THE ANALYSIS OF AGRICULTURAL PRODUCTIVITY: ALTERNATIVE VIEWS AND VICTORIAN EVIDENCE

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1. Introduction

The course of Australian agricultural development in the decades between 1870 and the first world war is frequently described in terms of the introduction and diffusion of important innovations that were essential to the process of closer settlement, the extension of the margin of cultivation, and the raising of farm efficiency. In such accounts, two phases of technological change in agriculture are normally distinguished. Prior to the 1890s agricultural development was *extensive* in character, and associated more with the introduction of a variety of machines and implements than with scientific or managerial changes in production methods. From the 1890s, however, and particularly in response to declining wheat yields on intra-marginal land and the encountering of geographical limits to cultivation, an *intensive* phase of development began. This was characterized by emphasis on non-mechanical technologies aimed particularly at raising (or restoring) yields. Changes in production methods associated with this period include the introduction of new (particularly rust resistant) varieties of wheat, superphosphate, fallowing, rotation cropping and mixed (especially wheat-sheep) farming.[1]

The appropriateness or accuracy of this stylized view has not been challenged, while the formal analysis of the role of technological change in Australian agricultural development has hardly begun. In this paper an effort is made to advance discussion on both issues. The approach taken is to focus on evidence of efficiency gains (as measured by various aggregate agricultural productivity indexes) as a key indicator of agricultural progress, and then to attempt an explanation of the temporal rates of efficiency improvement in farming in terms of the two-phase view of the period summarized above.

Estimates of agricultural productivity for the Australian agricultural sector as a whole are available in a number of recent studies by agricultural economists covering the period since 1920[2], but no comparable estimates exist for the period prior to 1914. The reason is that although rural output and investment estimates have been computed from 1861[3], there are no estimates of capital stock or factor shares for Australian agriculture before 1920, and the annual estimates of rural workforce begin in 1910-11[4]. Furthermore, differences in the methods and coverage of the agricultural censuses in each of the six colonies prior to federation constitute a major obstacle to the backwards extension of these series for Australia as a whole. For these reasons this paper relies on statistical estimates for Victoria alone, extending quantitative material previously reported.[5]

In the next section, an assessment is made of the relevance to Victorian experience of the induced agricultural development model associated particularly with the work of Hayami and Ruttan. With currently available data, an initial formal test of this model yields ambiguous results. In subsequent sections of the paper an alternative measure of efficiency improvement is derived, and a new method proposed for investigating the sources of productivity change. A concluding section assesses the significance of the paper's findings, and implications for further historical inquiry.

2. Labour Productivity

Indexes of partial productivity, though once the standard measure of economic efficiency, are usually avoided wherever all inputs can be measured and aggregated. In studies of agricultural efficiency the three 'primary' factors of land, labour and capital would conventionally be included in any index of aggregate input, while other (intermediate) inputs such as fertilizers, fuels and chemicals might also be included, together with some allowance for such non-conventional inputs as research, education and extension. In an influential study of comparative agricultural development in the United States and Japan since 1880, however, a partial productivity measure forms the basis of an interpretation of the links between technological change and productivity growth which purports to be quite general in its relevance.[6]

The first, essentially *descriptive*, step in the analysis of Hayami and Ruttan is to decompose changes in labour productivity into that which is attributable to changes in the land area per farm worker, and that to changes in farm output per acre, from the identity

$$Y/L = (A/L)(Y/A)$$

where Y = agricultural output, L = agricultural labour input and A = agricultural land in use. It is then *assumed* that changes in A/L and in Y/A are not only independent, but reflect (in fact, directly result from) quite distinct varieties of technological change:

> " ... the major source of increases in land area per worker has been progress in mechanical technology which facilitated the substitution of other sources of power for human labour. Similarly, the major source of increase in land productivity has been progress in biological technology which facilitated the conversion of a higher percentage of the solar energy falling on an area into higher levels of plant and animal production through improvements in the supply and utilisation of plant nutrients".[7]

Evidence drawn from the historical experience of Japan and the United States is then used to illustrate these two distinct paths to agricultural productivity improvement. Between 1880 and 1960, output per farm worker rose by 580 per cent in the United States and by 353 per cent in Japan. Whereas in the former some 76 per cent of this increase is attributed to the measured rise in A/L, with the remaining 24 per cent to the rise in Y/A, the Japanese proportions are very different at 32 per cent and 68 per cent respectively. In the American case, it is argued, changes in farm production methods primarily involved the introduction of mechanical (labour saving) innovations thus raising Y/L by raising A/L, with the effect of biological-chemical innovations such as hybrid seeds and artificial fertilizers dating only from the 1930s. In Japan, by contrast, agricultural innovations have been primarily of the yield-raising biological-chemical variety, with agricultural mechanisation acquiring significance only in postwar years.

In Hayami and Ruttan's study, this analysis is preliminary to their central hypothesis concerning the different paths of innovative activity - an induced innovation hypothesis:

> "the contrasting patterms of productivity growth and factor use in U.S. and Japanese agriculture can best be understood in terms of a process of dynamic adjustment to changing relative factor prices along a meta-production function - dynamic in the sense that production isoquants change in response to the changes in relative factor prices".[8]

This is found, broadly, to be supported by direct statistical test.[9] Their interest then moves to the *process* by which the appropriate responses to these price signals by innovators in the public and private sectors in the two countries actually occurred - the research and development role of farm supply firms, government agencies, etc.

The present examination of agricultural development in Victoria between 1870 and 1910 is concerned with the extent to which the suggested nexus between factor proportions, broad types of technological progress, and factor prices is consistent with available evidence. In particular, the Hayami-Ruttan perspective appears to offer a suitable framework within which one putative characteristic of Australian agricultural history (referred to in Section 1) can be assessed more carefully than hitherto, namely, that in the decades prior to 1900 the dominant form of technical change in agriculture was mechanisation whereas from that time "scientific" agriculture flourished, and was characterised by efforts to arrest and reverse declining yields by the adoption of a host of chemical-biological and managerial innovations.

The evidence relating to labour productivity and factor proportions in Victorian agriculture between 1870 and 1910 is presented in Table 1, columns (1) to (3). Labour productivity rose by 64 per cent over the period as a whole, but most of this occurred in the last decade. In partitioning this increase in agricultural efficiency between the two "sources" suggested by expression (1), it is found that changes in acreage per farm worker (A/L) made a *negative* contribution (declining by 44 per cent), leaving increases in output per acre (Y/A, which rose by 194 per cent) to account for all the improvement in labour productivity. A strict interpretation of these trends along the lines suggested by Hayami and Ruttan would suggest the following:

(a) Victorian agriculture 1870 to 1910 developed primarily along a path characterised by emphasising improved biological-chemical rather than mechanical rural technology;

(b) Victorian agricultural development would more closely resemble the Japanese than the American pattern; and

(c) the observed factor proportions adjustments must have occurred because of a rise in the price of machinery relative to labour and a rise in the price of land relative to labour.

Such inferences are, however, largely at variance with what is known about the progress of farming in Victoria at this time.

Firstly, there was considerable progress in rural mechanisation during the period, reflected not only in the introduction of many new and improved machine types, but also in an increase of 146 per cent in the real value of

TABLE 1

Labour Productivity, Factor - Factor and Factor - Price Ratios: Victorian Agricultural Sector 1870-1910

YEAR	Y/L (£) (1)	A/L (acres) (2)	Y/A (£) (3)	P_A/P_L (1910-11 = 100) (4)	P_M/P_L) (1910-12 = 100) (5)
1870-71	130.1	626.2	0.21	26	223
1875-76	125.7	477.3	0.26	38	215
1880-81	127.8	401.8	0.32	52	198
1885-86	139.5	388.9	0.36	57	162
1890-91	149.1	376.7	0.40	92	176
1895-96	128.4	320.1	0.40	115	231
1900-01	156.3	370.1	0.42	104	190
1905-06	187.2	370.1	0.51	118	139
1910-11	213.2	348.5	0.61	104	106

Sources and Notes: Y = net agricultural output in constant prices, and expressed as a five year centred annual average (from I.W. McLean, *Rural Output, Inputs and Mechanisation in Victoria 1870-1910*, (Ph.D. thesis, Australian National University, 1971), pp. 59-60). L = rural labour input measured in full-time working-age male equivalents (decimal census-year estimates from *ibid*, p. 112; interpolated as described in Appendix to this paper). A = rural land occupation (from *ibid*, p. 160). Price ratios based on series in *ibid*, pp. 188 and 223.

machinery per farm worker. It is unlikely that this had a negative effect on labour productivity, so that an explanation of the decline in A/L must lie elsewhere. Second, chemical-biological innovations such as superphosphate, improved seed varieties and new livestock breeds were widely adopted only towards the end of the period, and certainly not prior to 1890. How then are we to account for the virtual doubling of Y/A in the two decades after 1870?

Third, the movements in factor price ratios (Table 1, columns (4) and (5)) that actually occurred are only partly consistent with the Hayami-Ruttan interpretation. The price of machinery relative to labour *fell* during the period by more than 50 per cent, consistent with the observed rise in machinery per worker, but inconsistent with the interpretation Hayami and Ruttan place on a fall in the A/L ratio. The movement in the relative prices of land and labour are quite compatible with the observed change in A/L and with the "land-saving" bias implicit in the measured rise in yields (Y/A).

One major concern with the Hayami-Ruttan framework is its sensitivity to the definition of land, in particular the problem of allowing for quality variation. In the case of Victoria, the problem is that although the colony's farm lands were largely "occupied" and classified as "in use" by 1870, with little net change by 1910, the *nature* and *patterns* of rural land use underwent major changes during that forty year period. These included land clearing which raised stocking rates, the conversion of grazing to crop land, the substantial re-location of the main cereal production regions, and the spread of mixed farming. It is these changes which may largely account for the observed fall in the A/L ratio, since they represent more labour intensive (in this sense) farming methods, and not a decline in the level of mechanisation as implied by the Hayami-Ruttan interpretation. These same changes in land use and quality rather than the introduction of chemical and biological innovations, may also account for a sizeable part of the increased yield (Y/A). Yet this quality improvement is not allowed for in the land input measure as are analagous changes in the composition of the rural workforce.

In addition, one may directly question the view that an increase in mechanisation leads to a rise in acres per worker. This may be the major effect, but few would dispute the point that some mechanical innovations introduced during the period were important in other respects than saving labour. For example, the seed drill's principal advantage over broadcast sowing was said to lie in the more controlled distribution of seed, which raised yields per acre, and "saved" land rather than labour. Attributing just one type of factor-saving bias to the complex process of factor substitution and technical change loosely called "mechanisation" may not be adequate.

Hence, this examination of Victorian evidence suggests that although movements in factor proportions are everywhere consistent with movements in the corresponding factor price ratios, the Hayami-Ruttan assumptions that increasesin A/L primarily reflect increased mechanisation and that changes in Y/A mainly reflect biological-chemical improvements in farm production methods may be called into question. Until new or improved data are compiled (and the results reported are likely to prove most sensitive to any revised series of land input that incorporated some allowance for quality improvement) it appears that the simple analytical framework suggested by Hayami and Ruttan, and focusing on labour productivity, yields few insights when applied to the Victorian experience. We therefore turn to the measurement and the explanation of the more comprehensive *total* factor productivity measures.

3. Total Factor Productivity

Total factor productivity is the residual of output "unexplained" or "not accounted for" by the measured increases in the weighted index of total factor input. Any understatement of the "true" input will increase the measure of productivity. Particularly important in the agricultural sector is the omission of purchased intermediate inputs if, over the period of the productivity calculation, there has been any increase in their relative importance. Seeds, fuel and fertilizers are three examples from mid-twentieth century agriculture that make a significant contribution to agricultural production. In the late nineteenth century, however, intermediate inputs were certainly very much less important, although the process of substituting purchased off-farm inputs for on-farm inputs (e.g. superphosphate for farmyard manure) - a major characteristic of the process of commercialisation and specialisation in modern agriculture - was already underway by the first world war. The net rural output estimates used in this study do not capture these items.

The measure of total factor productivity used here is implicitly based on a Cobb-Douglas production function with properties of neutral technical change and constant returns to scale.[10] The separation of factor growth and the "residual" productivity growth also implicitly categorises the underlying changes in technology as being purely disembodied, and ignores interaction effects between technical change and increases in input levels.[11] Total factor productivity for the agricultural sector of Victoria for the period 1870 to 1910 was thus estimated as

$$\frac{\Delta P}{P} = \frac{\Delta Y}{Y} - [\alpha \frac{\Delta L}{L} + (1-\alpha) \frac{\Delta K}{K}]$$

where Y is net agricultural output in constant (end-of-period prices); L is agricultural labour input measured in full-time adult male equivalent units; K is the stock of rural capital including land, also measured in end-of-period prices; and α is the estimated share of output attributable to labour. (A more detailed discussion of data sources and methods is provided in an Appendix to this paper.) The changes in output and (weighted) inputs were specified in percentage form, so the resultant measure of productivity also becomes a percentage change. In theory, the time interval over which each calculation is made should be as short as possible; with 41 years of output and input data, 40 annual estimates of productivity change were possible. Cumulating these increases from a base 1870-71 = 100 provides an index of productivity improvement which equalled 128 by 1880-81, 140 by 1890-91, 157 by 1900-01 and 195 by 1910-11.[12] This represents an average of nearly 2.4 per cent annual growth in productivity over the period.[13] A summary of the estimates is given in Table 2, and a smoothed graph of the underlying annual series is shown in Chart 1.

TABLE 2

VICTORIA: Total Agricultural Factor Productivity

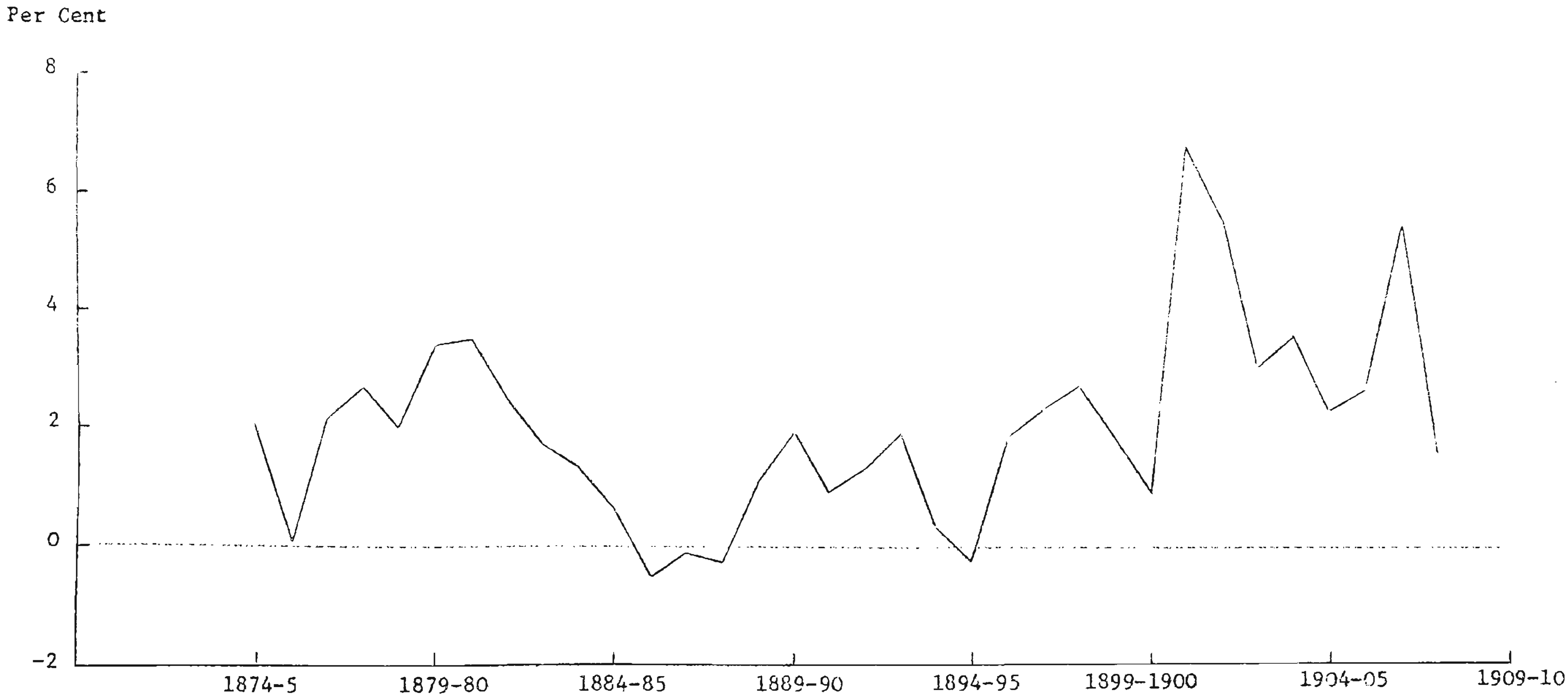
		No. of Years (1)	Cumulative Change (%) (2)	Annual Average Change (%) (3)
A.	1870-71 to 1910-11	40	94.81	2.37
B.	1870-71 to 1875-76	5	10.93	2.19
	1975-76 to 1880-81	5	16.73	3.35
	1880-81 to 1885-86	5	-1.46	-0.29
	1885-86 to 1890-91	5	14.33	2.87
	1890-91 to 1895-96	5	-2.96	-0.59
	1895-96 to 1900-01	5	19.13	3.83
	1900-01 to 1905-06	5	16.71	3.34
	1905-06 to 1910-11	5	21.40	4.28
C.	1870-71 to 1883-84	13	43.00	3.31
	1883-84 to 1896-97	13	-6.29	-0.48
	1896-97 to 1910-11	14	58.10	4.15

Within the four decades covered by this study, the productivity performance appears to have undergone at least one major change in trend and possibly two, although statements about trends are complicated by the annual fluctuations. Section B of Table 2 arbitrarily sub-divides the period into five-year intervals. The impression gained is one of fairly steady improvement during the 1870s at about the long-run trend rate, followed by three quinquennia of fluctuating productivity performance, and then a

CHART 1

VICTORIA: TOTAL FACTOR PRODUCTIVITY IN AGRICULTURE
1870-71 TO 1910-11

(Seven Year Moving Average)



further 15 years from 1895 of productivity growth substantially above the long-run trend.[14] It is perhaps safer to speak of a rather lower trend rate of productivity growth in the 26 years before 1896-97 (1.41 per cent) giving way to the rapid rise (4.15 per cent) to the end of the period. The break in the trend of productivity in Victorian agriculture earlier reported[15] as occurring at the turn of the century has been dated a few years earlier by the present study using slightly different methods, and based on annual rather than decennial estimates.

In one sense, the productivity estimates derived in Table 2 may simply reflect errors of measurement, particularly in the very limited adjustments for quality change that have been possible. No such allowance has been made for agricultural output; nor is it possible to assess whether the changes in the commodity composition of output that occurred during the period, had, ceteris paribus, either a positive or negative impact on measured productivity. So far as the labour input estimates are concerned, allowances have been made for changes in the age and sex structure of the rural workforce, in the grades of rural occupations recorded, and in the proportions working full-time or part-time. However, no allowance has been made for possible changes in skills not reflected in changes in the grades of occupation, or any improvement which might have occurred in the average educational attainments of the rural labour force.[16]

The capital input series, by comparison, are almost certainly very much less reliable, and in the present context two problems in particular should be noted. As the value of land component in the aggregate capital figure is simply the number of acres of agricultural land in use valued at base period prices, if some change in land use results in an increase in output per acre but requires no additional investment or labour, that increased output will be attributed to increased productivity. Examples from the period might be the introduction of fallowing, rotation cropping or mixed wheat-sheep farming, or the relocation of various agricultural activities within the state to areas more suited to them.

Also, there is reason to believe that the machinery component of the capital input understates the contribution to output from this source. The late nineteenth century was a period of extraordinarily rapid innovation in agricultural machinery. It is likely that the price index for machinery imperfectly captures the consequent changes in the quality of the machinery input into agriculture. The increase in machinery's contribution during the period will be further understated insofar as economies of scale in machinery production were achieved in the agricultural machinery firms selling to the Victorian farmer and these were reflected in lower retail prices.

In part, also, changes in measured productivity may have arisen from sources not directly related to the levels of input of the two primary factors we have been able to distinguish. It is likely, for example, that "learning" and the associated reduction in uncertainty that accompanied the accumulation of experience and information by farmers were important sources of efficiency improvement in agriculture during these years. A central theme of the agricultural history of the period is the gradual accumulation of knowledge about the soil and climatic conditions in different regions of the state. When the drier areas of Victoria were converted from lightly-settled pastoral-grazing occupation to more closely settled crop and wheat-sheep production, little was known about the appropriate management practices necessary to the maintenance of long-run profitability. Partly as a result of ignorance of local conditions, and partly encouraged by the provisions under which grants of land were obtained, some farmers in the wheat belt may have engaged in a form of "soil mining" in the 1870s and 1880s, making little effort to maintain or improve fertility.[17] By the 1890s, concern with declining wheat yields per acre had drawn attention to the views of those who advocated a less exploitive agriculture, incorporating the rotation of crops, the combination of wheat and sheep raising, or the practice of allowing cropland to lie fallow. By the first world war, there is evidence that these conservationist and yield-raising practices had become wide-spread, and since they required few if any additional capital inputs, some contribution to the recorded increase in productivity is most likely to have resulted.

Complementing these managerial innovations was the appearance of a number of new seed and livestock varieties, and the introduction of artificial fertilizers onto Victorian farms. The history of wheat breeding in Australia is associated with attempts to find varieties which were resistant to diseases (especially at this time wheat rust) and/or were suited to the much drier inland conditions than those encountered along the coast where wheat-growing areas were first located.[18] Farmyard manure had presumably always been spread on agricultural land, with limited use also being made of rock phosphate, bone-dust and guano as supplementary fertilizers in the 1870s and 1880s. In the middle of the 1890s, however, the simultaneous sowing of wheat and superphosphate was successfully demonstrated (possibly first in South Australia), and there followed a rapid diffusion of the practice among wheat-growers, with major improvements in yields reported.[19]

Finally, in addition to these changes in production methods that would have influenced measured productivity improvement over many years, short-run influences could also be important. The very high productivity improvement recorded for 1903-04 (see Appendix Table) largely reflects the end of the drought, and the recovery from the two previous years in which output had fallen more than the level of inputs. The trend decline in productivity in the early 1880s (evident in Chart 1) may also have been partly due to a number of years of below average rainfall. Neither must we overlook the possible role of the rabbit plagues at this time in adversely affecting rural production.

4. The Determinants of Productivity Change

To investigate more formally the determinants of changes in total factor agricultural productivity in Victoria, the following specific questions were posed: (1) to what extent can the variation in measured productivity be accounted for in terms of variations in proxy variables for at least some of the broad changes in production methods enumerated in the previous section; (2) is it possible to assess the *relative* importance of these changes; and (3) is the increase in the underlying trend rate of productivity improvement observed in the mid-1890s associated with the more rapid diffusion of the enumerated changes in production techniques? These questions are approached by first selecting proxy measures of four of the changes in production methods, then regressing these against the productivity estimates already obtained, treating the period as a whole as well as dividing it into two sub-periods at the mid-1890s.

As an indicator of the changes in the quality of agricultural land, the areas recorded as being planted to crops, lying fallow, or sown to 'artificial' (introduced) grasses have been summed, and the proportion of the total area of land in use for rural purposes which this represents has been computed. The result is shown in column (1) of Table 3 at five year intervals throughout the period. It is clear that initially only a small proportion of the land was 'improved' in this sense; the grazing of sheep on natural grasslands was the predominant form of land use in agriculture. By the end of the period one acre in every six was either under active cultivation or sown to improved pastures.[20]

TABLE 3

Changes in Production Techniques: Various Measures 1870-1910

	Proportion of Land Cultivated, in Fallow or in Sown Grasses (%)	Value of Farm Machinery per Labour Unit (£)	Ratio of Land in Fallow to Land Under Crops (%)	Superphosphate Used per acre under Wheat (lbs.)
	(1)	(2)	(3)	(4)
1870-71	2.5	15.6	10.0	-
1975-76	3.1	15.9	13.2	-
1880-81	6.2	18.3	12.5	-
1885-86	6.8	19.3	11.3	-
1890-91	8.1	19.7	19.0	-
1895-96	8.1	11.5	12.1	-
1900-01	10.5	18.5	19.4	21.7
1905-06	15.4	26.9	32.6	59.1
1910-11	16.9	38.3	36.3	80.6

In an effort to capture some of the understated effects of the use of agricultural machinery, the value of machinery in use on farms has been divided by the number of 'units' of labour input (full-time, male adult equivalents). The resulting machinery/labour ratio is shown in column (2) of Table 3. After a relatively gentle increase in the first decades of the period, this index of mechanisation rose rapidly to over twice its 1870 level by 1910. Since machinery has been included in the measure of agricultural capital used to estimate productivity it might at first appear that some double counting may result. It should be recalled, however, that in the present context the aim is to test the existence of any relationship between *variations* in (residual) productivity and in mechanisation, and that machinery formed a very small proportion of the total agricultural capital stock figures which were used in the derivation of the productivity estimates.[21]

Obtaining some proxy for changes in the quality of farm management during the period is difficult. For example, direct evidence of the practice of combining wheat growing and sheep raising *on the same farm* is not available since data on wheat production and sheep numbers are recorded by statistical areas not farms. However the practice of fallowing, one of the most frequently advocated management innovations, can be measured as the acres in fallow were recorded. Over the forty years covered in this study the area in fallow rose much more rapidly than that under all crops; in 1870 there was one acre of fallow for every ten growing crops; by 1910 the ratio had changed to one for every 2¾ (column (3) of Table 3) although most of this increase occurred towards the end of the period.

As the method of calculating agricultural productivity made no allowance for the contribution of purchased off-farm inputs, the effect of fertilizers such as superphosphate on output has been omitted. Of course the agricultural sector as a whole is included in this study, and the importance of the use of superphosphate was greater in some branches of agricultural activity than in others. For example, its early usage seems to have been largely associated with wheat production, with substantial increases in yields claimed.[22] However wheat was the most important cereal crop grown in Victoria, so some allowance for the effect of the fertilizer application on measured productivity seems necessary. The data on 'artificial' manures used on Victorian farms unfortunately begin only at 1898-99, although this may have been no more than five years after the practice of applying superphosphate at seeding time was first employed. On the assumptions that up to 1910 all superphosphate was applied to land sown to wheat, and that the 'artificial' fertilizer statistics are dominated by those relating to superphosphate, the average application per acre under wheat has been calculated, and is shown in column (4).

The general form of the model used for the explanation of agricultural productivity change was

$$PC = f(MN, LC, LF, SW, RA)$$

where PC refers to the percentage change in agricultural productivity recorded; MN the ratio of the value of agricultural machinery to agricultural labour input; LC the proportion of rural land under cultivation or sown to introduced grasses; LF the ratio of acreage in fallow to that under crops; SW the quantity of superphosphate used on farms per acre of wheat; and RA the average Victorian rainfall.[23]

Apart from the rainfall variable, all other variables have previously been discussed. The inclusion of RA is necessary since the measure of agricultural output used in the first stage of the productivity analysis was not 'weather adjusted'. The measure of capital input (and to a lesser extent the labour input as well) is a stock variable acting as a proxy for the preferred measure of the flow of capital services, and therefore fluctuations in capacity utilisation due to climatic-related influences will appear as fluctuations in output unaccompanied by any change in inputs. These fluctuations will have been attributed to total factor productivity. The rainfall figures for each year of the period, together with the annual values of all other variables, are shown in the Appendix Table.

The results of the regression analysis are summarised in Table 4. Three periods were investigated: the entire four decades treated as a single period;

TABLE 4

Analysis of Productivity Improvement 1870-71 to 1910-11

Period	1871-72 to 1893-94	1894-95 to 1910-11		1871-72 to 1910-11		
Eqn. Type	I	I	II	I	II	II
Constant	102.22 (5.90)	80.74 (7.97)	-2.11 (0.44)	89.40 (11.33)	0.700 (0.45)	1.297 (0.96)
MN	-0.145 (0.16)	1.641 (2.45)[b]	0.621 (1.57)[c]	0.16 (0.51)	0.408 (2.38)[b]	0.352 (2.13)[b]
LC	5.363 (5.85)[a]	2.406 (2.61)[b]	0.373 (2.06)[b]	5.05 (10.4)[a]	0.264 (1.87)[b]	0.174 (1.42)[c]
$LF_{(t-1)}$	-0.379 (0.82)	-0.515 (1.60)[c]	0.095 (1.46)[c]	-0.30 (1.15)	0.054 (1.17)	
SW		-0.053 (0.30)		0.09 (0.96)	0.045 (0.67)	
RA	0.015 (0.05)	1.191 (2.66)[b]	0.27 (2.17)[b]	0.35 (1.27)	0.147 (2.35)[b]	0.164 (2.70)[a]
$\bar{R}^2$	0.80	0.93	0.58	0.94	0.34	0.34
DW	1.43	1.83	2.35	1.54	2.40	2.48
F	23.06	43.06	5.40	120.1	4.88	7.36
n	23	17	17	40	38	38

a, b and c indicate t values significant at the 1, 5 and 10 per cent levels respectively.

and two sub-periods created by splitting the series between 1893-94 and 1894-95. The measure of land in fallow (LF) was lagged one year on the grounds that the influence of this practice on output would be evident only after the land in question was returned to productive use. Also, the form the regression equation should assume was not *a priori* clear, and two different versions were used. For the relationship between productivity and the independent variables to be consistent, either the measure of productivity employed has to be adjusted to correspond with the form in which the *un*adjusted values of the independent variables are expressed or, alternatively, the independent variables must be transformed into *changes* in their underlying values (to correspond with the form in which PC is derived). Equation Type I in Table 4 represents the former, and has the form

$$IPC_t = \beta_0 + \beta_1 MN_t + \beta_2 LT_t + \beta_3 LF_{t-1} + \beta_4 SW_t + \beta_5 RA_t$$

where IPC is a cumulated index of productivity change with 1870-71 = 100. Equation Type II represents the alternative specification in which the form in which the independent variables enter the equation is made consistent with the original form in which productivity was measured, namely, as an annual percentage change. It thus may be shown as

$$PC_t = \beta_0 + \beta_1 DMN_t + \beta_2 DLC_t + \beta_3 DLF_{t-1} + \beta_4 DSW_t + \beta_5 DRA_t$$

where D indicates the percentage change in the independent variable.[24]

There is some evidence to suggest that the *sources* of productivity improvement shifted after the mid-nineties (when the *rate* also accelerates), but this does not appear to be associated with a simple switch in emphasis from mechanical to scientific technology as implied by historians of the period. LC, the proportion of land under cultivation or sown grasses, is the sole independent variable that fairly consistently was positively and significantly related to productivity performance in the first sub-period. Perhaps this is not surprising given the greater measured increase in LC than in the proxy measures of management and mechanisation (LF and MN) prior to the 1890s, as shown in Table 3. Possibly, too, LC may be serving for more than just understated land input quality improvements, insofar as the rise in the proportion of cultivated land was associated with the many changes in farming methods associated in turn with the conversion from grazing to grain production or mixed farming. The poor showing of the mechanisation variable suggests that previous writers have tended to confuse innovation with diffusion, and have focused on the mechanisation of wheat production rather than, say, dairying or wool production which dates only from the late 1880s. Hence, mechanisation had little measurable effect on *aggregate* farm efficiency.

For the second half of the period LC, MN and RA were positively and significantly related to PC as hypothesized. The coefficient of SW, the ratio of superphosphate used to acres in wheat, was never significant. Replacing SW with a direct measure of superphosphate usage, on the argument that it may have been applied to crops other than wheat, did not improve the result. Whatever influence artificial fertilizer may have had on wheat *yields* during this period, no clear influence on the overall efficiency of agriculture can be identified.[25]

The two basic problems encountered in this analysis were firstly, that the productivity measure exhibited such sharp short-run fluctuations around trend, and secondly, that (with the obvious exception of rainfall) the unadjusted values of the explanatory variables tended to move together after the mid-1890s and (with the exceptions of rainfall and the land in cultivation) show relatively little variation before that time.[26] Nonetheless, some useful evidence has emerged relevant to the questions posed at the beginning of this section.

Depending upon the time period and precise specification chosen, a considerable proportion of the measured increases in agricultural productivity derived above appear to be accounted for in terms of the variables chosen. This is much more evident in the second half of the period, for which some 'explanation' of the observed faster productivity growth seemed crucial. Possible omitted influences may include changes in farm size distribution, changes in the composition of agricultural output, regional shift effects, the rise of mixed farming, and the introduction of improved seed varieties and livestock breeds. Some of these are not relevant to a study of the agricultural sector as a whole, or are obscured in an inquiry such as this which does not examine the regional experience within Victoria.

As to the *relative* importance of the several sources of productivity improvement investigated above, it would appear that (apart from the obvious influence of weather patterns) mechanisation and changes in the proportion of land under cultivation were of approximately equal significance over the period as a whole, with changes in fallowing being much less important and that of fertilizer of little consequence.[27] In the second half of the period the relative importance of fallowing appears to increase. With respect to the first half, only very tentative conclusions can be advanced, and they are that increases in the proportion of land in cultivation may have been quite a significant contributor to productivity improvement, but little consistent evidence can be found to support the view that the other changes in production methods were of much significance.

5. Conclusions

In this paper an examination of the sources of efficiency improvement in late nineteenth century Victorian agriculture has been made using two different though related approaches, and employing new estimates of some of the basic time series required for such an exercise. The induced agricultural development model of Hayami and Ruttan, which has been applied with apparently fruitful results to the experience of a number of other countries, did not prove a satisfactory framework for historical inquiry when applied to the case of Victoria. The model should have yielded information about the *relative* contributions to increases in farm (labour) productivity of mechanical and chemical-biological innovations, and on the degree to which any shift in emphasis from the former type of technological change to the latter was a response to changes in relative factor prices. The observed changes in factor proportions, though consistent with the movement of factor prices, suggest in the Hayami-Ruttan interpretation that agricultural technology in Victoria was overwhelmingly of the land saving and yield raising variety, that is, based on chemical and biological rather than mechanical innovations. Yet the mechanisation of farming during this period was quite dramatic, and it is inconceivable that it resulted in a *lowering* of labour productivity. The model has weaknesses either because it omits direct inclusion of capital, or because the assumed factor saving bias and the two types of technical change distinguished are not clearly enough specified. Also, in a region undergoing initial agricultural settlement, particular problems derive from the measurement of land input.

The annual estimates of *total* factor productivity derived in Section Three show, despite understandable year to year variation, periods of relatively rapid efficiency improvement in the late 1870s and early 1880s, and again after the mid-1890s. The explanation of these trends appears to lie partly in changing levels of input usage not fully captured by the estimation procedures, and partly in the diffusion of new production and organisation methods in agriculture which required few if any additional inputs of labour or capital and would therefore not be reflected in the input series. The attempt to account for the productivity increases using regression analysis, and where proxies for some of these changes in farm production methods were the independent variables, proved moderately successful. In the best results, more than three-quarters of the productivity variation was accounted for in terms of the exogenous variables. In the first half of the period (before 1893-94) the most important source of efficiency improvement appears to have been the conversion of land from grazing to cultivation, a conversion that reflected broad changes in land use patterns in the colony as "agricultural" pursuits (narrowly defined) expanded geographically at the expense of pastoral activities. After the early 1890s the sources of productivity change appear to have included the effects of mechanisation not fully captured by the machinery component of the capital input series, and the vagaries of the weather. Perhaps most interesting is that this analysis places the period of greatest efficiency (not output-generating) effects of mechanisation after the mid-1890s, whereas historians have tended to stress its importance somewhat earlier; and whereas the introduction of "scientific" agriculture is generally dated from the 1890s, the one major innovation of this type which we were able to include in this study (the use of superphosphate) was not significantly related to measured *aggregate* farm productivity.

Appendix

Intercensal Interpolation of Census Labour Input Estimates: For the purpose of arriving at an estimate of *annual* productivity change it was necessary to interpolate the agricultural labour input figures between census years. The use of two contemporary estimates of rural workforce running from 1868 to 1881 and from 1904 to 1914 were considered unsuitable for direct use, although in the case of the earlier series, they were used as an interpolation proxy. Between 1870-71 and 1880-81 this "male farm hands employed" series increased by 35.05 per cent while the intercensal increase in the labour input estimates was only slightly higher at 36.8 per cent. After slight adjustment due to apparent underreportage in non-census years, the "male farm hands employed" figures were used to estimate total agricultural labour input in each year between 1871 and 1881 by use of the interpolation formula

$$\hat{L}_i = L_o + \left[\frac{P_i - P_o}{P_n - P_o} \quad (L_n - L_o) \right]$$

where L_o and L_n are the (known) labour input figures for the initial and terminal years respectively, P represents the interpolation proxy series (for which all values are known from period o to n), and $\hat{L}_i$ is the estimated labour input for all i lying between o and n.

This same interpolation procedure was employed in each of the three subsequent intercensal periods. However, suitable annual proxy series were more difficult to obtain. The population estimates for Victoria in non-census years (estimated, it appears, by adjusting census year data for births, deaths and net migration) are available by sex but not by rural/urban location. An annual series of rural population (perhaps based on ratepayers living in shires, i.e., outside the boundaries of urban areas - cities, towns and boroughs) is also available and is more appropriate in terms of geographical coverage.

This, hoever, does not indicate age or sex composition. Because the year-to-year fluctuations in the total rural population were more likely to be related to changes in the rural workforce, the labour input estimates between 1881 and 1911 were interpolated using the second proxy series.

Factor Share Estimates: The most hazardous step in estimating total factor productivity in Victorian agriculture was the derivation of the weights to be assigned to the capital and labour input series. In theory, under perfect competition each factor will be paid its marginal product, and, with additional assumptions, it is possible to show that the share of each factor in total income will be equal to its contribution to total output. On the basis of this theoretical conclusion it has become accepted practice (where data limitations preclude more direct estimation of the contributions of inputs to output) to estimate the share of labour as the ratio of the wage bill to income (output), and that of capital (in a two input model of production) as unity less this ratio. With every awareness of the dubious validity of the underlying assumptions to the case of late nineteenth century agriculture, there is little choice but to follow this same procedure in the present study. One alternative (used by Gallman[28] in his study of nineteenth century American agriculture) would be to guess the likely rate of return earned on the principal forms of agricultural capital, and obtain the income share of capital directly and that of labour residually. However, considerably greater confidence can be placed in the labour input series and the evidence on agricultural wage rates than the farm capital estimates used in this study, so this alternative was rejected.

The first step in computing the labour share in Victorian agriculture was to settle on a suitable wage or average earnings estimate. Fortunately, the "average" or "prevailing" wage rates for a variety of agricultural occupations were published annually during the period, sometimes quoted on a weekly or annual basis (for year-round occupations such as farm labourers, ploughmen, shepherds and stockmen), and sometimes on a "piece rate" basis (such as per hundred sheep in the case of shearers). The wage rates for strictly seasonal work such as harvesting or shearing were not directly usable because of uncertainties surrounding the proportion of the year during which this type of work was available. And the rates for other types of rural work could not be aggregated into an index because the occuptional categories in the population censuses (on the basis of which a suitable weighting system might have been devised) were not comparable with the published wage rate information. As a consequence, the wage of general farm labourers was chosen as an "average" wage. Where a comparison with other farm occupations is both possible and meaningful (being year-round activities) the following approximate relativities appear to have prevailed through the period. "Married couples" (working on farms) received a wage about 50 per cent above that of farm labourers, ploughmen and stockmen (or stock-keepers) 20 to 30 per cent above, while shepherds and "generally useful men" received about the same wage as farm labourers. When it is remembered that the "unit" of agricultural labour to which this wage rate is to be applied is a "working-age full-time male equivalent" the appropriateness (or otherwise) of the labourer's wage is more clearly appreciated.

However, doubts remain about this choice. The much higher rate for "married couples" may be more "typical", although the differential over the (presumably single) farm labourers may in part be attributed to certain duties expected of the married worker's wife, and also in part to the likelihood that "rations" were provided for the farm labourers. The appropriate imputed wage for an owner-occupier of a farm might also be much higher given his managerial functions; on the other hand many of Victoria's farmers in the period of closer settlement during the late nineteenth century were ill-equipped with requisite skills. In many cases, these "selectors" spent part of the year away from their farms working for wages at shearing, fencing, and land-clearing to supplement their cash income while their own farm was being established. On balance, however, the chosen wage rate is more likely to under-state rather than overstate the "average" wage of the adult male employed full-time in agriculture.

The calculation of the labour share requires some estimate of farm output in current prices, but only constant (end-of-period) price estimates were available because of the limited array of commodity prices published during most of the period. The problem was tackled by devising a price index covering wool and wheat (with weights supplied by the shares of each in the combined value of output of the two), and multiplying the constant price total agricultural output estimates by this index. The resulting "current price" estimates for output were derived only for the census years (for which the labour input series were best) and then on a five year average basis (to smooth out short-run fluctuations). The wage bill was then divided by the current output to provide labour share estimates for the census years. These did not vary greatly from 26.1 per cent in 1871 through 28.0, 34.8 and 31.5 per cent respectively at the next three census years to 25.6 per cent in 1911. For intercensal years, the labour share was linearly interpolated. Of the many assumptions underlying this estimate perhaps the most difficult to appraise are that the weighted average of prices of all farm products moved broadly in sympathy with our index based on wheat and wool prices only, and that the chosen wage rate is a suitable basis for estimating agricultural labour's average compensation.

One major point in defence of so crude an estimation procedure is that given the form of the productivity estimation equation, wide variations in the factor shares will have little impact on the estimates of total factor productivity unless the rates of growth of labour and capital input are markedly different. This insensitivity was assessed by arbitrarily increasing by 50 per cent the labour share estimates, and recomputing productivity. With 1870-71 = 100, the resultant cumulative index stood at 191.28 compared with 194.8 based on the initial factor shares.

APPENDIX TABLE

SERIES EMPLOYED IN PRODUCTIVITY ANALYSIS

Years Ended March	PC (1)	MN (2)	LC (3)	LF (4)	RA (5)	SW (6)
1871	-	15.6	2.5	10.0	35.34	
1872	13.95	16.4	2.6	11.1	28.56	
1873	-6.95	16.5	2.6	11.0	29.86	
1874	1.66	15.6	2.7	9.5	26.40	
1875	5.45	15.9	2.8	11.2	27.81	
1876	-3.18	15.9	3.1	13.2	30.86	
1877	7.53	16.5	3.3	10.3	21.89	
1878	-4.02	17.3	3.9	7.4	20.11	
1879	-0.24	17.4	4.6	8.8	26.14	
1880	8.22	17.7	5.1	13.5	23.46	
1881	5.24	18.3	6.2	12.5	27.61	
1882	0.54	18.1	5.6	10.0	22.25	
1883	6.55	18.3	6.1	10.0	22.68	
1884	8.25	18.5	6.5	9.9	24.90	
1885	-11.23	19.1	6.7	10.1	22.09	
1886	-5.57	19.3	6.8	11.3	22.95	
1887	4.79	19.0	7.0	14.9	25.84	
1888	1.00	19.8	7.3	17.7	32.32	
1989	-7.67	19.4	7.2	16.3	19.70	
1890	9.96	19.3	7.7	18.1	32.77	
1891	6.25	19.7	8.1	19.0	28.51	
1892	-1.17	17.8	8.1	18.7	25.90	
1893	0.46	15.5	8.8	22.0	25.46	
1894	-2.12	14.1	8.8	19.6	28.99	
1895	3.80	12.6	8.6	14.2	29.69	5.2
1896	-3.93	11.5	8.1	12.1	20.88	10.1
1897	-0.86	11.9	8.5	9.8	22.03	13.6
1898	2.20	12.5	6.5	22.9	21.94	17.3
1899	13.28	14.8	10.3	16.1	21.30	16.7
1900	4.19	17.0	10.4	16.1	24.22	16.7
1901	0.32	18.5	10.5	19.4	24.79	21.7
1902	-2.57	21.5	10.8	23.0	22.05	30.0
1903	-10.55	19.7	13.0	15.2	18.55	41.1
1904	40.48	23.6	16.0	18.7	27.44	47.4
1905	-6.96	26.7	15.9	25.7	23.49	45.2
1906	-3.69	26.9	15.4	32.6	24.53	59.1
1907	7.29	29.0	15.3	30.0	28.49	67.1
1908	-12.89	29.3	14.0	27.7	20.40	75.6
1909	4.82	29.9	14.6	29.9	20.02	81.4
1910	8.84	33.1	15.3	32.1	26.52	82.9
1911	13.34	38.3	16.9	36.3	25.96	80.6

NOTES: PC = the percentage change in total factor producivity over the previous year; MN = the value of agricultural machinery (in constant prices) per unit of farm labour; LC = the percentage of agricultural land under cultivation or sown grasses; LF = the ratio of land in fallow to land under crops as a percentage; RA = average Victorian rainfall in inches; SW = the estimated average application of superphosphate per acre sown to wheat (in lbs.).

Footnotes

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1 Perhaps the clearest statement of this perspective is to be found in C.M. Donald, 'Innovation in Agriculture' in D.B. Williams, eds., *Agriculture in the Australian Economy*, (Sydney: Sydney University Press, 1967). For the wheat industry, see chapters IV and V of E. Dunsdorfs, *The Australian Wheat-Growing Industry 1788-1948*, (Melbourne: The University Press 1956).

2 The most recent estimates are provided by R.A. Powell, *Technological Change in Australian Agriculture 1920-21 to 1969-70*, Ph.D. Thesis, University of New England, Armidale, 1974.

3 These are contained in N.G. Butlin, *Australian Domestic Product, Investment and Foreign Borrowing 1861-1938/39*, (Cambridge, England: The University Press, 1962).

4 M. Keating, *The Australian Workforce 1910-1911 to 1960-61*, (Canberra: Department of Economic History, Australian National University, 1973). An attempt to extend the workforce estimates to earlier census years has been made by N.G. Butlin and J.A. Dowie, 'Estimates of Australian Work Force and Employment, 1861-1961', *Australian Economic History Review*, IX, 2 (September 1969), 138-55; see the comments on these estimates by M. Keating, 'A Comment on the Butlin-Dowie Australian Work Force and Employment Estimates', *ibid*, XI, 1 (March 1971), 59-62.

5 I.W. McLean, 'Growth and Technological Change in Agriculture: Victoria 1870-1910', *Economic Record*, 49 (December 1973), 560-74, where only decennial estimates of the workforce were provided, and hence the productivity figures related solely to decadal changes.

6 Y. Hayami and V.W. Ruttan: *Agricultural Development: An International Perspective*, (Baltimore: Johns Hopkins University Press, 1971). A recent survey of related research is H. Binswanger, et al., *Induced Innovation: Technology, Institutions and Development*, (Baltimore: Johns Hopkins University Press, 1978).

7 Hayami and Ruttan, *Agricultural Development*, p. 118.

8 *Ibid*, p. 122.

9 *Ibid*, pp. 128-133 .

10 M.I. Nadiri, 'Some Approaches to the Theory and Measurement of Total Factor Productivity: A Survey', *Journal of Economic Literature*, 8, 4 (December 1970), 1139.

11 L.R. Christensen, 'Concepts and Measurement of Agricultural Productivity', *American Journal of Agricultural Economics*, 57, 5 (December 1975), 913.

[12] A comparison with an arithmetic weighted productivity estimating formula (the Kendrick measure) showed similar results. Using the same notation, this equation is

$$\frac{\Delta P}{P} \doteq \frac{Y_1/Y_0}{\alpha_0\ (L_1/L_0) + (1-\alpha_0)\ (K_1/K_0)} - 1$$

The cumulated index of productivity change obtained stood at 193.5 in 1910-11 compared with 194.8 for the index based on geometric weights. At one time there was considerable doubt as to the relative merits of the alternative estimating formulae employing geometric and arithmetic indexes. It is now established that "[w]here the changes [in the underlying time series] are small, the differences between the various measures are negligible, and of theoretical interest only": E. Kleiman, et al., 'The Relationship Between Two Measures of Productivity', *Review of Economics and Statistics,* 48 (August 1966), p. 345. For a recent Australian study where this condition is not satisfied, see G.D. Snooks, 'A Note on the Use of Alternate Total Factor Productivity Indexes', *Economic Record,* 52 (September 1976), 373-377.

[13] Differences in the details of estimating procedures, in data quality and in the composition of agricultural activity naturally occur over time and between regions, but to place the 2.4 per cent figure in some perspective, we may cite Young's estimate of 2.04 per cent for the Australian agricultural sector between 1948-49 and 1967-68. R. Young, 'Productivity Growth in Australian Rural Industries', *Quarterly Review of Agricultural Economics,* 24, 4 (October 1971), 185-205.

[14] Inspection of the underlying data suggests 1883-84 and 1896-97 as more suitable dates for sub-dividing the total period. This results in three sub-periods of very different experience (Section C of Table 2), with the rate of productivity improvement changing from +3.3 per cent (1871 to 1884) to -0.5 per cent (1884 to 1897) and back to +4.2 per cent (1897-1911). These rates, particularly in the first two sub-periods, are still sensitive to the choice of terminal dates.

[15] I.W. McLean, 'Growth and Technological Change in Agriculture'.

[16] The Victorian population censuses throughout this period included a question on literacy levels for the total population. The figures collected suggest that between 1871 and 1911 the percentage of adult males who could both read and write rose from 90 to 98 the corresponding figures for females were 83 and 98 per cent respectively. A more suitable measure of the educational standards of the agricultural workforce has thus far not been devised.

[17] The first report of the Secretary of Agriculture in Victoria in June 1873 emphasised the 'desirability of instituting an enquiry into the composition of our old and worn-out lands with a view to discover of what elements of fertility they have been exhausted, and to suggest means by which these may be restored,... That which but a few years since was fertile country, pouring its large yields into our markets, is now a comparatively barren waste, so poor that our farmers are fast deserting it and seeking new homes'.

[18] An account of the introduction of new wheat varieties is provided by Dunsdorfs, *The Australian Wheat Growing Industry,* pp. 189-195.

19 Evidence of the early use of superphosphate in South Australia is contained in M. Williams, *The Making of the South Australian Landscape: A Study in the Historical Geography of Australia*, (London: Academic Press, 1974), 280-287. Import but not local production figures for Victoria are available from the *Statistical Registers*.

20 Any explanation of this rise in the proportion of land cultivated would have to consider several influences. One possibility is that it simply reflects changes in the relative profitability of sheep and cereal crops: if such a nexus was established, the interpretation of any relationship between productivity and the proportion of land cultivated would be clearer. To assess the former hypothesis, the price of wheat relative to that of wool in each year of the period was regressed against the proportion of land cultivated in the subsequent year. The relative prices are probably the best available proxy for relative profitability, and if the assumed lag structure is correct, a *positive* relationship would support the hypothesis. The estimated equation was

$$LC_t = \underset{(4.78)}{11.759} - \underset{(1.36)}{0.027} (P_{wheat}/P_{wool})_{t-1}$$

with the coefficient on the independent variable just significant at the 10 per cent level. The hypothesis was thus rejected.

21 The value of machinery on farms as a proportion of total agricultural capital rose from 0.7 per cent in 1870-71 to 2.2 per cent in 1910-11.

22 Some results of field trials using superphosphate on wheat-growing areas are reported in the 1910 *Statistical Register*, 'Production (Agriculture)', p. 83.

23 The figures are the mean rainfall for the state, obtained by weighting the eight rainfall divisions by their relative means. *Results of Rainfall Observations Made in Victoria*, (Melbourne: Bureau of Meteorology, 1937) p. 15.

24 Neither specification is ideal, but it is difficult to see that any alternative formulation can be considered superior. (For example, the results obtained were little affected by transforming Equation Type I into logs). The index of productivity (IPC_t) is somewhat arbitrarily based at the beginning of the period; some independent variables may impact on output beyond one year (e.g., SW, LC and LF); the mechanisation variable is based on *stock* of machinery capital in use rather than the desired measure of the *flow* of machinery capital services; and the rainfall measure does not reflect the effective precipitation or its distribution within the year.

25 An additional problem with the superphosphate figures is that we are unable to compute the application rate *per acre fertilized*. Many farmers may have had very high application rates at this time to establish (or restore) maximum yields; others may have used excessive amounts of fertilizer simply through ignorance of the appropriate maintenance rate of application. Either circumstance lessens the appropriateness of the superphosphate variable used in the regression analysis.

[26] The direct correlation coefficient between LF and LC was particularly high, suggesting the presence of multicollinearity. However, removing LF from the equation did not greatly alter the coefficients on the other variables nor their *t* values: compare the last two regressions in Table 5.

[27] This assessment is based on an examination of the *t*-values of the estimated coefficients reported in the text, and on the beta coefficients not reported here. For a discussion of the latter as a basis for making judgements about the relative importance of individual explanatory variables in multiple regression analysis, see R.S. Pindyck and D.L. Rubinfield, *Econometric Models and Economic Forecasts*, (New York: McGraw Hill, 1976), pp. 71-72.

[28] R.E. Gallman, 'Changes in Total U.S. Agricultral Factor Productivity it the Nineteenth Century', *Agricultural History*, 46, 1 (January 1972), 204-205.