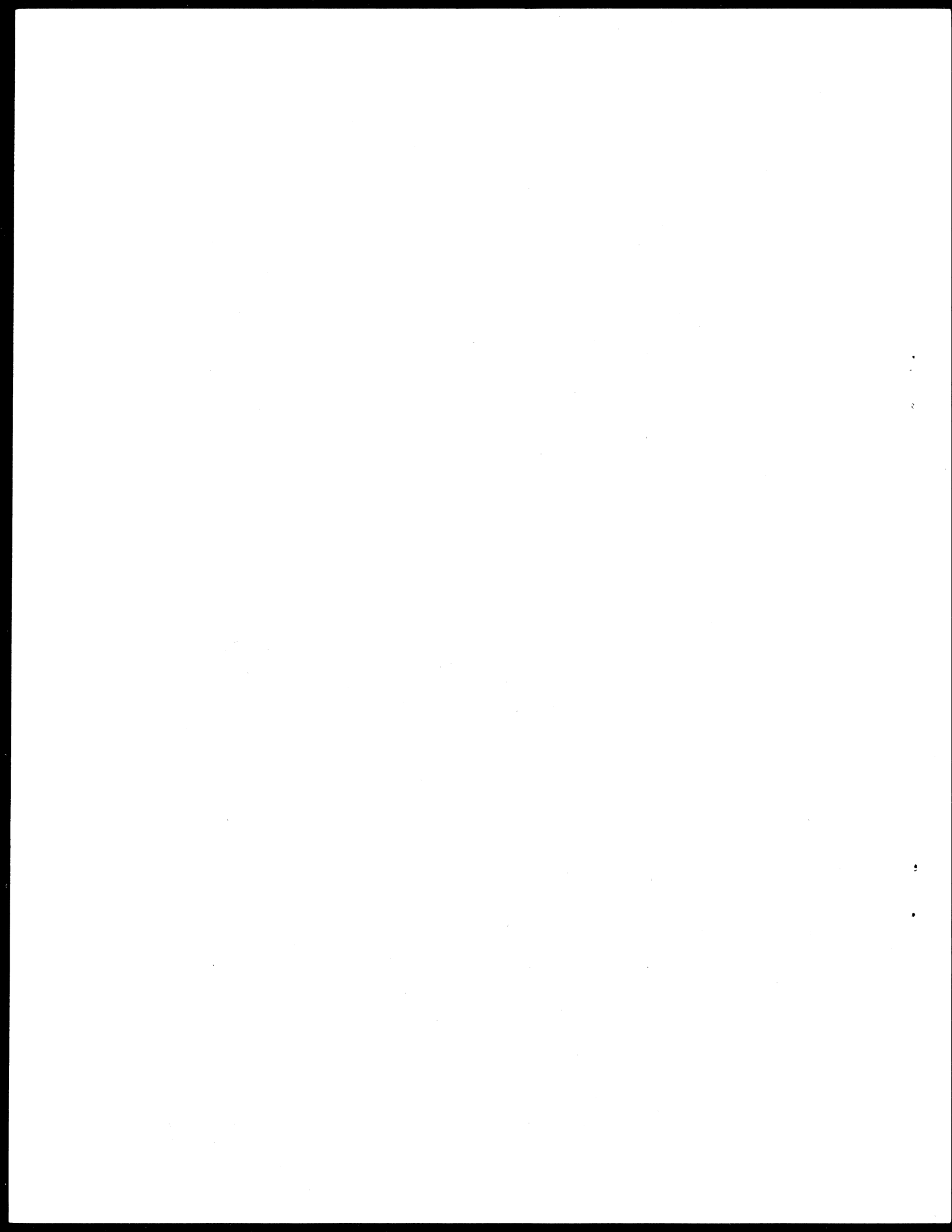
Figure 7: Total Factor Productivity
Ireland

■ Fisher   ◆ Malmquist   ▲ Hulten
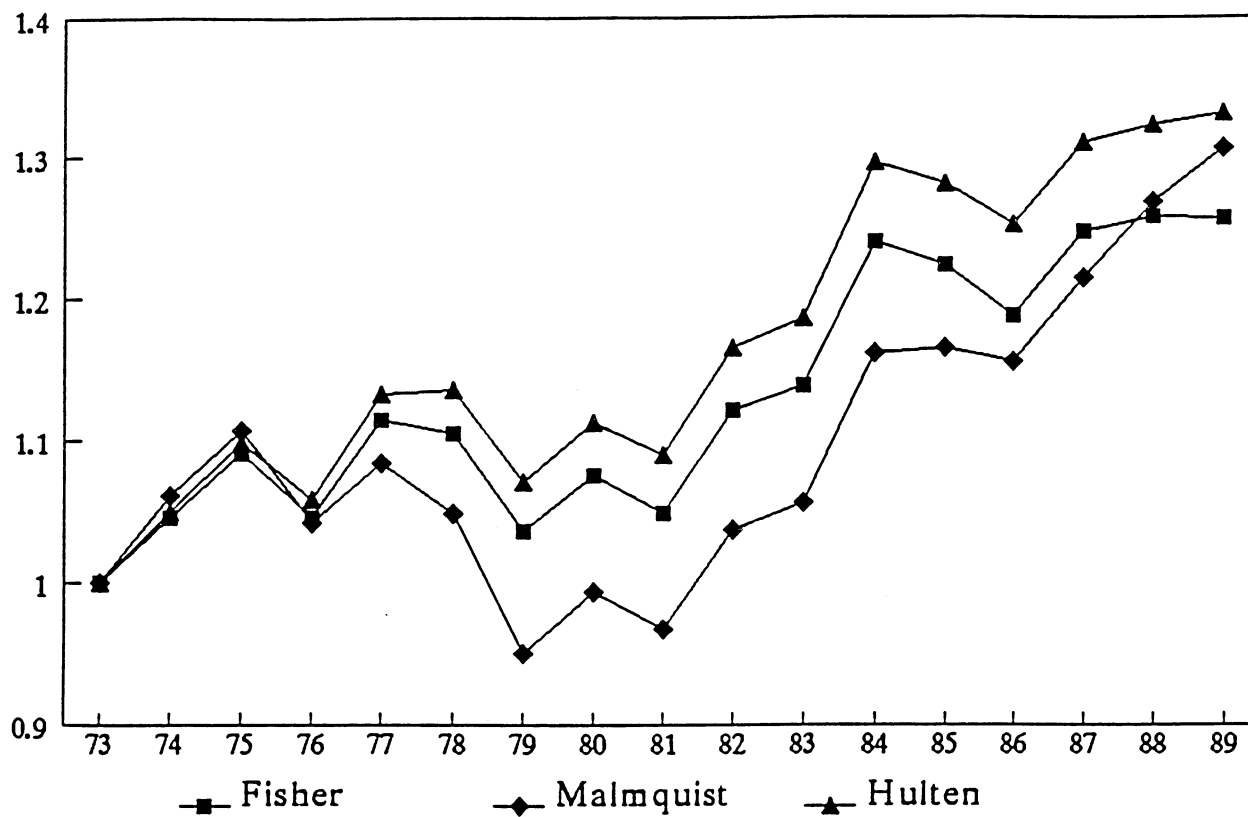
Figure 8: Total Factor Productivity
Denmark

■ Fisher   ◆ Malmquist   ▲ Hulten
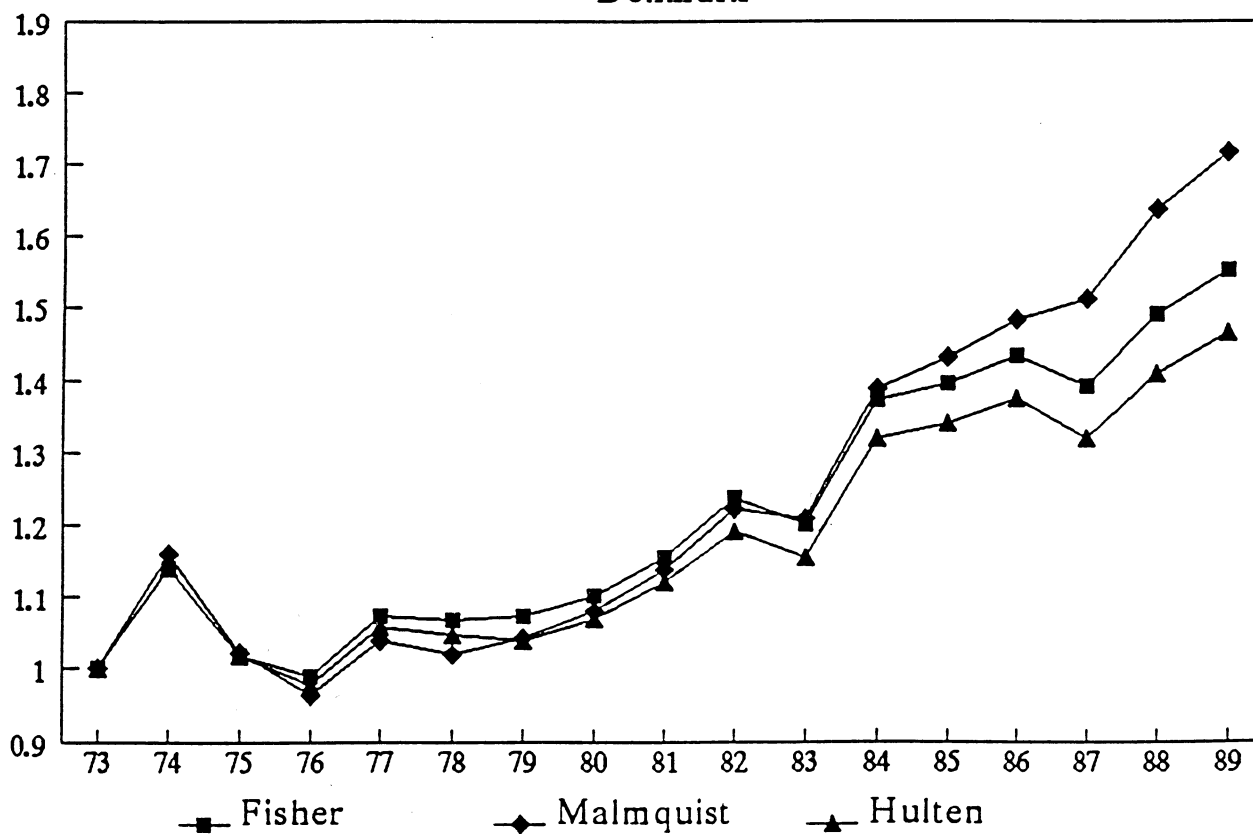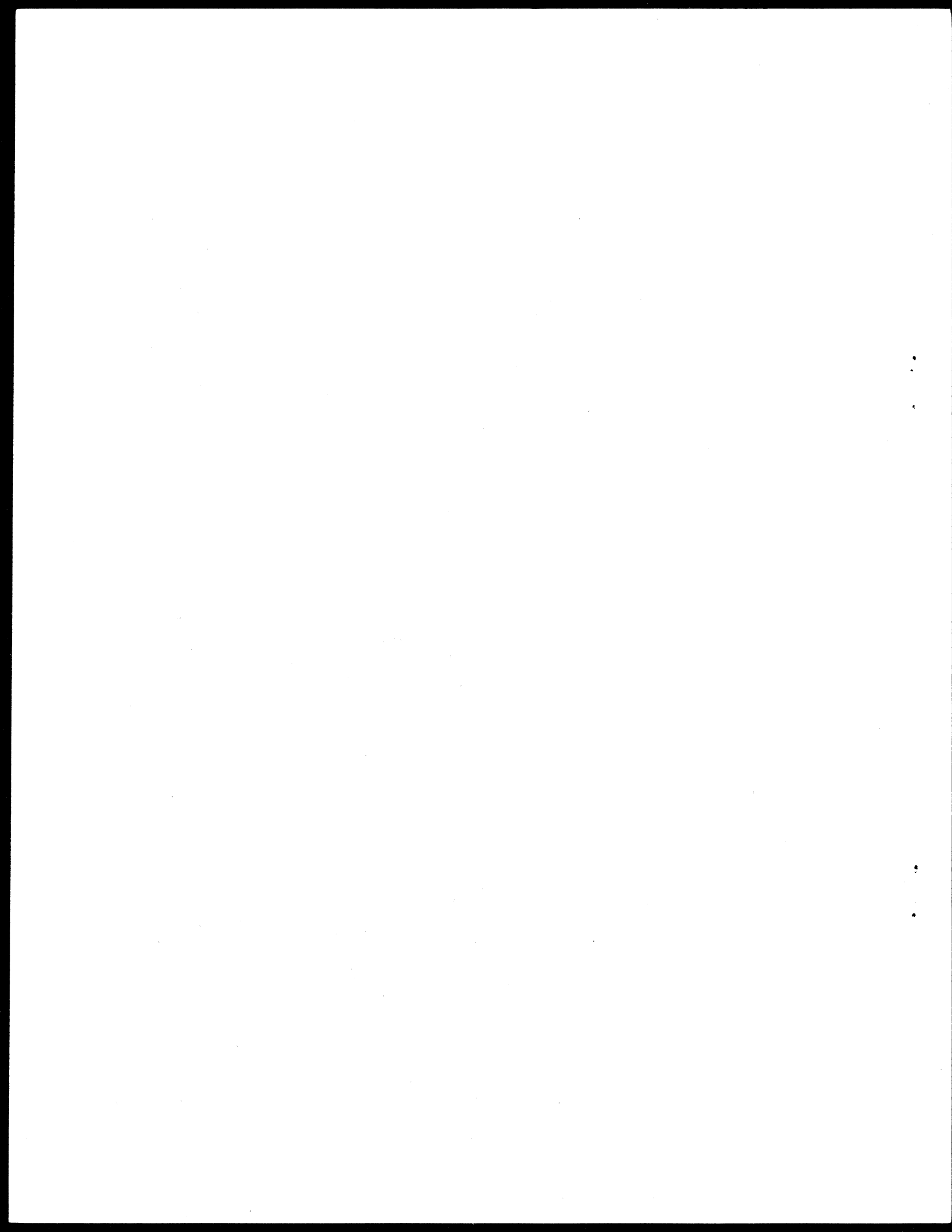
Figure 9: Total Factor Productivity
Greece

◼ Fisher   ◆ Malmquist   ▲ Hulten

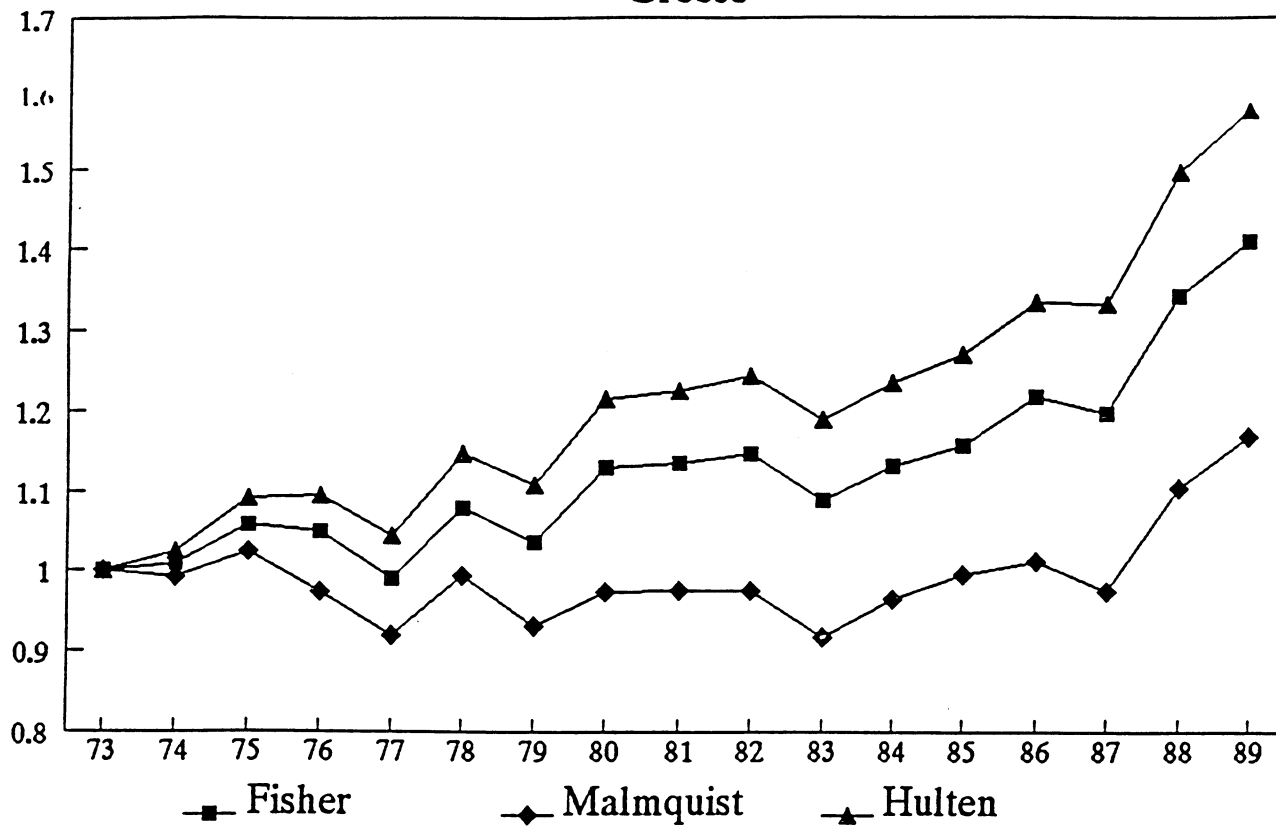# Figure 10: Total Factor Productivity
United States

◼ Fisher   ◆ Malmquist   ▲ Hulten