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TESTING LONG-RUN PRODUCTIVITY FOR THE CANADIAN AND U.S. AGRICULTURAL SECTORS

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ABSTRACT

This paper discusses a portion of our work linking data on the agriculture sector in the United States and Canada. The purpose of this work is to explore the evolution of gains in agricultural productivity in the two countries during the post-WWII period. Comparable data has been developed for each country and a series of tests have been applied about the nature of the long-run production sector. These tests are designed to evaluate the alternate possible structures of shifts in the long-run technology over time.

There is considerable evidence in both countries that the long-run shifts have been Hicks Neutral in models that use gross, not net, output measures. The reverse is true for the net output models. The use of the conventional net output measures is strongly rejected. However there is evidence, in both countries, in support of the hypothesis that separability of a type that is similar to, but weaker, than real-value added is not rejected.

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Introduction*

Much debate has surfaced over the use of gross versus net productivity measures to characterize the growth in the agricultural sectors. The AAEA Task Force on Measuring Agricultural Productivity concluded that "the best approach [to productivity measurement] is the gross output/total input concept that the USDA currently uses in terms of clearness of meaning and applicability to concerns that people have when they ask about agricultural productivity." (USDA (1980), page 27). However the issue is much deeper than what appears to afford the most easily understood yardstick, and relates to what each measure implies concerning the underlying structure of the agricultural sectors. There is a clearly defined linkage between the type of measure of productivity growth and the production structure. Furthermore to suggest that one measure is preferred over another is to implicitly assume that the structure implied by the preferred measure more accurately reflects the "true" structure of the sector. Alternatively, one can offer the following rationale: if we can statistically accept the underlying structural restrictions implied by either a gross or net index measure, then we can rely on the simple nonparametric total productivity index associated with that structure to characterize productivity growth. However, one cannot know a priori which measure is better without econometrically testing the various production structures.

The primary objective of this paper is to develop the linkages between the gross and net productivity indexes and the implied production structures. We proceed to test the various parameter restrictions for the U.S. and Canadian agricultural sectors that are appropriate for agricultural productivity measurement, i.e., test in direct and sequential manners the hypotheses associated with gross and net productivity indexes.

An additional motivation for writing this paper is interest in Canadian and U.S. agricultural productivity comparisons, and in the relative biases in technical change. For both countries, export markets for agricultural products are increasingly important as an outlet for domestic production. The attractiveness of a country's exports depends, in part, on the productivity of its agricultural sector vis a vis other countries. With a valid measure of relative agricultural productivity, we can begin to investigate the sources of the differences in the growth rates in the two countries and the effects of government policies which may be altering the rates of growth.

Productivity measurement implicitly assumes a very simple economic model of production with technical change. These models are delineated into two variants of the total factor productivity models. Kendrick (1961) and Jorgensen and Griliches (1967) have used the net output or real-value added approach; Star (1974), Gollop and Jorgensen (1977), and Gardner (USDA, 1980) have chosen a broader gross output measure.

Beginning with a general production function with time as an argument, we test the restrictiveness of conventional gross and net productivity models. In order to be consistent with the underlying structure for index numbers which are linearly homogenous functions of their components, we restrict the production structure to be linearly homogenous. It is not our intent to pursue the issue of what is the most appropriate economic model of technical change. However, within the confines of our "time-drift" specification of technical change, the empirical results do provide information on the biases and rates of change in technology.

Section one begins with a description of our basic long run model of production that changes with time. Restrictions on this general model are derived which conform to the two primary models of total factor productivity--gross and net output measures. These restrictions take the form of separability restrictions on various subgroups of inputs and time. These restricted models are arranged in sequences that form the bases for nested hypothesis testing.

In order to compare our productivity models with explicit structural models of the technology, we rely on the theoretical results developed by Diewert (1976) and others. These are briefly reviewed in section two. Section three uses the translog production technology with technical change to provide the set of parameter restrictions for testing alternative models.

Estimation of the models and nonparametric index number calculations utilize comparable agricultural data for the U.S. and Canada for the last two decades. In section four the growth rates in agricultural productivity using index numbers are presented. In general, TFP grew faster in Canadian agriculture than in U.S. agriculture. In both countries, capital and material inputs were being rapidly substituted for labor.

The parameter estimates and test results are given in section five. The net output total factor productivity model is rejected in both the U.S. and Canada; the gross output TFP model is accepted in both countries. The sequential tests provide additional information for alternative hypotheses regarding the biases of technical change.

1. Technical Change and Productivity

Consider a production process that uses three inputs to produce one output represented by the production function, (1.1) $Q = f(K,L,M,T)$

with inputs (K), labor (L) and materials (M). Technical progress is specified in very general form in (1.1) and we proceed to restrict its form to yield productivity indexes. To be comparable to index numbers, we impose the restriction that the production function is linearly homogenous.

Our testable restrictions take the form of imposing a variety of separability conditions on (1.1). Weak separability will be used wherever possible. Weak and strong separability are equivalent in certain cases and in a few places we are concerned explicitly with strong separability.

As indicated in the introduction, there are two basic forms of productivity indexes. Both cases are measures of total factor productivity. The first is gross output productivity and the second is net output productivity. We define these more explicitly below as the final steps in a sequence of restrictions on the general production technology.

Consider some very weak restrictions on the form of technical change. The two weakest conditions are called partial materials separability and partial technical separability. Under partial materials separately, M is separable from capital and labor, but not from the time trend:

(1.2) partial materials: $Q = f(g(K,L,T), M,T)$

Under partial technical separability, T is separable from capital and labor, but not from materials:

(1.3) partial technical: $Q = f(g(K,L,M), M,T)$

These rather odd forms of separability are not immediately important in themselves. However, they are the weakest links in the two chains that lead to productivity indexes.[1] In each case, either technical change (1.3) or materials (1.2) is weakly separable from capital and labor. Adding further restrictions to (1.2) and (1.3) respectively, we have,

(1.4) <u>materials</u>: $Q = f(g(K,L,T),M)$

(1.5) <u>technical</u>: $Q = f(g(K,L,M),T)$

It is easy to show that <u>materials</u> separability (1.4) is a more restrictive form of <u>partial materials</u> separability. The same is true for (1.5) relative to (1.3). <u>Materials</u> separability can be further constrained to result in measures of net output factor productivity. Similarly, <u>technical</u> separability is part of a series of restrictions that are related to gross total factor productivity. The steps leading to these two major sequences -- net total factor productivity and gross total factor productivity -- are portrayed in Figure 1.

If technical change is Hicks Neutral, we can rewrite (1.5),

(1.6) $Q = A(t)f(K,L,M)$

It is possible to test sequentially (1.3), (1.5) and (1.6).[2] If the first test is rejected, there is no need to proceed. We have included a description of the sequence in the lefthand side of figure one, in order to inform the reader of the possibilities.

The simple measure of technical change in (1.6) can be directly related to measures of gross output factor productivity. Let

$$F_t = f(K_t, L_t, M_t)$$

be a measure of aggregate input. Productivity P_t is defined as

$$(1.7) \qquad P_t = Q_t/F_t.$$

This total factor productivity measure can be compared to the Hicks Neutral measure of technical change $A(t)$ given in (1.6).[3]

It is common to see measures of net total factor productivity. Beginning with (1.4), materials separability, further restrict the function so that,

$$(1.8) \qquad Q = f(A(t)g(K,L),M)$$

Net total factor productivity measures assume that technical change effects only the primary inputs and is Hicks Neutral with respect to the primary inputs. Equation (1.8) exhibits Hicks Neutral technical change in the primary inputs only. These additional restrictions are required in order to specify the structure implied by the net total factor productivity measure. The sequence of restrictions from (1.1) through (1.2) and (1.4) to (1.8) can be tested to evaluate the appropriateness of net total factor productivity measure. This sequence forms the right-hand side in figure one.

While one can estimate or measure real value-added productivity using (1.8), the usual practice is not to do this.[4] National Accountants have developed a notion of real value added based on the method of "double-deflation." Taken literally, this requires that the production technology be separable in the form,[5]

$$(1.9) \qquad Q = f(K,L,T) + h(M)$$

This additional restriction will also be tested.

We bring together the two sequences of restrictions depicted in Figure 1 by advancing the argument that the technical change that occurs in the world may be both materials and technical separable. It would have the form,

$$(1.10) \qquad Q = f(g(K,L),M,T).$$

"Primary input jelly," represented by $g(K,L)$ in (1.10), is combined with materials to produce output and the technology for doing this changes through time in an unrestricted fashion. This "primary input jelly" option is the only link between the two sequences that we test in this paper.

To summarize, we have selected for testing a subset of all possible separability tests on the three inputs and the time trend. The basis for utilizing this subset of tests is the direct comparability with gross and net productivity measures.

2. Functional Forms and Index Numbers

This section relates Diewert's (1976) theoretical results to our particular problem. Diewert defined the notions of exact and superlative index numbers. A quantity index formula is exact for a particular functional form if the ratio of the outputs between any two periods is identically equal to the index of outputs. Among the set of all exact index numbers, the superlative index number formulas are exact for a functional form that is a second order approximation to an arbitrary linear homogeneous function.

These results are important to our analysis of productivity models. Since we do not know the true functional form for the production technology, we begin with a second order approximation to our production technology. We must also choose a functional form for our index of inputs, F_t required for our productivity measure. Diewert's results suggest that we choose an index number formula that is superlative for the functional form that is used in our estimation of the production technology.

The Translog form will be used to estimate the production technology. In order to limit the disparities in our results that arise due to the selection of functional forms, the index number formula for the direct measurement of productivity must be superlative for the Translog. Diewert has shown that the Tornqvist discrete approximation to the Divisia index is superlative for the linearly homogeneous Translog function. The empirical work that follows will make use of this relationship.

Quantity indexes are functions of the prices and quantities of the components. Implicit in Diewert's theorems that relate index numbers to functional forms is the assumption of competitive behavior. This is necessary in order to eliminate prices in moving from the index numbers to the functional forms which do not contain the prices.[6]

Both econometric estimates and the index numbers reported later in the paper are based on the competitive behavior assumption. Any differences in the results from the measurement of productivity and technical change will arise directly from behavioral assumptions. It is the difference in statistical assumptions that will lead to differences in the estimates.

3. Technical Change and the Translog Production Function

The Translog production function is a second order approximation to an unknown production function. Suppose we have a production function that changes with time, T,

$$(3.1) \qquad Q = f(K, L, M, T).$$

The Translog approximation to this function may be written:

$$(3.2) \qquad \log Q = \alpha_0 + \beta_t \log T + \alpha_l \log L + \alpha_k \log K + \alpha_m \log M + 1/2\gamma_{ll}(\log L)^2$$
$$+ \gamma_{lm}\log L \log M + \gamma_{lk}\log L \log K + 1/2\gamma_{kk}(\log K)^2 + \gamma_{km}\log K \log M$$
$$+ 1/2\gamma_{mm}(\log M)^2 + \theta_{lt}\log L \log T + \theta_{kt}\log K \log T + \theta_{mt}\log M \log T$$
$$+ 1/2\theta_{tt}(\log T)^2.$$

By assumption, the production function is linear homogeneous in the inputs. This condition implies a number of constraints on the Translog form.

$$(3.3) \qquad \alpha_l + \alpha_k + \alpha_m = 1 \qquad \gamma_{mm} + \gamma_{lm} + \gamma_{km} = 0$$

$$\gamma_{ll} + \gamma_{lk} + \gamma_{lm} = 0 \qquad \theta_{lt} + \theta_{kt} + \theta_{mt} = 0$$

$$\gamma_{kk} + \gamma_{lk} + \gamma_{km} = 0$$

The representation of technical change in (3.2) is not constrained by any limitations on the form of technical change. In section one a series of separability restrictions were discussed. From the perspective of testing there are two non-tested sequences which were depicted in Figure 1. The specific restrictions on the Translog function will now be discussed.

We are interested in linking technical change to productivity. Our testing procedure will invoke the developments discussed in Denny and Fuss (1977) and Jorgenson and Lau (1975). The Translog form is an approximation to a true underlying function. Since it is an approximation about a point, the hypothesis tests will require that the hypothesis holds only at the point of approximation.[7] For almost all of our tests the exact form of the test invokes spurious constraints. In general, it is possible to test for exact separability only as a joint test with some other hypothesis.[8]

The first test in the gross output sequence requires that the production technology be separable of the form,

$$\text{(3.4)} \qquad \log Q = f(g(\log K, \log L, \log M), \log M, \log T)$$

This was called partial technical separability. This case will be developed more completely than the tests for the other hypotheses.

Viewed as a second order approximation at the point of expansion, the parameters of the Translog function (3.2) correspond to the first and second order partial derivatives of the true function. To test the hypothesis of partial technical separability the following procedure is followed. The restricted function (3.4) must be expanded and the first and second order derivatives calculated. Since these derivatives correspond to the parameters of the Translog form, any relationships among the derivatives implies restrictions on the Translog function.

The relevant first and second order partial derivatives of the expansion of (3.4) are:[9]

$$\text{(3.5)} \qquad \frac{\partial \log Q}{\partial \log K} = \frac{\partial f}{\partial g}\frac{\partial g}{\partial \log K} = \alpha_K$$

$$\frac{\partial \log Q}{\partial \log L} = \frac{\partial f}{\partial g}\frac{\partial g}{\partial \log L} = \alpha_l$$

$$\frac{\partial^2 \log Q}{\partial \log K \partial \log T} = \frac{\partial f}{\partial g \partial \log T}\frac{\partial g}{\partial \log K} = \theta_{kt}$$

$$\frac{\partial^2 \log Q}{\partial \log L \partial \log T} = \frac{\partial f}{\partial g \partial \log T}\frac{\partial g}{\partial \log L} = \theta_{lt}$$

These equations (3.5) indicate that the parameters of the Translog must have the following restriction,

$$(3.6) \qquad \alpha_k \theta_{1t} = \alpha_1 \theta_{kt}.$$

for approximate partial technical separability.

The next step in the sequence requires technical separability (1.5). This may be written,

$$(3.7) \qquad \log Q = f(g(\log K, \log L, \log M), \log T).$$

It may be shown that the restrictions on the parameters of the Translog for technical separability are

$$(3.8) \qquad \alpha_k \theta_{1t} = \alpha_1 \theta_{kt} \quad \text{and} \quad \alpha_k \theta_{mt} = \alpha_m \theta_{kt}.$$

Two parameter restrictions are required for separability of the form (3.7). Only one additional restriction for technical separability is required in addition to the one for partial technical separability.

It is not possible to impose the restrictions for technical separability on the system of equations that we are estimating without imposing Hicks neutrality. The condition that the factor shares add up to one plus the constraints (3.8) for technical separability imply the constraints for Hicks neutrality (Denny and May (1975)).

The final step in the gross output sequence imposes the restrictions required for multiplicative separability (1.6) necessary for Hicks Neutral technical change. The expansion of

(3.9) $\log Q = \log A(t) + \log F(K,L,M)$,

implies the constraints,

(3.10) $\theta_{1t} = \theta_{kt} = \theta_{mt} = 0$

The last restriction for the maintained hypothesis (3.3) implies that there are only two additional restrictions required for (3.10). These two restrictions are only one more than is required for (3.6). Consequently, given the nesting of (3.6), (3.8) and (3.10), there is no independent set of restrictions for (3.8) as we noted above.

The sequence presented in column two results in real value-added or net output productivity measures. The tests and specific restrictions on (3.2) for this second sequence are:

partial materials: $\log Q = f(g(\log K, \log L, \log T), \log T, \log M)$

(3.11) $\alpha_k \gamma_{1m} = \alpha_1 \gamma_{km}$

materials: $\log Q = f(g(\log K, \log L, \log T), \log M)$

(3.12) $\alpha_k \gamma_{1m} = \alpha_1 \gamma_{km}$ and $\alpha_1 \theta_{mt} = \beta_t \gamma_{1m}$

net productivity: $\log Q = f(\log A(t) + \log g(K,L), \log M)$

(3.13) $\alpha_k \theta_{1t} = \alpha_1 \theta_{kt} \theta_{kt} \gamma_{1m} = \theta_{1t} \gamma_{km}$

$\beta_t \gamma_{km} = \alpha_k \theta_{tm}$

The gross output and net output sequences can be joined in the common hypothesis

primary input jelly: $\log Q = f(g(\log K, \log L), \log M, \log T)$

with restrictions,

(3.14) $\alpha_k \gamma_{1m} = \alpha_1 \gamma_{km}$ and $\alpha_k \theta_{1t} = \alpha_1 \theta_{kt}$

These constraints (3.14) involve the joint imposition of partial technical (3.6) and partial materials (3.11) separability. One might also note that the constraints for net output productivity (3.13) add one additional constraint to those required for primary input jelly hypothesis (3.14). There are obviously other links between these chains which we do not explore in this paper.

There is one further test that was discussed in section one. It was noted that the double-deflation or common method of net total factor productivity requires further restrictions on (3.13). Denny and May (1975) have shown that this requires at least one of the following constraints,

(3.15) $\alpha_m = 0$ or $\alpha_K = \alpha_1 = 0.$

4. Productivity Growth in U.S. and Canadian Agriculture

In this section we discuss the growth in agricultural productivity for the U.S. and Canada for the years 1962-78 using index numbers. The Canadian data are based on a recent study by Brinkman and Prentice (1983); the U.S. data are taken from Capalbo and co-authors (1985).[10] Table 1 provides estimates of labor productivity and total factor productivity for two sub-periods (1962-1970 and 1970-1978) and for the 1962-1978 period. Note that labor productivity and total factor productivity are measured using gross, not net, output, and using the usual Tornqvist approximation to the Divisia index.

For the years 1962-78, both labor productivity and TFP grew more quickly in Canada than in the U.S. During the sixties, labor productivity growth was similar in the two countries. Average U.S. labor productivity growth fell by two percent during the seventies while the Canadian rate remained roughly the same. In both countries TFP growth was substantially less than labor productivity growth. Capital and material inputs were being substituted for labor. The difference between the growth in labor productivity and TFP growth equals the growth in factor intensity. The latter is a weighted sum of the growth in the capital-labor and materials-labor ratio. In both periods, the growth in Canadian TFP exceeded the American growth by roughly one percent.

In Canada labor productivity growth was being driven by the contribution of TFP growth which was roughly fifty percent. In the U.S., labor productivity growth was more heavily driven by factor substitution, i.e. the growth in factor intensity. This is particularly true in the 1960s. The U.S. decline in labor productivity growth during the 1970s was entirely due to the decline in the growth in factor intensity, as evidenced by U.S. TFP growth being higher in the 1970s than in the 1960s.

The growth in productivity is due to many factors but may be measured by the difference in the rates of growth of outputs and inputs. Table 2 provides information on the average annual growth rates of outputs and inputs. In both countries, aggregate agriculture output has grown slowly. This was particularly true during the 1960s. During the second period, Canada's output grew at a much faster rate than in the U.S.

In both countries, aggregate agriculture inputs have been fairly stable during the 1962-1978 period. However, this constant aggregate input level disguises the large shifts in particular inputs. Labor inputs have been declining rapidly in both countries. This decline was very rapid in the sixties and slowed during the seventies. Capital inputs have been growing modestly in the U.S. compared to Canada. Likewise, material inputs have also grown at a faster pace in Canada.

As we previously noted, the nonparametric index calculations are closely linked to structural restrictions and thus their validity to depict productivity growth is linked to statistical acceptance of the structural models.

We turn now to a discussion of the alternative estimates of the changes in technology based on the production relations described in sections 1 and 3.

5. Estimation of the Translog Production Technology and Tests for Restrictions on Technical Change

The translog production function (3.2) and the corresponding share equations for capital and labor were estimated as a system of three equations, subject to the linear homogeneity constraints (3.3). The estimation technique is described in Berndt and coauthors (1974). The parameter estimates for this unconstrained model are provided in Table 3.[11] In subsequent discussions this model is referred to as the maintained hypothesis model.

Since the paper is primarily concerned with productivity comparisons, only the parameters that relate to technical change are discussed. In Canada, the share of labor has decreased due to technical change, while the share of capital has increased. A similar pattern is observed for the U.S. For both countries the effect of technical change on the share of materials is imprecisely estimated. Thus the hypothesis of neutral technical bias for materials could not be rejected. One might also note the lack of a significant relationship between materials and the other primary inputs (γ_{lm}, γ_{km}).

The two parameters, β_t and θ_{tt}, indicate the inward shifting of the isoquants. This is occurring at a substantially faster pace in Canada compared to the U.S. Furthermore, the rate of change, θ_{tt}, is four-times greater in Canada.

The tests for the alternative forms of technical change are based on the likelihood ratio test. Defining λ as the ratio of the maximum of the likelihood function in the constrained and unconstrained models, the test statistic, $-2 \log \lambda$, has an asympotic χ^2 distribution. The degrees of freedom equal the number of restrictions. The critical values of the χ^2 test statistic for various levels of significance and number of restrictions are given in Table 4.

In section 1, we discussed two major sequences which theoretically leads to measures of gross and net total factor productivity. We proceed to test each sequence independently, as well as testing each hypothesis independently. Our rationale is as follows. Consider the gross output Hicks neutral technical change hypothesis (1.6). This can be tested as part of our nested sequence. If we reject partial technical separability this implies that we would also reject Hick neutrality since it is part of the nested sequence. However, there may be other testing sequences that would theoretically lead to (1.6), and would not reject Hicks neutrality. Thus we will present the sequential test results as well as the direct test results for both types of Hicks neutrality. Following the analyses for the two major sequences, we proceed to test the primary input jelly sequences, and the real value added hypothesis.[12]

Gross Output Hicks Neutrality sequence:

The direct test for gross output Hicks neutrality yielded the following test statistics:

$$(5.1) \qquad Q = A(t)\, f(K,L,M): \qquad \chi^2_{us} = 4.818$$
$$\chi^2_{ca} = 5.296$$

There are two restrictions imposed on the maintained hypothesis. Using the χ^2 values in Table 4, (5.1) is accepted in both the U.S. and Canada at the .05 level of significance.

For the sequential tests, the overall level of significance is .05. Thus if α_i is the significance level of the i^{th} test in the sequence, the $\Sigma\alpha_i = .05$. For a sequence of three tests, $\alpha_1 = .01$, $\alpha_2 = .015$, and $\alpha_3 = .025$. Thus for the second test in this sequence, the significance level is $\alpha_1 + \alpha_2$ or .025.

For partial technical separability, the test statistics are:

$$(5.2) \qquad Q = f(g(K,L,M),M,T): \quad \chi^2_{us} = 4.718$$
$$\chi^2_{ca} = 5.290$$

Since only one additional restriction is required to those given in (3.3), the hypotheses is accepted in the U.S. and marginally rejected in Canada.

In earlier discussions, we noted the impossibility of imposing the restrictions for technical separability without simultaneously imposing the stronger structure for Hicks neutrality on the translog model. Conditional on (5.2) the test statistic for the second test in the sequence, Hicks neutrality, are

(5.3) $Q = A(t)f(K,L,M)$: $\chi^2_{us} = 0.100$

$\chi^2_{ca} = 0.001$

With one additional restriction to those already imposed for partial technical separability, the hypothesis is accepted for the U.S. conditional on (5.2); the hypothesis is also accepted for Canada. However, given the rejection of (5.2) for Canada, this result is not directly relevant.

Net Output Hicks Neutrality sequence:

The direct test for net output Hicks neutrality resulted in the following test statistics:

(5.4) $Q = f(A(t)g(K,L),M)$: $\chi^2_{us} = 9.412$

$\chi^2_{ca} = 6.854$

The hypothesis is rejected in both countries at the .05 level of significance.

For the second major sequence, there are three nested tests leading to net output Hicks neutrality. The first hypothesis is partial materials separability. The appropriate test statistics for this hypothesis are:

(5.5) $Q = f(g(K,L,T),M,T)$: $\chi^2_{us} = 2.876$

$\chi^2_{ca} = 0.184$

With one restriction, and $\alpha_1 = .01$, the hypotheses is strongly not rejected in either country.

For the second nested test, materials separability, the test statistics are:

(5.6) $\quad Q = f(g(K,L,T),M)$: $\quad \chi^2_{us} = 2.248$

$\chi^2_{us} = 1.562$

The hypothesis is accepted in both the U.S. and Canada.

The final hypothesis in the second sequence imposes net output Hicks neutrality,

(5.7) $\quad Q = f(A(t)g(K,L),M)$: $\quad \chi^2_{us} = 4.288$

$\chi^2_{ca} = 5.359$

Net output Hicks neutrality is rejected in Canada and the U.S. There is one additional restriction to that required for materials separability, and the appropriate level of significance is .05.

To summarize our results so far, the direct and sequential tests for net output Hicks neutrality do not conflict. Hicks neutrality with respect to the primary inputs only is rejected in both the U.S. and Canada. The results for gross output Hicks neutrality are less consistent. The direct tests (5.1) were <u>not</u> rejected for either country. The sequential test results do not conflict for the U.S., but do conflict for Canada (although the rejection is weak). To have an invariant index of productivity, some version of Hicks neutrality is required (Hulten, 1973). Since we do not reject gross output Hicks neutrality for either Canada or the U.S., this suggests placing some reliance on the gross output productivity indexes for the U.S. and Canadian agricultural sectors reported in Table 1.

Primary Input Jelly:

As indicated in section 3, the primary input jelly hypothesis links the net and gross output sequences. It requires the joint imposition of the restrictions for partial materials and partial technical separability. We test the hypothesis of primary input jelly directly against the maintained hypothesis, and sequentially as shown in figure 2.

The direct test of primary input jelly hypothesis for the U.S. and Canada yielded the following results.

(5.8) $\quad Q = f(g(K,L),M,T)$: $\quad \chi^2_{us} = 6.836$

$\chi^2_{ca} = 6.132$

The hypotheses is reject in both countries, at the .05 level of significance.

The sequential testing leads to somewhat different results. For U.S., our earlier results lead to acceptance of both partial technical separability and partial materials separability. Conditional on each of these hypotheses, we test for primary input jelly. The appropriate test statistics are:

(5.9) $\quad Q = f(g(K,L),M,T)$

(a) Conditional on partial technical separability (5.2):

$\chi^2_{us} = 2.118$

(b) Conditional on partial materials separability (5.5):

$\chi^2_{us} = 3.960$

For one restriction, (5.9a) is not rejected at the 0.05 levels of significance; (5.9b) is not rejected at the 0.025 level of significance.

Thus the sequential tests conflict with the direct test of primary input jelly for the U.S.

For Canada, the appropriate test statistics are:

(5.10) $Q = f(g(K,L),M,T)$ (a) Conditional on <u>partial technical separability</u> (5.2):

$\chi^2_{ca} = 0.842$

(b) Conditional on <u>partial materials separability</u> (5.5):

$\chi^2_{ca} = 5.946$

Although (5.10a) is accepted at the 0.05 level of significance, partial technical separability (5.2) was marginally rejected, which implies rejection of primary input jelly in this sequence of nested tests. In the alternative sequence, partial materials separability was accepted, but (5.10b) is rejected. Thus the rejection of the sequential tests is consistent with the direct test results (5.8) for Canadian agricultural sector.

<u>Real Value Added</u>:

Although real value added functions are not the bases for productivity measurement in the agricultural sectors, they are important for comparisons of productivity rates with other sectors of the U.S. and Canadian economies. Our final set of tests for the long run production structure deals with the real value added function.

The strong nonrejection of <u>partial materials separability</u> (5.5) in both countries lends some support for a real value added function that includes technical change, T. Furthermore, the acceptance of <u>materials</u>

separability (5.6) in both countries supports the argument that technical change has only affected real-value added, or the primary inputs, K and L. The results of (5.9b) and (5.10b) provide weaker support for real value added models that exclude technical change.

The direct test of double-deflation real value added (1.9) against the maintained hypothesis yielded the following test statistics:

$$(5.11) \qquad Q = f(K,L,T) + h(M) \qquad \chi^2_{us} = 96.07 \quad \chi^2_{ca} = 160.05$$

Thus the double-deflation real value added is soundly rejected. If a net total factor productivity measure is desired, one should use an alternative specification. One suggestion might be to calculate the growth in real value added and net productivity as the rate of growth of gross output productivity divided by the share of capital and labor. This can be done using the information provided in section 4.

6. Summary

As we noted in the introduction, the purpose of this paper is to test alternative models of productivity. The long run models more closely replicate the underlying economic structure for index number measures of total factor productivity. We do not wish to argue that these models can provide anything but limited ex post information about technical change.

Utilizing the long run production function framework, we failed to reject the hypotheses of gross output Hicks neutrality in both Canada and the United States. The sequential test results for Canada, however, did lead to rejecting partial technical separability and thereby rejecting gross output Hicks neutrality. The net output Hicks neutrality hypothesis is rejected in both countries. These results lend support to the use of productivity indexes to measure gross output total factor productivity. The direct tests for the "primary input jelly" and the real value added hypotheses are also rejected for the U.S. and Canada.

The sequential test results support a number of alternative hypotheses. Partial materials separability and materials separability are not rejected. The latter hypotheses relate technical change to the primary inputs, in a nonneutral manner. Models that ignore technical change (partial technical separability and the sequential tests for gross output Hicks neutrality and for primary input jelly) are supported by the U.S. data. These sequential results lend support for the variety of partial production models that have been used in agricultural studies.

The results presented here, although preliminary, are of particular interest at a time when the U.S. government is preparing legislation for the 1985 Farm Bill. Hopefully, these results can contribute to a better understanding of the sources of variations in the patterns of productivity growth and technical change in Canadian and U.S. agricultural sectors.

Footnotes

*The authors would like to thank Trang Vo for technical assistance.

(1) Diewert does not stress the fact that alternative behavioral assumptions would result in a different set of relations between index numbers and functional forms.

(2) In our particular case some difficulties arise that will be discussed below.

(3) Any attempt to avoid Hick's neutrality in productivity studies founders on the 'path dependence' problem. Hulten's discussion of the Divisia index may be consulted.

(4) See Denny and May (1978) for an outline of the method.

(5) See Denny and May (1975) for an analysis of this condition.

(6) Diewert does not stress the fact that alternative behavioral assumptions would result in a different set of relations between index numbers and functional forms.

(7) The approximating function is constrained everywhere but the constraint implies the hypothesis holds exactly only at the point of approximation.

(8) Larry Lau (1975) has developed a general statement of the conditions.

(9) The right hand sides of (3.5) are the parameters of the Translog approximation.

(10) The data bases are described in more detail in the Appendix.

(11) Symmetry is imposed for these estimates. Summary statistics are excluded since the ones produced by the estimating program are potentially misleading. Conditions for monotonicity were accepted at all data points.

(12) We are not considering using the primary input jelly hypothesis as a link to further sequences.

(13) Models that attribute changes in the technology through time to technical change are notoriously weak in explaining technical change.

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Appendix

The agricultural database developed by Capalbo and Vo (1985) is the basis for the U.S. analysis. However, to maintain consistency between the Brinkman and Prentice data on Canadian agriculture, we have made the following changes to the Capalbo/Vo database. First, labor is non-quality adjusted and is aggregated into family labor and hired labor and further aggregated into a composite labor index. Second, capital gains have been excluded in calculating the service prices for capital. Third, animal capital is excluded from the capital component and land has been aggregated with structure and equipment using a divisia indexing procedure. Thus, we have three inputs: capital (land, non-residential structure, and durable equipment), labor, and intermediate inputs. It should be noted that the intermediate input category includes both purchased and non-purchased material inputs.

The Canadian agriculture data have been taken from a recent productivity study by Brinkman and Prentice (1983). There are three basic changes that we have made to maintain consistency with the U.S. database. First, the stock of inventories is not treated as part of the production process. That is, we have taken a narrow flow basis for the production process. Brinkman and Prentice include inventories as an input. Second, we have aggregated the data using Divisia indexes with service prices as the weights. As for the U.S. data, the service prices do not include capital gains. Finally, we have re-allocated some of the inputs so that the Brinkman/Prentice aggregate input categories are not identical to the ones used in this paper.

Canadian labor data are available by farm operators, unpaid family labor and hired labor. These have been aggregated using the farm hired wage rate for unpaid family labor and hired labor. The wage rate for farm operators is roughly equivalent to the industrial wage rate for production workers. These data have not been quality-adjusted. The materials data are an aggregate of inputs of feed, seed, pesticides, fertilizer, fencing, lime, twine, livestock services, irrigation, fuel, electricity, telephone and miscellaneous material inputs. The capital inputs include land, buildings and machinery. The quantities are taken directly from Brinkman and Prentice, but reaggregated using service prices.

The output data for both the U.S. and Canada reflect quantities produced and are taken directly from Capalbo/Vo and Brinkman/Prentice, respectively.

Figure 1. Tests for Restricted Technical Change: Major Sequences

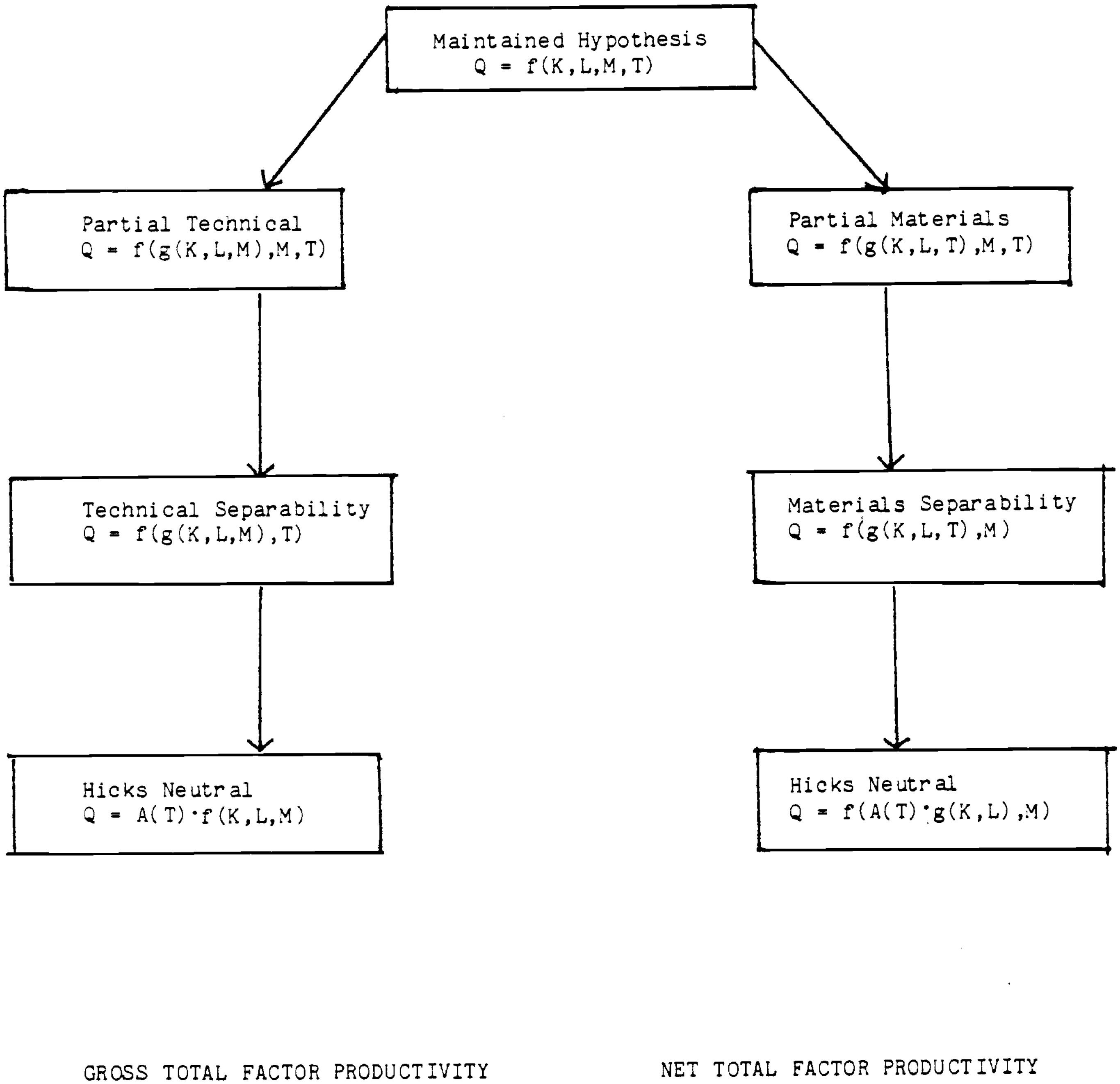

Figure 2. Sequential Testing of Primary Input Jelly Hypothesis

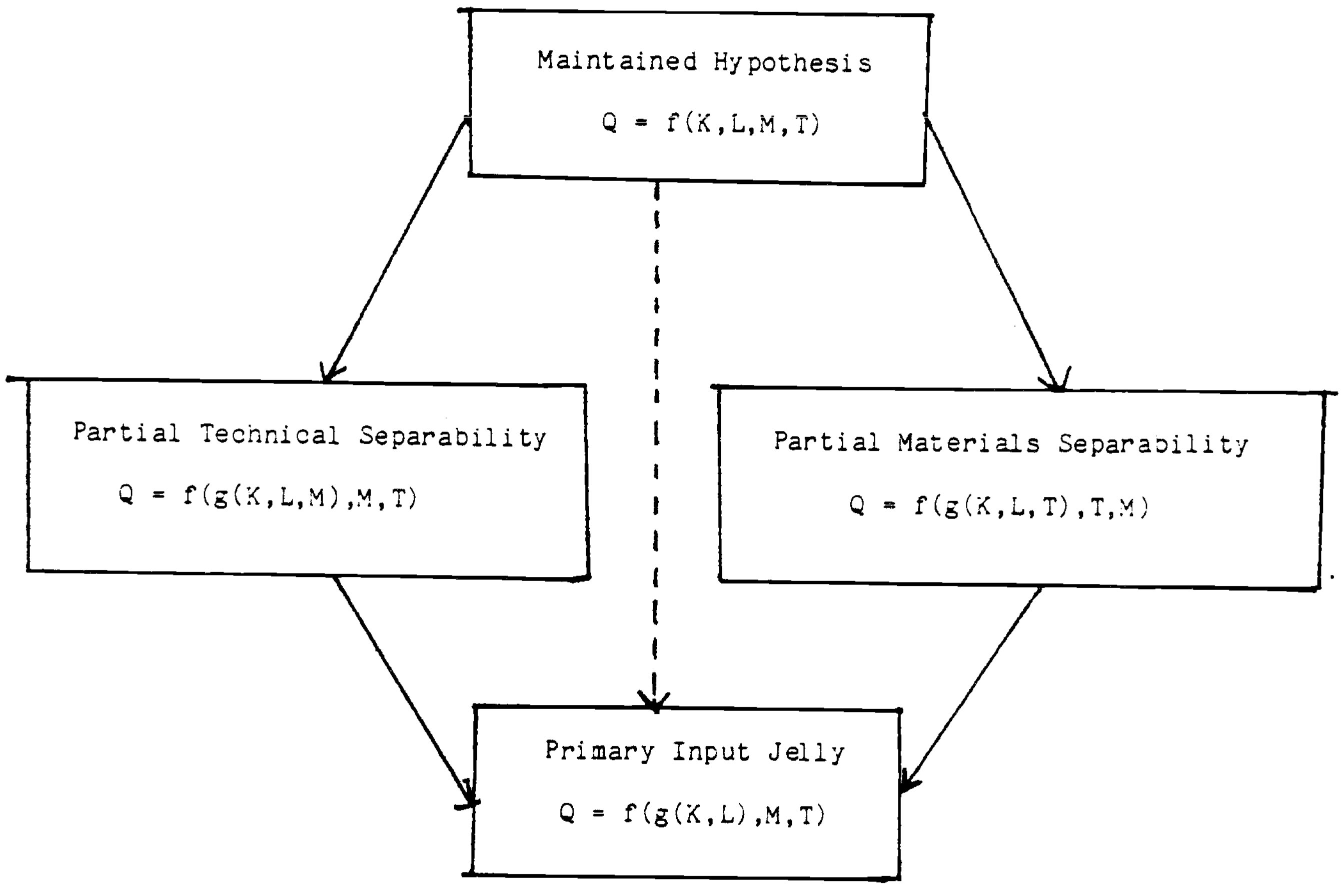

Table 1. Agricultural Productivity Growth, Canada and U.S., 1962-1978

Period	Labor Productivity		Total Factor Productivity	
	Canada	United States	Canada	United States
	(annual percent)			
1962-1970	5.67	5.94	2.22	1.13
1970-1978	5.43	3.80	2.52	1.67
1962-1978	5.54	4.87	2.37	1.41

Table 2. Translog Growth Rates for Agricultural Inputs and Output, Canada and U.S., 1962-1978

Period	Labor		Capital		Materials		All Inputs		Outputs	
	Canada	U.S.	Canada	U.S.	Canada	U.S.	Canada	U.S.	Canada	U.S.
	(annual percent)									
1962-70	-4.50	-4.73	2.21	0.81	4.58	2.83	-1.06	0.08	1.17	1.21
1970-78	-1.86	-1.58	3.77	0.85	3.15	1.45	1.05	0.55	3.57	2.22
1962-78	-3.17	-3.15	2.99	0.83	3.86	2.14	0.01	0.31	2.37	1.72

Table 3. Translog Parameter Estimates for Unconstrained Production Model*

	Canada	United States
α_o	-.044 (.022)	-.005 (.005)
α_l	.488 (.006)	.210 (.005)
α_k	.289 (.008)	.420 (.007)
α_m	.223 (.004)	.370 (.010)
γ_{ll}	.045 (.083)	.201 (.046)
γ_{lk}	.015 (.091)	-.311 (.065)
γ_{lm}	-.030 (.035)	.109 (.066)
γ_{kk}	.062 (.116)	.393 (.133)
γ_{km}	-.047 (.047)	-.083 (.107)
γ_{mm}	.077 (.029)	-.027 (.135)
θ_{lt}	-.012 (.005)	-.005 (.002)
θ_{mt}	-.002 (.002)	.003 (.004)
θ_{kt}	.014 (.005)	.002 (.003)
β_t	.190 (.003)	.013 (.001)
θ_{tt}	-.004 (.001)	-.001 (.0003)
Log of Likelihood Function	145.410	158.868

* The restrictions for symmetry and linear homogeneity are imposed. The Canadian estimates are based on 1961-1980, the U.S. estimates are for the 1960-1978 period.

Table 4. Critical Values of χ^2 Test Statistic

Number of Restrictions	Significance Levels .01	.025	.05
1	6.63	5.02	3.84
2	9.21	7.38	5.99
3	11.35	9.35	7.81

Note: In our analysis, the statistic, $-2 \ln \lambda$, has an asymptotic χ^2 distribution. λ is defined as the ratio of the maximum of the likelihood function in the constrained and unconstrained cases.