‘On the Cambridge Correction to the Measurement of Productivity in Manufacturing”*

T.K. Rymes

Author Information: T.K. Rymes
Distinguished Research Professor
Department of Economics

Mailing Address: Carleton University
1125 Colonel By Drive
Ottawa, Ontario

Telephone: 613-520-2600-3771

Fax: 613-520-3906

Email: trymes@ccs.carleton.ca

* A paper presented to the CSLS Conference on the Canada-U.S. Manufacturing Productivity Gap, 21-22 January 2000. I report my indebtedness to René Durand, now of Industry Canada, not only for providing me data used in the paper but also for comments and many challenging and fruitful discussions. I am also indebted to Professors Robert Gordon and Richard Harris for their comments. None bears any responsibility for any misuse of data nor any failure on my part to heed advice.

June 25, 2000

Introduction

Apparent 'gaps' in productivity between Canadian and U.S. manufacturing industries raise policy, theoretical and measurement issues. At a low level, one asks if such gaps are 'just' artifactual - a problem of measurement error. At a high level, issues of capital theory are involved. I position this paper between these two levels, dealing with theoretical and measurement matters which should be resolved before policy problems are discussed.
I claim the conceptual and measurement problems are severe enough to cast much doubt on how reliable any 'gaps' said to exist might be..

Prologue

Two awesome warnings about problems in measuring productivity have recently appeared in the endogenous growth literature. In Barro and Sala-I-Martin (1995, 352, my emphasis) we read

> To see the basic limitations of growth accounting, consider the example of a neo-classical economy in the steady state. Assume that the production function is Cobb-Douglas with exogenous, labor-augmenting technological progress at the rate x:
>
> $$Y = AK^{\alpha}(Le^{xt})^{1-\alpha}$$
>
> Assume, for simplicity, that the aggregate labor force L, is constant.
>
> We found in Chapters 1 and 2 that output and the capital stock in this economy grow in the steady state at the rate x. If there was no technological progress, then output and the capital stock did not grow. If we use the [standard] growth-accounting methodology ...then we attribute αx of the steady-state growth rate of output to the growth of capital at the rate x and therefore compute a [standard] TFP growth rate of $(1-\alpha)x$. We therefore assign only the fraction $(1-\alpha)$ of the growth rate of output to technological progress, whereas, in fact, no growth would have occurred without this progress. The problem is that the growth of capital at rate x is endogenous in the sense that it is driven by the technological progress at rate x. If technological progress is truly endogenous, then the reasonable economic statement is that different rates of technological change show up one-to-one in the long run as differences in growth rates of output.

While the theory of growth is of course more complex than growth accounting, this quote suggests an inherent conflict between growth theory and traditional productivity accounting - a conflict arising from the theoretical endogeneity of capital as an input and its appearance as a separate source of growth in standard growth accounting.

Second, we learn from the appendix "On some problems in measuring knowledge-based growth" in Afghion and Howitt (1998) that "As the English side of the Cambridge capital controversy used to insist, the real question is one of meaning, not measurement."[1]

PART I: Concepts

Two basic concepts of capital are confused sometimes in economic theory and almost continually in standard growth accounting. In the form of standard total factor productivity (TFP) measurement, though one starts with measures of the stock of capital goods, one really wants measures of the service flows of the capital goods. Thus, while one focuses upon the stock of capital goods (e.g., machines), as part of the wealth of the economy, one wants the service flows of such inputs, that is, the flow of services per year or per hour of the machines. In that static framework, for production analysis, the stock of capital goods is taken as given, though when the economist and national accountant try to measure the service flows, the intensity of use begins to raise all the problems associated with the measurement of economic depreciation. When the context is dynamic and the stock of capital is not given but is endogenously determined, an alternate concept of capital is required. That concept is the waiting undertaken directly or indirectly by the owners of the capital goods of the economy.

One sees this immediately in a one-commodity Solow growth model, which is free of aggregation, measurement and index number problems. Letting the technology be Cobb-Douglas and being modified in the standard Hicks-Solow-Jorgenson way, one writes
with standard notation

$$Q(t) = A(t)L(t)^{\alpha}K(t)^{\beta}$$

$$Q(t)/L(t) = q(t) = A(t)[K(t)/L(t)]^{\beta} = A(t)k(t)^{\beta}$$

In full equilibrium, where labour force growth is zero for simplicity, one has, without technical progress, capital formation equal to depreciation

$$sq(t) = \delta k(t)$$

Solving for the endogenous k and q, one has

$$k(t) = [s/\delta\ A(t)]^{1/\alpha}$$

---

[1]The appendix is drawn from Howitt's paper "On some problems in measuring knowledge-based growth, ed. Peter Howitt, **THE IMPLICATIONS OF KNOWLEDGE-BASED GROWTH FOR MICRO-ECONOMIC POLICIES** (Calgary: University of Calgary Press for the Ministry of Supply and Services, Canada, 1996). My comments on Howitt's paper in that volume deal more with the measurement of the depreciation of capital, physical and human, than I do in this paper.

and

$$q(t) = (s/\delta)^{\beta/\alpha}A(t)^{1/\alpha}$$

In strict neo-classical general equilibrium, k and q are solved for in terms of the technology, rates of depreciation (by decay), endowments (the technology permits output and capital being measured per unit of labor) and preferences (willingness of people to work as represented by L(t) and s, the rate of saving or the willingness to postpone consumption or, that is, the willingness of people to wait). If we now allow the technology to be improving, we have

$k'/k = q'/q = (1/\alpha)\,[A(t)]'/[A(t)]$, where x'/x is the growth rate of the variable..

The rates of growth of capital and output exceed the total factor productivity growth, $[A(t)]'/[A(t)]$, conceived in the standard way.

Recast the problem as

$$Q(t) = H(t)L(t)^{\alpha}[K(t)/H(t)]^{\beta}$$

$$Q(t)/L(t) = q(t) = H(t)[k/H(t)]^{\beta}$$

so that, again in steady state,

$$k(t) = (s/\delta)^{1/\alpha}H(t)$$

and $q(t) = (s/\delta)^{\beta/\alpha}H(t)$

so that the rate of growth of 'capital' and output equals the rate of total factor productivity so conceived. The basic limitation of growth accounting, alluded by Barro and Martin, is resolved.

What is H(t)? In the standard formulation, A(t) is the rate at which the efficiency of the inputs of the services of labour and capital are advancing. The standard procedure, however, fails to take into account the fact that with advances in technology the capital goods themselves being endogenous are being produced with ever increasing efficiency. From $Q(t) = H(t)L(t)^{\alpha}[K(t)/H(t)]^{\beta,}$ we see that H(t) simultaneously measures the increasing efficiency of the labour and capital and the fact that the capital good is itself being more efficiently produced, so that the standard capital input, K(t), is replaced by the Working and Waiting involved in its production just as the output Q(t) is being so expressed. Because the input of Working, the labour input is being recorded separately, it mean that the capital input is being measured in terms of the Waiting required both for its maintenance and augmentation.

Again, allowing the technology to be improving, then $k'/k = q'/q = H(t)'/H(t)$ so that the rate of growth of output and capital are equal to the rate of growth of total factor productivity measured in Harrod units, exactly consistent with economic theory.

The Harrodian rate of technical progress shows that output is the result of the application of the services of those supplying labour and those supplying capital or more simply and exactly Working and Waiting, both of which are exogenous and the efficiency of both which is being augmented by technical progress. Flows of consumption must be given up in order for the capital stock to be maintained in a stationary context and for it to be growing in the dynamic context of technical progress.

In the standard growth accounting case, "the growth rate of capital is endogenous" yet is treated as primary input source of growth. In the Harrod case, the capital being waiting, it is not endogenous and if there were any exogenous increase in such capital, it would in the Harrod case be correctly treated as a source of growth. The capital goods are simply part of the outputs and inputs of the economy and should not meaningfully be assigned a separate role in economic growth.

As well, consumption per head

$$c(t) = (1-s)q(t)$$

will in the standard case be,

$$c(t) = (1-s)(s/\delta)^{\beta/\alpha}A(t)^{1/\alpha}$$

and will be growing faster than productivity as conceived in the standard way while in the Harrod case

$$c(t) = (1-s)\,(s/\delta)^{\beta/\alpha}H(t)$$

will be growing at the rate of productivity advance.[2]

Of course, if one mistakenly (as the Barro-I-Martin would seem to imply) takes Harrodian technical progress as only labour augmenting and writes

$$Q(t) = A(t)L(t)^{\alpha}K(t)^{\beta}$$

then

$$q(t) = A(t)^{\alpha}k(t)^{\beta}$$

so that from steady state one has

[2] Hulten (1992 , 1999) argues that the traditional measures are appropriate for the study of production or capacity efficiency while the Harrod measures are more appropriate for the study of improvements in welfare over time. In my view the traditional measures are conceptually inadequate for both concerns.

$$sA(t)^{\alpha}k(t)^{\beta} = \delta k(t)$$

or

$$k(t) = (s/\delta)^{1/\alpha}A(t)$$

and

$$q(t) = A(t)(s/\delta)^{\beta/\alpha}$$

so $$q'/q = k'/k = A(t)'/A(t) = H(t)'/H(t) \text{ as before.}$$

Considering again the two concepts of capital, one thinks of the service flows provided by the buildings, machines and inventories making up the items in a stock of capital. The prices of such items are the gross rentals (net if the problems of depreciation can be handled). The stocks are taken as given. In the second question, additions to the stock of capital can only occur if saving or waiting is occurring if one lives in a classical world and if savings and capital formation are occurring if one lives in a Keynesian world. The prices of such waiting are the rates of return. Ignoring depreciation and capital gains, the rentals or service prices in equilibrium will be RP_k where R is a vector of rates of return and P_k is a vector of the prices of the stocks of capital goods. The Rs are the prices of waiting.

The concept of waiting must not be confused with merely net savings. In a stationary economy, where the gross savings are just sufficient to match the depreciation on the stock of capital goods, then net savings would be zero. Owners of capital goods in a classical world would still be waiting (carrying the stock through time) in the sense that consumption could be higher in the present if, in the one commodity case, part of the stock of capital were consumed, resulting in lower consumption flows in the future. In optimal neoclassical growth theory, the rate of saving is also endogenous but the fundamental capital concept, the flow of waiting, remains unimpaired.

Total Factor Productivity (Aggregate)

The modern theory of growth correctly assumes that capital accumulation, given the willingness to wait, and technological advance are endogenous. In the old Solow growth theory, capital was endogenous while technical advance was taken as exogenous. In both theories whether one is measuring rate of exogenous or endogenous rates of technical change, it is wrong in the measurement of productivity to account for capital in the sense of reproducible goods as a separate source of growth. It is clear from neoclassical growth theory that the capital stock and its services are endogenous. When corresponding productivity measures are attempted, however, capital and technology surprisingly play independent roles in standard growth and productivity accounting.

In the context of a one commodity world,[3] with competitive pricing, one starts with a standard measure of the GDP: PQ = WL + RPK + DPK. The additional notation is that P stands for the nominal level of the commodity price, RP the net rental on capital goods and R the net rate of return to capital or the rate of return to waiting and D is the rate of depreciation.

In standard Hicks-Solow-Jorgensen growth accounting formats, from $Q(t) = A(t)L(t)^{\alpha}K(t)^{\beta}$, one has

$$[\propto w + \beta(r+p) + \gamma(p^* + p)] - p = t = q - [\alpha l + \beta k + \gamma k]$$

where α, β and γ are the relevant partial input elasticities and where p* is the growth rate of the price of capital consumption (since D is a constant rate of depreciation by decay in this simple exposition, $p^* = 0$).

In the steady state $q = k$, $D'/D = 0$, $r = R'/R = 0$, so one has

$$\alpha(w-p) = t = \alpha(q-l)$$

Given the Harrod transforms, which follow from $Q(t) = H(t)L(t)^{\alpha}[K(t)/H(t)]^{\beta}$ and were first introduced by Professor Lawrence Read (1968), one has

$$[\alpha w + \beta® +p+h) + \gamma(p+h)]-p = h = q - [\alpha l + \beta(k-h) + \gamma(k-h)]$$

so that one has

$$w - p = h = q - l$$

as we saw before. As was previously indicated, the basic mistake of the standard Hicks-Solow-Jorgenson growth accounting, alluded by Barro and Martin, is eliminated.

The Harrod transforms complete, so to speak, the logic of the standard exercise. The latter measures the transformation of primary inputs into outputs but fails to complete the exercise even though in this simple case the capital input is the same 'stuff' as output (see Bliss, 1975). The Harrod transforms complete the exercise by transforming the growing capital into the primary inputs, labour and waiting, required for its production and reproduction. Since the labour inputs are accounted for, the waiting primary inputs are exactly isolated by the Read-Harrod procedures, that is, k-h is the rate of change of waiting. This is even more clearly and sharply illustrated by comparing the two measures expressed in terms of the transformation of input prices into output prices. Technical progress means primary capital input prices will, in general, be rising relative to output prices. Yet, in the

---

[3]In this paper, I ignore all natural agents, including land.

standard transformation, among the rates of change of input prices, there is an output price in the expression r + p. Since r = 0 by argument, the rate of change of the capital input price, p, is the identical to the rate of change of the output price. The Harrod transformation replaces that with r + p + h which says, when technical progress is occurring, if that change is neutral, the price of working and waiting must also be rising at the same rate h.

In words, if one thinks in terms of the representative agent assumption (with all the known pitfalls spelled out by Hartley, 1997), the fundamental primary inputs are the Working and Waiting supplied by the representative person.[4] In a technically progressive world, the efficiency of these inputs is increasing - which is what the Harrod concept and measures reflect. In such a world the stock of capital is growing (unless the technical progress is ultra-anti-waiting biased) but this growth cannot be considered a separate source of growth.

The late Edward Denison (1993, 52), inventor (see Gordon, 1993) of growth accounting, in accepting the Read-Harrod transforms or what I now call the Cambridge Correction, says

> Suppose that new knowledge permits more capital goods, unchanged in design, to be produced with no increase in the factor units used in their production. The usual procedure....will show the capital stock increasing as the extra capital goods enter the stock and will credit capital (and total input) with the resulting gains in national product. This occurs even though the increases in output of capital goods results from advances in knowledge, not from saving in the fundamental sense of foregoing consumption.

Three final points can be made in the simple one commodity world. First, suppose the exercise were done in net terms, so that one would have

$$PY = WL + RPK$$

where Y is Pigovian national income. In standard growth accounting, one has

$$\alpha^*(w-p) = t^* = \alpha^*(q-l)$$

and $$(w-p) = h = q-l$$

Since $t^* > t$, while h is unchanged, the standard measures are not invariant to aggregation over capital inputs.

---

[4] For a discussion of the fundamental inputs of Waiting and Working in economic production see F. Lavington, (1934), Part III The Transport of Capital and Rymes, (1997).

Second, no steady state neutrality need be imposed. In the Harrod transform, one has

$$t/\alpha = h$$

so that $q - k - h = q - k - t/\alpha$

and $r + p + h = r + t/\alpha$

so that $q - k < 0$ or >0, $r < 0$ or >0 and the shares may be changing.[5] The meaningful Cambridge Corrections still go through.

Would the Cambridge Correction make a difference? As illustrated later, Alexandra Cas and I showed in our experimental estimates that ***the Cambridge Correction increases the rate of total factor productivity growth in Canada between 1961 and 1980 by some 28%, almost a third increase - a substantial result.*** (The difference is even greater for the 1960s). Professor Charles R. Hulten (2000) reports similar results for East Asian economies when the Harrod transforms or the Cambridge Corrections are made.

I emphasize the confusion in standard total factor productivity measurement arises in the most simple one commodity growth parable. No problems of capital aggregation or measurement are involved. The problem stems from confusion, as Howitt warn, about the concept of capital.

Further insights may be gleaned from the simple two sector story. It is examined because it raises, in the most simple guise, all the conceptual and measurement problems encountered at the level of manufacturing and its subcomponents.

The accounts are

$$P_C C = WL_C + R_C P_K K_C + D_C P_K K_C$$

$$\Delta GK = WL_K + R_K P_K K_K + D_K P_K K_K$$

where the subscripts denote sectors or industries, ΔGK is the value of gross capital formation or the gross output of the capital good sector.

The competing measures of total factor productivity, where the δ_s represent D'/D, are

$$c - [\alpha_c l_C + \delta_C + k_C)] = t_C = [\alpha_C w + \beta_C(r_C + p_K) + \gamma_C p_K] - p_C$$

[5]This is where such constru $\beta_C k_C + \gamma_C$(cts as Tornquist indexes must come into play. The fundamental problem remains, however, theoretical and conceptual.

for the consumption good sector and

$$dk - [\alpha_K l_K + \beta_K k_K + \gamma_K(\delta_K + k_K)] = t_K = [\alpha_K w + \beta_K(r_K + k_K) + \gamma_K(k_K)] - p_K$$

for the capital good sector

and

$$c - [\alpha_C l_C + \beta_C(k_C - h_K) + \gamma_C(\delta_C + k_C - h_K)] = h_C = [\alpha_C w + \beta_C(r_C + p_K + h_K) + \partial_C(p_K + h_K)] - p_C$$

$$dk - [\alpha_K l_K + \beta_K(k_K - h_K) + \gamma_K(\delta_K + k_K - h_K\_] = h_K = [(\alpha_C c + \beta_K(r_{K+} p_K + h_K) + \gamma_K(p_K + h_K)] - p_K$$

All the previous discussions apply. If there is no technical progress in the production of capital goods ($t_k = h_k = 0$), then the competing measures of productivity in the consumption good sector will be the same.

When there is technical improvement in the production of the capital good, then the traditional measures not only understate productivity advance in the capital good sector (for reasons dealt with in the one commodity case) but also in the consumption good sector. The traditional measures would show a greater output of consumption goods because more capital is involved in their production, even though the waiting undergone to obtain consumption may not have changed.

Two things should be noted. The Harrod-adjusted or Cambridge Corrected measures of total factor productivity are ‘predictors’ of the change in the price of capital goods relative to consumption goods (See Rymes, 1971 and Cas-Rymes, 1991). Given the conceptual base involved on their construction, this is hardly surprising. The traditional measures exhibit no such relationship. Under competitive conditions, where primary output prices of working and waiting were the same in the two sectors, one would predict that different rates of technical process or productivity growth of these primary inputs in the two sectors would ‘predict’ relative price movements. Indeed, that is what one would associate with different rates of productivity advance.

If the capital goods sector was not merely producing more capital goods more efficiently but was as well said to be producing better capital goods, then one would argue that the hedonically-corrected price of the capital good would be falling relative to their unit money prices. The constant price capital stocks and capital consumption inputs, and the gross output of the capital good sector would be shown as exhibiting higher rates of growth. The revised growth accounts would be:

$$c - [\alpha_C l_C + \beta_C k_C^* + \gamma_C(\delta_C + k_C^*) = t_C^* = [\alpha_C w + \beta_C(r_C + p_K^* + \gamma_C(p_K^*)] - p_C$$

$$dk^* - [\alpha_K l_K + \beta_K k_K^* + \gamma_K(\delta_K + k_K^*)] = t_K^* = [\alpha_K w + \beta_K(r_K + k_K^*) + \gamma_K(k_K^*)] - p_K^*$$

and

$c - [\alpha_C l_C + \beta_C(k_C^*-h_K^*) + \gamma_C(\delta_C+k_C^*-h_K^*)] = h_C^* = [\alpha_C w+\beta_C(r_C+p_K^*+h_K^*) + \partial_C(p_K^*+h_K^*)] - p_C$

$dk^*-[\alpha_K l_K +\beta_K(k_K^*- h_K^*) + \gamma_K(\delta_K + k_K^* - h_K^*)] = h_K^* = (\alpha_C c + \beta_K(r_{K+}p_K^*+h_K^*)+\gamma_K(p_K^*+h_K^*)]- p_K^*$

It can be immediately seen that the traditional measures will show slower rates of productivity advance in the consumption goods sector and higher rates of such advance in the capital good sector — simply because of the hedonically adjusted price indexes for the capital goods. The corrected productivity measures will tend to show unchanged productivity advances in the consumption goods sector. (If $h^*_c - h^*_k = h_c - h_k$ and if $p^*_k + h^*_k = p_k + h_k$ which would be the case if the rate of change of the prices of the primary inputs in the production of capital and consumption goods remained invariant to the hedonically-adjusted price indexes.)[6]

Shortage of space prevents me from discussing the vexed problem of measuring depreciation and net stocks of capital when the hedonically-adjusted price indexes for capital goods are used because, in that case, the rate of depreciation on existing capital reflects obsolescence. The rate of depreciation must reflect the decline in the prices of older capital goods as they are superseded by new models, which poses difficult aggregation and strictly measurement problems.

How does one aggregate the two measures of total factor productivity? In the Harrodian case, the answer is straightforward whether the aggregate is gross or net domestic product. In the Harrodian case, the weights, if the aggregate is GDP, will be $P_C C/P_C C + P_K \Delta K$ and $P_K \Delta K/P_C C + P_C \Delta K$ so the aggregate of productivity advance will be

$$[P_C C/(P_C C + P_C \Delta_K)](h_c) + [(P_K \Delta K)/(P_C C + P_K \Delta_K)](h_k)$$

and if the aggregate is NDP, the aggregate measure will be

$$P_C C/[P_C C + P_K(\Delta K-D_C K_C-D_K K_K](h_C)+ [P_K(\Delta K-D_C K_C-D_K K_K)]/[P_C C + P_K(\Delta K-D_C K_C-D_K K_K]h_K$$

[6]I conjecture it is the ‘buckets in the well’ movement of total productivity in the consumption and capital goods sector measured in the standard way which led Edward Denison to question the hedonically-adjusted price indexes for capital goods like computers. See Denison and Gordon (1993). In addition, Denison was possibly pointing out that the procedure involves confusion in attributing higher marginal products to new capital goods which would reduce the importance of standard total factor productivity, a factor discussed by Professors Lipsey and Carlaw (2000).

In this case, $P_C C$ and $P_K(\Delta K - D_C K_C - D_K K_K)$ are the appropriate measures of net sectoral output.

For GDP for the traditional measures the weights would be the same, but for NDP the sector weights would have as numerators

$P_C C - P_k D_C K_C$ and $P_K \Delta K - P_k D_K K_K$

(and the productivity measures for each sector would be constructed over such sectoral net output measures). As we saw previously, the netter the output concept in sectoral total factor productivity measures, the higher the rate of sectoral and aggregate productivity advance.

This is partly the aggregation puzzle[7] previously discussed but also results from two things: i) the 'netter' the output concept in sectoral productivity estimates the higher will be traditional productivity estimates, and ii) the use of a meaningless output concept at the sector level - the so-called real net value added approach to sectoral output measurement.

PART II - MEASURES

Total Factor Productivity (Manufacturing)

We are now in a position to examine total factor productivity measurement at the industry level in manufacturing. The sector manufacturing entails major groups (and three digit industries) which are similar to consumption and capital goods sectors. Two interconnected points may be made.

1. To the extent that Canadian manufacturing industries import capital goods produced in America when hedonically-adjusted price indexes are employed, only half the 'buckets in the well' problem appears.[8] Manufacturing industries in Canada using such capital goods will be shown as evidencing low productivity increases as their capital stocks and capital consumption allowances in constant prices increase. The US capital goods producing industries, where the hedonically-generated production advance is occurring, will show, other things being equal, greater total factor productivity advance. However, to the extent that there are capital goods industries in Canada producing goods where the hedonic adjustment is applied and exporting such goods to America (e.g., the high tech software manufacturers in Ottawa), the other 'half' of the 'buckets in the well' problem applies, namely it will be the producing industries in Canada showing the hedonic productivity

---

[7]See the discussion on this point in the OECD Manual on Productivity Measurement (Schreyer, 1999)

[8]For a discussion of the empirical importance of hedonic manufacturing gross output price indexes for computers in Canada and the USA, see Baldwin et al (1997)

advance whereas the importing American industries will be showing lower productivity advance. Thus, it may well be that the superior performance of electrical apparatus and supplies major groups in US versus Canadian manufacturing is simply a hedonic artifact — badly necessitating the Harrod or Cambridge correction![9]

2. More generally, manufacturing is a sector in which the major groups and industries are characterized by substantial intra sector or inter industry technological interdependence. To that problem, I now turn.

At the industry level, where industries, for statistical purposes, are composed of establishments and where such industries use large amounts of intermediate inputs from other industries, total factor productivity measures produced in the standard will be much smaller, if the output concept is gross compared to the result when the output concept is net value added. It is now well understood that constant price net value added measures at the industry level are meaningless. Again, this is a conceptual as distinct from an index number or measurement problem.

In the two sector story, net value added by sector is $P_C C - P_K D_C K_C$ and $P_K \Delta K - P_K D_K K_K$ whereas net output by sector is $P_C C$ and $P_K \Delta K - P_K (D_C K_C + D_K K_K)$ the latter two being meaningful measures of output. In current prices, the net value added constructs are meaningful, in constant prices the measure for the consumption good sector is without meaning. What theoretical sense can be attached to the theory of consumption goods less the capital goods used up in their predictions - a problem made even worse by the hedonically corrected capital consumption allowances.

If, in the two sector story, there is technical advance in the production of capital goods, the consumption good sector will 'hire' more of them. Both the stock of capital and the capital consumption allowances in 'real' terms, that is, in terms of capital goods in the production of consumption goods, will rise. The production of consumption goods will rise but the net output of consumption goods, net output in terms of 'real' net value added will not rise by as much (the rise in such net output will be equal to the increase in the gross output less the weighted increase in the capital consumption allowances in 'real' terms. (Of course, if the technology is Cobb-Douglas, the shares will be unaffected.) The increase in the net output of consumption goods will, it is argued in traditional measures of total factor productivity, be completely accounted for (or more so if the hedonic adjustment is made) by

[9] Since manufacturing industries in Canada (U.S.) export intermediate outputs to and import intermediate inputs from the U.S. (Canada), the general problem of measuring quality change in such constant price outputs and inputs will bedevil the traditional estimates much more than the Cambridge Corrections. This point assumes that it is the new goods which are exported and imported not the sales or purchases of new firms whose prices depend upon the capitalized ideas which may eventually take the form of computers and software. On this point, I am indebted to Professor Richard Lipsey.

the increase in the constant price net stock of capital in the production of the consumption goods. Thus there would be shown no productivity advance in the production of consumption goods even though real wages and real returns to waiting in terms of consumption goods would be higher.

The representative agent in the economy would be enjoying increases in his or her consumption even though the traditional measures would show no increase in the productivity of the factors of production involved in the production of consumption goods. The Cambridge Correction would show that the productivity of the primary inputs of working and waiting, directly and indirectly involved in the production of consumption goods would be higher, reflecting precisely the result the economic system itself would be generating.[10]

If one rejects ‘real net value added’ as a meaningful measure of output, then both the standard and Harrodian measures of total factor productivity must use gross output measures. When the traditional measures are aggregated over three digit industries to major groups and manufacturing, the Domar-Hulten aggregation procedures must be followed with the result that total factor productivity of the major group level will in general exceed that for the three digit industries and that for all of manufacturing will also exceed that for all the major groups. Once again, the traditional measures are subject to the aggregation over capital or endogenous inputs problem. The Harrod constructs incorporate the advance in the efficiency of all the primary inputs including those in the industries supplying the industry in question with intermediate inputs and fixed capital inputs. Since the industry in question may itself be supplying such industries with some intermediate inputs, the idea that the interdependence of technology can be disentangled in the traditional way breaks down and use must be made of input -output accounts supplied by statistical agencies in the preparation of the Harrodian estimates..

As an illustration, suppose we consider two industries, i and j shipping intermediate outputs to each other as intermediate inputs. To focus only those intermediate relationships in growth accounting format, traditionally, one has

$$t_i = q_i(=m_{ij}) - [...\beta_{ji}m_{ji}]$$

$$t_j = q_j(=m_{ji}) - [...\beta_{ij}m_{ij}]$$

where the m_{ij}s are the rates of growth of the intermediate inputs used in industry j produced in industry i and so forth.

---

[10]If in the two sector story whether or not the two Harrodian measures of total factor productivity are the same, ie, hc = hk, the re-expression of the capital goods in terms of consumption goods is not necessary, contrary to the belief expressed in the OECD manual, 53, n. 50.

With the Cambridge Correction, one has

$$h_i = q_i(=m_{ij}) - [...\beta_{ji}(m_{ji} - h_j)]$$

$$h_j = q_j(=m_{ji}) - [...\beta_{ij}(m_{ij} - h_i)]$$

The interdependence of technologies must be taken into account, as economic theory would suggest, in the Corrected versions. Thus,

$$h_i - \beta_{ji}h_j = t_i$$

$$-\beta_{ij}h_i + h_j = t_j$$

or $$h_i = [t_i + \beta_{ji}t_j]/[1 - \beta_{ij}\beta_{ji}]$$

and $$h_j = [t_j + \beta_{ij}t_i]/[1 - \beta_{ij}\beta_{ji}]$$

so that $hi > ti$ and $hj > tj$.

If we further supposed that, in the standard way, $tj = 0$, then

$$hi = ti/(1 - \beta ij\beta ji)$$

and $$hj = \beta ijti/(1-\beta ij\beta ji)$$

We saw in the one sector case that $h = t/\alpha$. Here, for industry i, α is replaced by $1 - \beta ij\beta ji$ reflecting the Leontief-type interconnections among the two industries such that if industry i advances in its productivity, though it produces none of its own inputs directly, it does so indirectly which must be factored into an account of how much total factor productivity growth in industry i is in fact taking place.

Further Problems

The analysis in this paper is extendable to 'human capital'. Estimates of human capital stocks will grow in technically progressive economies as the ability of the economic system, through formal education and training 'on the job', to produce more of it. Again, enhancement of the efficiency of the production of human capital must be formally incorporated in productivity estimates as a fortiori in the human capital case, the distinction between 'waiting' on the part of the owners of the human capital and the stocks they carry and augment is paramount. Yet, it must not be forgotten that, with technical progress taking the form of the production of 'better' human capital via the hedonically adjusted inputs approach, the depreciation of human capital becomes critical. Here the measurement problems are particularly severe! That is, when the hedonic adjustment is made to the price indexes for new capital goods, it must not be forgotten that the rate of depreciation by obsolescence of existing capital goods is higher and the growth rates of constant price capital consumption allowances will likely be greater. One must not forget that human capital is also being made obsolete. I have seen no adequate discussion of these problems in the endogenous growth literature.

The interindustry flow of intermediate inputs and outputs will be enhanced as more and more such specialization occurs. One industry, the banking industry, supplies transaction services which appear as intermediate inputs in every industry. Elsewhere (Rymes, 1999) I have tried to show how monetary policy affects the efficiency and prices of banking services and how such productivity effects lead through into the non-banking sectors of the economy. I conjecture that the tight monetary policy in Canada of the 80s and 90s must surely be considered as one of the sources of the 'observed' productivity slowdown in Canadian relative to American manufacturing.

Empirical Counterparts

In aggregate terms, the differences between the Harrodian and traditional measures of total factor productivity can be substantial. Earlier experimental estimates found in Cas-Rymes and shown in Table l indicate that for the decade of the 1960s before the major downturn in productivity advance in the early mid-70s, the new measures show total factor productivity increasing by some 28% whereas the traditional measures show 20%, a not insignificant 40 percent difference.[11]

More interesting, as they pertain to major groups in manufacturing, for the period 1961-73, the Cas-Rymes estimates are compared with the traditional measures in Table 2.

As would be expected the Harrodian transforms show greater productivity advance than do the traditional measures. It is of interest to note that the ranking among the industries as well is not invariant to the transforms. Thus not only are the standard measures of multifactor productivity questionable at the sectoral level, not unexpectedly, they even misrepresent the relative rates of TFP growth.

More up-to-date measures for manufacturing are available from Statistics Canada.[12] From the small matrix aggregation of three digit and major groups up to the Manufacturing Division, in Table 3 are shown log growth rates of total factor productivity for Manufacturing

---

[11]The partial labour productivity indexes reveal that the Harrodian measure grew less rapidly indicating that while output per unit of waiting was growing, it was not growing as rapidly as output per unit of labour, illustrating that Harrod measures need not be seen as just labour-augmenting.

[12]Again, I acknowledge the kindness of René Durand and continue to warn the reader about any possible misuse I make of the data from Statistics Canada.

for 1961 to 1992. The Harrodian estimates in Table 3 transform only the domestically produced intermediate inputs used in Canadian manufacturing into their primary inputs. No transform is done for imported intermediate inputs or for capital goods, whether domestically produced or imported. The Harrodian estimates therefore have a downward bias. The traditional estimates, at the gross output level, must be less than such estimates at the level of value added. Again, the Harrodian estimates tend to run ahead of the traditional measures. Over the thirty one year period, the average rate of growth of the Harrodian TFP is 3.1 while that for the traditional measure is 0.7. As was revealed as well in the aggregate estimates in Table 1, productivity advance can sometimes appear to be negative and sometimes more so for the Harrodian transforms.

For selected major groups, more up-to-date Statistics Canada data are presented in Table 4 for Machinery, Transportation Equipment and Electrical Products. Three TFP concepts are illustrated. The first measures are presented on a gross output basis, the second illustrates the BLS procedure where the Bureau of Labour Statistics in the USA attempts to account for the productivity associated with intermediate inputs from industries within Manufacturing used by the three major groups while the third are the quasi-Harrod approximations, which take account of the productivity advance in all industries, not just in Manufacturing as in the BLS way, producing intermediate inputs used by the three major groups under examination. It should be remembered again the Harrod approximations are just that because no account is taken of the productivity advance of those intermediate inputs imported nor the productivity advance taking place in those industries supplying capital goods to the three major groups, again whether such capital goods are imported or domestically produced . As expected, measured total factor productivity are higher as the approximations move closer to the desired Harrodian measures.

These data illustrate how different are the measures of TFP whether at the aggregate level for the Canadian economy, total manufacturing or major groups within Manufacturing as we move away from the standard growth accounting formats towards the Cambridge Corrections. A full and complete comparison of Canadian and US manufacturing TFPs requires similar Harrodian estimates for American industries when account is taken of the extensive interindustry technological relationships between Canadian and American manufacturing activities. To prepare such estimates thoroughly, one would need constant price American and Canadian integrated input output systems. I do not understate the empirical problems involved. Properly done, to avoid standard problems in international comparisons, the constant price measures at the industry level (or more precisely the constant price input-output accounts) in Canada and US must be constructed in both Canadian and American prices (see Heston and Lipsey, 1999).

Even with the limited evidence presented here, it is clear that grave questions may be raised about any standard TFP comparisons between American and Canadian manufacturing industries. Much more empirical work has to be done before any 'GAPS 'in Canadian versus American TFPs for Manufacturing could possibly be entertained.

Table 1

Indexes of Harrodian and traditional measures of multifactor productivity
private Canadian economy, 1961-80 (and partial labour productivity indexes),
1971=100.0

	Multifactor		Partial Labour Productivity	
	New (1)	Traditional (2)	(3)	(4)
1961	77.8	83.1	71.3	65.8
1962	83.3	87.4	74.0	68.9
1963	85.7	89.4	76.6	71.8
1964	88.5	91.5	79.6	74.9
1965	90.6	93.2	81.8	77.9
1966	92.4	94.7	84.8	81.6
1967	92.2	94.1	85.6	82.9
1968	96.2	97.1	90.7	88.6
1969	98.3	98.7	93.9	92.3
1970	98.2	98.6	95.3	95.1
1971	100.0	100.0	100.0	100.0
1972	102.5	102.1	103.5	104.0
1973	106.3	104.8	107.2	107.8
1974	104.7	103.4	106.2	108.4
1975	102.9	101.5	105.0	108.5
1976	105.9	104.1	109.9	113.8
1977	105.8	104.0	111.0	116.5
1978	105.5	104.0	111.8	117.0
1979	106.4	104.7	114.4	118.1
1980	106.7	104.5	112.9	118.0

Sources: Columns 1-3, Cas-Rymes; column 4, Statistics Canada, *Aggregate Productivity Measures* (various issues).

Table 2

Rates of Growth of Total Factor Productivity, 1961-73

Major Groups 1949 SIC	Harrodian	Traditional
Food & beverages	2.9	0.6
Tobacco products	4.6	1.7
Rubber & plastic products	4.5	2.8
Health	1.9	0.6
Textiles	4.4	2.6
Knitting mills	4.6	2.5
Clothing	2.5	0.7
Wool products	1.4	0.0
Furniture & fixtures	2.9	1.3
Paper and allied industries	2.5	0.8
Printing, publishing & allied industries	2.2	1.0
Primary metals	2.3	0.6
Metal fabricating	3.2	1.7
Machinery	2.3	0.9
Transportation equipment	3.4	2.0
Electrical products	3.8	2.2
Nonmetallic mineral products	3.5	1.8
Products of petroleum and coal	2.5	1.0
Chemicals	3.2	1.5
Miscellaneous manufacturing	2.5	1.2

In Table 2, the inputs are intermediate, imported, government, labour, capital consumption allowances and the net capital stocks. The Harrodian estimates are biased downward because no account is taken as the improving efficiency with which imports are produced. Following the Domar-Hulten aggregation, the traditional estimates would be higher if the output concept had been value added and even higher had it been net value added.

Source: Cas-Rymes, Table V-2.

Table 3

Log Rates of Growth of Total Factor Productivity 1961 to 1992
Total Manufacturing, Canada

	Harrodian	Traditional
1962	5.4	3.0
1963	3.7	1.5
1964	3.0	1.9
1965	2.3	1.3
1966	1.0	0.2
1967	-2.0	-0.8
1968	2.9	1.7
1969	3.4	1.8
1970	-1.3	-0.9
1971	3.3	1.7
1972	3.4	2.1
1973	4.9	2.4
1974	-1.2	0.0
1975	-3.3	-2.1
1976	3.8	2.2
1977	1.8	1.7
1978	0.6	0.7
1979	0.6	0.2
1980	-2.1	-1.1
1981	6.5	1.1
1982	-4.1	-0.2
1983	4.1	2.5
1984	5.1	2.8
1985	1.5	1.0
1986	0.0	-0.5
1987	0.1	0.2
1988	0.5	-0.1
1989	-0.7	-0.5
1990	-2.3	-1.4
1991	-1.5	-1.3
1992	0.6	0.3

Source: Statistics Canada

Table 4

Average Log Rates of Growth of Total Factor Productivity, 1961-92
Effects of Different Concepts

Three Selected Major Groups in Canadian Manufacturing

	Gross Output	BLS	Quasi-Harrodian
Machinery	-0.1	0.3	0.5
Transportation equipment	1.0	1.2	1.5
Electrical products	1.6	1.8	2.4

Source: Statistics Canada

Conclusion

In this paper, I have shown that the Cambridge Corrections to total factor productivity measurement resolve the Barro-Sala-I-Martin so-called limitations to growth accounting by identifying that capital input, waiting, which in classical analysis is exogenous to the growth process. Capital goods and intermediate inputs are strictly endogenous and therefore must not be accorded separate roles, as they are in standard Hicks-Solow-Jorgenson measures, in accounting for total factor productivity.

The problems discussed and data presented here suggest, where industries in Canadian and U.S. manufacturing are technologically interdependent, we still are a long way from any satisfactory comparison of the total factor productivities of such industries. The gaps remain in our concepts and measures.

REFERENCES

Aghian, Philippe & Howitt, Peter, 1998, **ENDOGENOUS GROWTH THEORY** (Cambridge: MIT Press,).

Baldwin, Andrew et al., 1997, "New goods from the perspective of price making in Canada and Japan", eds. Timothy F. Bresnahan and Robert J. Gordon, **THE ECONOMICS OF NEW GOODS** (Chicago: University of Chicago Press for the NBER)

Barro, Robert J. and Sala-I-Martin, Xavier, 1995, **ECONOMIC GROWTH** (New York: McGraw-Hill).

Bliss, Christopher, 1975, **CAPITAL THEORY AND THE DISTRIBUTION OF INCOME** (Amsterdam: March Holland).

Cas, Alexandra and Rymes, Thomas K., 1991, **ON CONCEPTS AND MEASURES OF MULTIFACTOR PRODUCTIVITY, CANADA 1961-80** (New York: Cambridge University Press).

Denison, Edward F., 1993, "The growth accounting tradition and proximate sources of growth", eds. A. Szirmai, et.al., **EXPLAINING ECONOMIC GROWTH: Essays in Honour of Angus Madison** (Amsterdam: North Holland).

Denison, Edward F., 1993, "Robert J. Gordon's Concept of Capital", **REVIEW OF INCOME AND WEALTH**, XXXIX, March, 89-102.

Domar, Evsey, 1961, "On the measurement of technological change", **ECONOMIC JOURNAL**, LXXI, 709-29.

Gordon, Robert J., 1993, "Reply: The Concept of Capital", **REVIEW OF INCOME AND WEALTH**, XXXIX, March, 103-110.

Hartley, James E., 1997, **THE REPRESENTATIVE AGENT IN MACROECONOMICS** (London: Routledge).

Heston, Alan, and Lipsey, Robert E., 1999, **INTERNATIONAL AND INTERAREA COMPARISONS OF INCOME, OUTPUT AND PRICES** (Chicago: University of Chicago Press for the NBER).

Hulten, Charles, 1978, "Growth accounting with intermediate inputs", **REVIEW OF ECONOMIC STUDIES**, XLV, 511-19.

Hulten, Charles R., 1992, "Accounting for the Wealth of Nations: The net versus gross output controversies and its ramifications", **SCANDINAVIAN JOURNAL OF ECONOMICS**, XCIV, Supplement, 9-24.

Hulten, Charles R., 2000 "Total factor productivity: A short biography", NBER Working Paper 7471

Lavington, F. 1934, **THE ENGLISH CAPITAL MARKET** (London: Methuen Co. Ltd.), Part III The Transport of Capital.

Lipsey, Richard G. and Calaw, Kenneth, 2000, "What does total factor productivity measure?" Vancouver, Simon Fraser University, Mimeo, 02 May.

Read, L.M., 1968, "The measure of total factor productivity appropriate to wage-price guidelines", **CANADIAN JOURNAL OF ECONOMICS**, I, May, 349-58.

Rymes, Thomas K., 1971, **ON CONCEPTS OF CAPITAL AND TECHNICAL CHANGE** (Cambridge: Cambridge University Press).

Rymes, Thomas K., 1997, "Productivity of Working and Waiting: Static and Dynamic Aspects of the Capital Controversy", ed. P. Arestis et al, **CAPITAL CONTROVERSY, POST-KEYNESIAN ECONOMICS AND THE HISTORY OF ECONOMIC THOUGHT: Essays in Honour of Geoff Harcourt**, I (London: Routledge)

Rymes, Thomas K., 1999, "Effects of monetary policy on productivity in Canada", **CARLETON ECONOMIC PAPERS 99-09**, forthcoming in Statistics Canada, **PROBING THE NEW ECONOMIC REALITIES**.

Schreyer, Paul, November 1999, **OECD MANUAL ON PRODUCTIVITY MEASUREMENT** (Paris: OECD).

-tk-