THE INTRODUCTION OF THE MECHANICAL REAPER IN CANADA 1850-70; A CASE STUDY IN THE DIFFUSION OF EMBODIED TECHNICAL CHANGE

by

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ABSTRACT

The primary aim of the thesis is to provide an economic explanation of the rate of diffusion of the mechanical reaper in Canada. Widespread adoption of reapers in Canada started some thirty years after they were first available in North America, and this was a decade later than the period of rapid diffusion in the U.S.A. These are intriguing phenomena in themselves, but the occurrence of rapid diffusion of reapers in a critical period of Canada's economic development also gives historical importance to the question. The broader intention of the study is to lend insight into the general question of the diffusion of embodied technical change.

A model, based on David's concept of a threshold farm size, is developed. The fundamental hypothesis is that reapers were only profitable on farms above a certain size. Thus, if the distribution of farm sizes is known, then the number of reapers can be predicted. Predictions can also be made of what the number of reapers would have been in the absence of certain changes, thus giving some measure of the importance of those changes.

The extension from previous diffusion models is the explicit consideration of the farm size distribution. In David's work the threshold size is compared with the mean farm size, which prevents quantitative tests of the hypothesis.

The weaknesses of the model are that it assumes indivisibility of reaper services and unidirectional causation from farm size and factor prices to reaper adoption. These problems are examined and no empirical evidence is found to invalidate our model.

The estimates derived from the model follow the actual diffusion path. This supports the hypothesis that the economic variables of factor

prices, size of farm and technical change provide an explanation of the diffusion of the reaper. The findings from the hypothetical predictions are that technical change, i.e. design improvements which shifted the production function, is the most important explanatory variable and changing scale of operations is more important than changes in factor prices. It is also found that the effects of changes in one variable depend on the level of the other variables; in particular, there is a critical region, depending on the shape of the farm size distribution, where previously insignificant changes in factor prices or average farm size have a much greater effect than before on the number of reapers adopted.

The significance of these results for understanding the diffusion process is threefold. They direct attention to improvements in the initial invention as a critical factor, and yet little work has been done by economists in examining the genesis of such improvements. The finding that scale of operations can be more important than relative factor prices in explaining the adoption of embodied technical change is contradictory to the usual emphasis in the literature. David reached the opposite conclusion to ours, asserting the primacy of factor prices. This was due to his failure to use the whole farm size distribution. The introduction of the distribution of innovating units is also the crucial factor in explaining the observed S-shaped diffusion pattern. Since this pattern is common for many types of technical change, the model may have wide applicability.

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CHAPTER I

INTRODUCTION

The primary aim of this dissertation is to explain the rate of diffusion of the mechanical reaper in Canada. The historical importance of the question lies in the relationship between reaper diffusion and a period of rapid Canadian economic development. The broader intention of the work is to lend insight into the general question of the diffusion of embodied technical change. The reaper in Canada appears especially appropriate for this diffusion question since the basic invention was available some thirty years before it was widely adopted. Thus it is possible to concentrate on the economic decision to innovate with an available invention rather than on isoquant shifts caused by inventions.

In this chapter the historical evidence of the time-path of reaper diffusion in Canada and the analytical counterpart of the historical phenomenon are outlined. The latter question is shown to be crucially dependent on the form of the production function, and in this particular case it depends on how the capital argument of this function is measured. The remainder of the chapter consists of a survey of the relevant historical literature on Canadian development and the introduction of the reaper in Canada and of some of the literature on the diffusion of technology and choice of technique. Finally, one model is selected from this literature as the basis for our study of the Canadian reaper case and the extensions which are to be made to this model are outlined.

The history of mechanical reapers goes back at least to the start of the nineteenth century, but the first patents suitable for commercial production were not available until the 1830s. In the U.S.A. these new techniques saw a slow, limited diffusion for twenty years, then a rapid burst of production in the 1850s (David 1966). The invention was available almost as early in Canada and in the 1840s some American reapers were imported. In the late 1840s several Canadian producers started operations and by the second half of the 1850s they dominated the market to such an extent that a commentator in 1860 could say:-

> "an American made machine is now as great a rarity as a Canadian one was a few years ago" (quoted in Jones, p.102)

The threefold protection of high transport costs, relatively low wages and imperial preference on English steel gave the local producers a considerable price advantage over U.S. competitors ($125-130 against $160) in the Canadian market (Phillips, p. 10). The useful consequence of this is that we can roughly equate introduction of reapers in Canada with domestic production. Between the 1861 and 1871 censuses the value of Canadian annual output of agricultural implements rose from $413,000 to $2,685,000 (i.e. by 550%). In the next two decades the value of the industry's output continued to expand, but more slowly (by 64% and 70%). The rapid expansion in the 1860s appears to have been concentrated in Ontario, e.g. the 1871 census gives 36,874 reapers and mowers in use in Ontario and 5,149 in Quebec. These conclusions regarding the timing and location of reaper introduction are also supported by available evidence from newspapers (cf. quotations from the "Canada Farmer" in Phillips p. 40, Landon p. 168) and reports of agricultural societies (in Ontario Sessional Papers), which take reapers as commonplace in Ontario by the early 1870s.

Some idea of the importance of the reaper in increasing agricultural productivity may be obtained from the results of Parker and Klein's study of changes in productivity in American small grains production between 1840-60 and 1890-1910:-

> "The values ... showing the relative importance of the different types of mechanization, indicate that the traditional emphasis

> on the reaper and thresher is not misplaced. Alone or in interaction, these accounted for over 80 percent of the improvement due to mechanization in both wheat and oats" (Parker and Klein, p. 544)

and:-

> "Mechanization ... was the strongest direct cause of the productivity growth in the production of these grains. It accounted directly for over half of the improvement" (Parker and Klein, p. 543)

Given the importance and complexity of this technical diffusion it is desirable that any model we develop should be able to predict the speed and timing of the diffusion process and the absolute numbers of reapers in Ontario from 1850 to 1870.

The historical question has as its analytical counterpart the problem of choice between two techniques involving differing factor proportions. The predictions of economic theory as to why such a change in factor proportions should have occurred depend on the shape of the isoquants. If the production function is such that the expansion path is a ray from the origin of the isoquant map, then for any given factor price ratio the factor proportions will be the same whatever the scale of output.[1] In this case the only reasons why factor proportions should change are either that factor prices have changed or some technical progress has shifted the isoquants. In all other cases, factor proportions also depend on the scale of operations.

In Canada in 1860 there were two dominant harvesting techniques, i.e. hand-rake reapers requiring two man-days for each reaper-day and cradling requiring no reaper-days. Thus the isoquants should appear as:-

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[1] A sufficient, but not necessary, condition for a straight-line expansion path is that the production function be homogeneous of any degree, i.e. $f(tK,tL) = t^{\lambda} f(K,L)$, cf. Henderson & Quandt, p. 63.

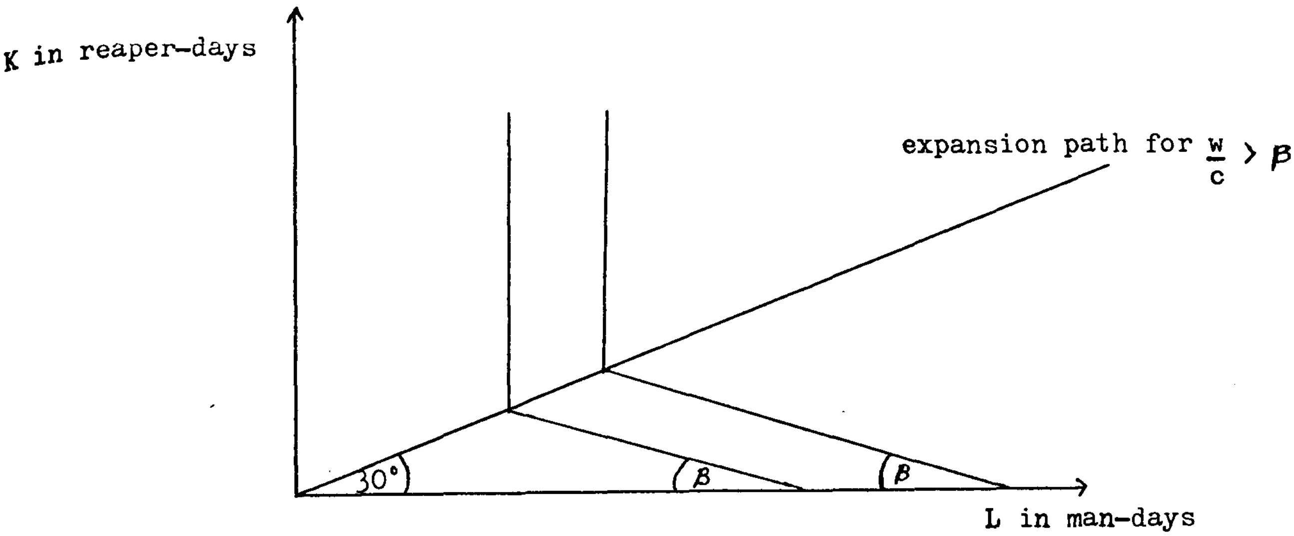

Figure 1. Isoquant map for the harvesting of small grains when both capital and labor are perfectly divisible.

and a change in $\frac{K}{L}$ can only result from a change in the factor price ratio, $\frac{w}{c}$, or a change in the shape of the isoquant (i.e. because of the introduction of the self-rake reaper which only required one operator).[2]

Implicit in Figure 1 is the assumption that reapers are divisible. If there were no reaper rental markets or cooperation between farmers in this matter, then the vertical axis should be measured in whole reapers rather

[2] The conclusion that in this case the capital-labour ratio is independent of the scale of output can be spelt out in greater detail. The production function is homogeneous of degree one. Since there are constant returns to scale and the production function is additive (i.e. both techniques may be used simultaneously), the oblique portion of the isoquant, representing situations where both techniques are in use, is technically feasible (Dorfman, Samuelson and Solow, p. 300-2). No point on this portion of the isoquant will ever be superior (i.e. a lower cost situation) to the corner solutions, and for all wage-rental ratios other than β this portion of the isoquant will be economically inferior to one of the corner solutions. For any wage-rental ratio greater than β the optimum capital-labour ratio is 1:2. If the wage-rental ratio is less than β, then the expansion path is the horizontal axis and no capital is used. Both of these conclusions about the capital-labour ratio are independent of the scale of output.

than in reaper-days and the isoquant map should look like:-

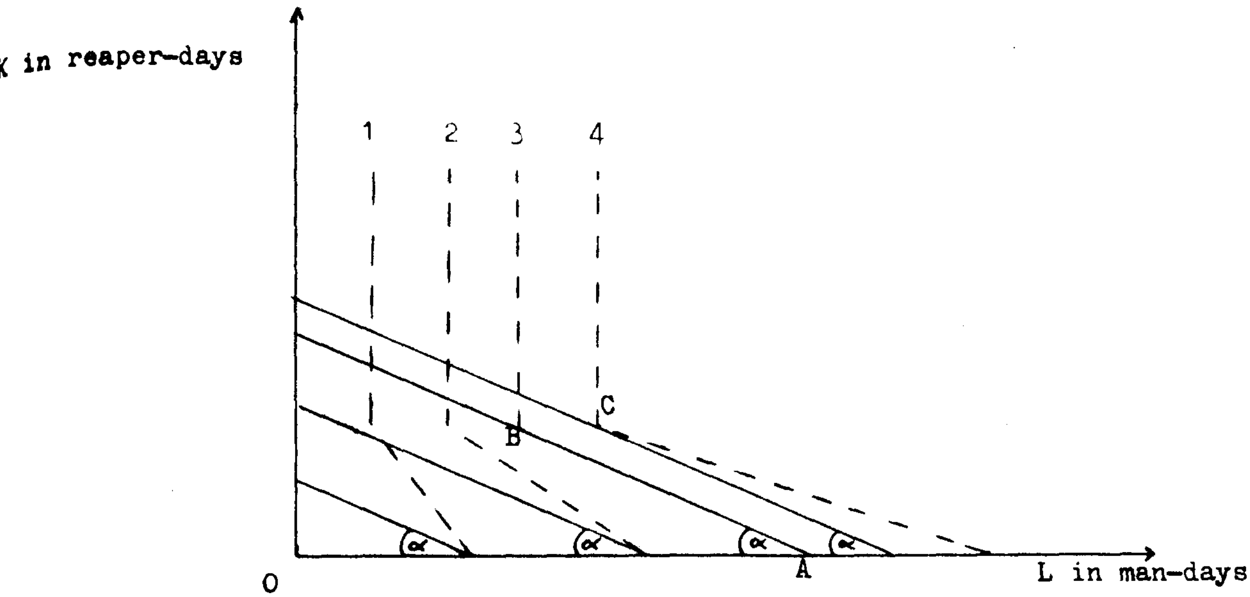

Figure 2. Isoquant map for the harvesting of small grains under the assumption that reaper services are indivisible.

As output doubles from isoquant 1 to isoquant 2 labour requirements with both techniques double, but since the cradling labour requirements are higher absolutely the slope of the isoquant changes.[3] Now, for a given wage-rental ratio α, cradling is the rational technique at output levels 1 and 2 and a mechanical reaper is the rational choice at output level 4, while at output

[3]The isoquants in this case are not continuous, because the assumption of additivity no longer holds. Thus if the farmer has a reaper he will apply all his man-days to that technique, as long as his small grain acreage is not greater than the annual harvesting capacity of a reaper, i.e. around 110 acres (for farms above this size there are three dominant production processes and the same analysis applies, but the number of farmers in this situation was minimal, cf. Table VIII infra). The only technically feasible positions are then the corner solutions (e.g. points A and B on isoquant 3).

Construction of lines between these solutions does, however, have heuristic value. It is the slope of this non-feasible part of the isoquant which should be compared to the wage-rental ratio in order to determine the least cost technique for a given output. Since this slope changes as output increases, the expansion path is non-linear, e.g. at a wage-rental ratio of α the expansion path is OABC.

level 3 the farmer will be indifferent between the two techniques. Thus, in the presence of an indivisible reaper the expansion path is Z-shaped and we no longer have $\frac{K}{L} = f\left(\frac{w}{c}\right)$ but rather that $\frac{K}{L} = f\left(\frac{w}{c}, Q\right)$, where Q is output (i.e. acres harvested). One view even ascribes to the size of the market the major part of this relationship, e.g. Kaldor (following A. Smith and Young) suggests that $\frac{K}{L} = f\ (Q)$ in practice.

Thus economic theory indicates three relevant sets of variables in explaining the adoption of a more capital intensive technique: factor prices, technical change[4] and the scale of operations. Our aim is to determine whether these three sets of variables are sufficient to explain the rate of diffusion of reapers in Ontario, and if so what is their relative importance.

Surprisingly few attempts have been made to explain the introduction of the reaper into Canada. This is primarily a reflection of the traditional view of Canadian economic history (as expounded by Skelton, Mackintosh, Buckley, Caves and Holton, inter alia) that the years after the Crimean War boom of the 1850s were a period of "secular depression" until in 1896 "Canada's hour had come" in the wheat boom. In consequence, apart from a few studies on the transcontinental railways and commercial policy, economic historians have until recently paid little attention to the 1860-90 period. This view has been challenged by Firestone who found higher per capita growth rates for 1867-96 than for the 1867-1967 period as a whole (e.g. Firestone 1969, p. 123), and concluded that an industrial revolution took place in Canada in the 1860s and 1870s with the introduction of the factory system (Firestone 1960, p. 230).

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[4]Technical change is defined as anything which alters the shape of the isoquant map. Here we are specifically concerned with technical change which is labour-saving in the Hicksian sense.

This "revisionist" view of the time-path of Canadian economic development received further statistical support from the estimates of manufacturing output by Bertram and McDougall.

Although this new view has become widely accepted, it has not yet produced any disaggregated studies which attempt to locate productivity increases in the 1860s. An obvious place to look is agriculture, which was the dominant sector in the economy at that time and which was undergoing a major change in the mechanization of harvest operations. One sector in which the introduction of the factory system was occurring was the agricultural implement industry, whose main product in the 1860s was the reaper. We will not be dealing directly with the contribution to growth aspect of the introduction of the reaper, but it seems reasonable to assume that this contribution was significant and that the paucity of literature on the introduction of the reaper is not a reflection of the importance of the event.

Some discussion of why reapers were introduced in Ontario in the 1860s is contained in Fred Landon's article on the effects of the American Civil War on Canadian agriculture. Landon saw this as a major change in a critical period of Canadian history:-

> "Among the agricultural changes of the Civil War period none is more noticeable than the stimulus given to the introduction and use of labor-saving farm machinery" (Landon, p. 167)

The "stimulus" was not in the form of a shortage of labour; some Canadians left to enlist in 1864 when bounties were high, but an offsetting northward flow of draft-dodgers "tended to depress wages in some of the trades, but had no visible effect on the farm labour situation" (Landon, p. 168). Landon gives no data on the price of agricultural machinery, but does mention a shortage of currency which, he claimed, led to high interest rates. Thus he identifies a reduced wage-rental ratio as a consequence of the Civil War, but this would scarcely be a stimulus to the introduction of labour-saving machinery. The puzzle is solved when he makes the increased demand for grain, which accompanied the war, the stimulus for the introduction of the labour-saving technique. Thus, the shift in demand for grain is not only more significant than the change in factor prices, but is so by an extraordinary degree, since it has to offset the opposite effect of a reduced wage-rental ratio.

The other noteworthy agricultural history of the period is that of Jones, whose chapter on the Civil War is based on Landon's work. Jones, however, saw labour market conditions as reinforcing, rather than reducing, the effect of the shift in final demand:-

> "It was natural that wheat growers should buy reapers as soon as the high price of wheat and labour made their use economical" (Jones, p. 96)

It is unclear which of these high prices Jones considered the more important.

Apart from these agricultural histories, the only discussion of the introduction of the reaper in Canada is in the business histories of the agricultural implement industry. Phillips' standard history of the industry is concerned with industrial organization rather than causes of expansion, and in connection with the latter question tends to be encyclopaedic rather than analytical:-

> "The economic conditions of the sixties favoured growth in the industry. The completion of a number of additional local railways, the shortage of farm labour occasioned by the demands of the railway builders and by the American Civil War, the spectacular increases in the price of wheat in 1864 and 1867, the continued exploitation of American patents by Canadian manufacturers, and the almost complete absence of American competition during the Civil War years, all paved the way for expansion." (Phillips, p. 40)

It is not clear which of these causes he sees as the most significant, and with some of them it is not easy to see any significance at all. We have already mentioned that American competition had little significance for the

Canadian market by 1860; a fact confirmed by Phillips himself:-

> "The two industries grew up around their respective markets in the nineteenth century, neither doing much traffic across the international boundary." (Phillips, p. 37)

Nor is there evidence of any major change in the rate of utilization of American patents during the 1860s.

Two of Phillips' arguments, that rising farm wages and high wheat prices occassioned the increased demand for reapers in the 1860s, are stressed by Denison in his history of Massey-Harris:-

> "The outbreak of the Civil War in the United States brought prosperity to Canadian agriculture and to the country's embyonic implement industry. Not only was there a steady demand for farm produce at increased prices, but young Canadians in large numbers (historians estimate as many as 40,000) crossed the border to join the Union Armies." (Denison, p. 45)

This conclusion is partly vitiated by doubts about the figure 40,000 which is not documented. A similar figure was given in a speech by Sir John Macdonald, as being the number of Canadians serving in the Northern Army, but this included Canadian residents in the United States who enlisted (Landon, p. 168). Since Denison also neglects the reverse flow of draft dodgers, it is doubtful whether migration induced by the war was sufficient to alter the wage rate much by itself.

In his more recent study of the same corporation, Neufeld is concerned with its current organization rather than its early development, but he does make some allusion to the company's history. He primarily stresses the agricultural labour shortage in the face of abundant land and demand for industrial labour, which provided the impetus for adopting labour-saving techniques (Neufeld, pp. 8-9), but in the specific context of the 1860s he also mentions high grain prices and the availability of new techniques in harvesting machinery (Neufeld, p. 16). This last point suggests that improved reapers in the 1860s provide a case:-

> "... of a major technological development in farm machinery that suddenly reduced costs of farm production and left some farm labour redundant." (Neufeld, p. 9)

If Neufeld is correct, then technical change (presumably the development of the self-rake reaper) was a significant cause of the rapid reaper diffusion of the 1860s.

Thus the historical literature suggests that all three sets of variables (factor prices, technical change and scale of operations) are relevant to the spread of the reaper in Canada, but it provides little guide as to their relative importance. Landon emphasizes the increased demand for the final product. Jones, Denison and Phillips stress this and the shortage of labour, while Neufeld emphasizes labour scarcity and technical change.

A further relevant variable is suggested in Hutchinson's, biography of C. H. McCormick. In explanation of why McCormick reapers didn't sell well in Canada, an agent of the company is quoted as saying:-

> "The Canadians are clannish and strongly prejudicial" and "where a machine gets a right start and works up to the mark ... it is hard to convince them that any other ... will do" (Hutchinson II, p. 647)

This may have been sour grapes, and indeed Canadian farmers had good reason to purchase the cheaper domestic products. Nevertheless, there is the charge of lack of good business sense which has often been levelled at the Canadian, especially in the form of characterizing him as more conservative and less enterprising than his American counterpart. This is still to be heard today in the debate over foreign ownership (Watkins). In the context of the present study it is clearly a sufficient explanation of Canadian tardiness in reaper adoption, but on the other hand it is scarcely very enlightening and incapable of generalization to other countries. Furthermore, the current debate on the climacteric in nineteenth century England suggests that apparent defects in entrepreneurship may merely mask the real reasons for failure to follow the most innovative course of action (McCloskey). Thus, if we do find a suitable explanation of reaper adoption based on economic rationality, it will have the consequence of revealing the "conservative Canadian" image as a red herring, at least in this case.

To conclude this survey of the literature on the mechnization of agriculture in the 1860s, mention may be made of a recent study of a similar problem in a later period of Canada's development. Norrie in his work on the Prairies' wheat economy 1911-46 is primarily concerned with evaluating the degree of capital/labour substitution and the bias of technical change, but he also found that "average farm size was a significant and consistent determinant of labour productivity" (Norrie, p. 16). This points to the scale factor, but it must be emphasized that this is not the major thrust of Norrie's argument.

Apart from the literature on Canada, there is also a body of writing on the diffusion of new techniques which is of interest in the present context. One branch of this has been concerned with measuring and explaining the lag between the invention of a new technique and its economic application (Enos).[4a] An important question here is whether the lag occurs because of the need for technical improvements to the basic invention or because of changes in economic conditions. We will return to this question in chapter 6. A second branch of the diffusion literature has been concerned with studying the pattern of diffusion. Rather than all economic units switching simultaneously

[4a]Salter is also concerned with this question (Salter ch. 4-6). He explains the rate of adoption of the best practice technique in terms of the gross investment rate, i.e. it is strongly affected by the rate at which firms replace their existing capital:-

> "... this inability to realize the full potential of technical progress arises out of the existence of fixed capital equipment which inhibits immediate adjustment to a flow of new techniques" (Salter p. 66)

Since the reaper replaced a technique which used no capital, his diffusion analysis concentrating on replacement rates is not relevant to the present context.

from not using a given technique to using it, the typical diffusion pattern is one of slow adoption at first, followed by a more rapid rate and then flattening out to approach some saturation level asymptotically. On a graph where the abscissa measures time and the ordinate measures the proportion of units using the new technique, this produces an S-shaped curve (Mansfield, Griliches, Hagerstrand). From the description given above, the rate of reaper adoption in Canada appears to have fit this pattern. The consequence of this for our study is that we cannot adopt a completely aggregative model, but must allow for variation between farmers, i.e. in 1860 some farmers did possess reapers though this was uncommon and in 1870, although reapers were used by many farmers, a great many still did not use them.

The extensive literature on the choice of technique is also relevant to our study. The bare bones of the theoretical literature have already been presented, although more exists in the areas of growth theory and development economics.[5] Of more direct interest is the historical debate over why the U.S.A. adopted more labour-saving techniques than the U.K. in the nineteenth century. The central figure in this debate has been Habakkuk who produced a barrage of arguments which at times appear confusing but whose central point is that, because land was plentiful, the opportunity cost of wage labour was higher in the U.S.A. than in England and thus there was greater incentive to adopt labour-saving techniques there. This is of course related

[5] The major works are Sen, Salter (Ch. 1-3) and Hicks (esp. ch. VI). Hick's theory of induced innovation, which stresses the role of relative factor prices in influencing the bias of innovation, has been developed in an agricultural context in Hayami & Ruttan. These works are of little use here because they argue in an "aggregative" context, which has been rejected as a relevant approach to the current problem (cf. last sentence of the previous paragraph). This criticism also applies to Habakkuk's work discussed in the present paragraph, but in this case the ensuing debate produced a model which is capable of a disaggregative approach.

to the earlier mentioned debate over whether English entrepreneurs were rational not to adopt these new techniques. In the Canadian context the question arises of whether the inferiority of the land in central Canada relative to that of the American Midwest is sufficient explanation of the slower adoption of the reaper.

The most important contribution to the above debate so far as this study is concerned is the work of David (1966, 1971), who tries to explain why reapers were introduced in the 1850s in the U.S.A. and why the process was much slower in Britain. David's hypothesis is that reapers will only be profitable on farms above a certain acreage of small grains, and that this threshold size will vary inversely with the ratio of the cost of farm labour to the cost of the machine; e.g. in Figure 2 for the wage-rental ratio α the threshold size is the farm size associated with isoquant 3. In applying this model to the introduction of reapers in the U.S.A. in the 1850s, David found that reductions in the threshold size were more important than any exogenous increase in average farm size. Although farms were smaller in Britain than in the U.S.A., the major difference vis-a-vis the adoption of reapers was that much more land improvement was required before reapers could be utilized in Britain, i.e. the capital costs were larger there. Thus, David's conclusion is essentially an assertion of the primacy of factor prices in determining factor proportions.

The model which we will apply to Canada is based on David's concept of a threshold farm size. The major extension is that we will compare the threshold size with the distribution of farm sizes, rather than just with the average farm size. Quantification of the predicted adoption of reapers at any given time will depend on the shape of this distribution as well as its mean. If the model provides a good explanation of the rate of reaper adoption, then we can disaggregate the causes of rapid diffusion and estimate the relative importance of changes in factor prices, technological conditions and the scale of operations. The introduction of the farm size distributions is important here because, if the distribution is asymmetrical, the conclusions reached by looking only at average farm size may be wrong (cf. chapter 6).

David's work has been criticized for being simplistic, in particular for ignoring the possibility of cooperation (Davis, p. 87-8; McCloskey, p. 206-14). The consequence of cooperation for the model is that it will fail to predict any reapers owned by cooperating sub-threshold-size farmers or by reaper rental institutions. The extent of cooperation depends on the level of transactions costs; if these are zero, then reaper services are perfectly divisible and scale of operations is not a determinant of factor proportions, whereas if they are infinite there can be no profitable cooperation and David's threshold size remains applicable. The strongest argument against the existence of cooperation over reapers in Ontario 1850-70 is that there is no empirical evidence of it. Some arguments as to why transactions costs might have been high are given in chapter 3. The strongest of these arguments is that the pattern of landholdings and the geographical conditions inhibited the movement of reapers between potential cooperators' farms. Random samples of farms from three counties provide the basis for tests of this argument. The case against cooperation is far from proven, but is sufficiently strong to suggest that cooperation was uncommon; a conclusion implying that our estimated number of reapers will be biassed downwards, but not sufficiently to invalidate use of the model.

A further problem with the model is the possibility of reverse causality; in particular, is it valid to treat small grains acreage and the distribution of farm sizes as exogenous or are they determined, in whole or in part, by other variables in the model? If the availability of the reaper alters the distribution of farm sizes or encourages increased acreage, then we would be wrong to ascribe a causal role to the latter phenomena. The question of what determines farms' acreage and whether the farm size distribution can reasonably be treated as independent from the availability of the reaper is examined in chapter 4.

Although there are other problems regarding the specification of the model, the data and the derivation of results, the problems of cooperation and reverse causality are the most critical. They are, however, critical for different reasons. The existence of widespread cooperation over reapers would invalidate the whole threshold size approach, while reverse causality invalidates only the separation of causal factors and not the total explanation of reaper adoption.

In this chapter we have seen that recent research has pointed to the 1860s as a critical period in Canadian economic development. The rapid diffusion of the mechanical reaper was an important component of this transition period, but there is little rigorous analysis of this phenomenon in the historical literature. The literature does suggest that the major explanatory variables were factor prices, demand for small grains and technical improvements in reaper design, but the weights of these factors are unknown. The model which we propose permits an analysis of the effects of these three variables on reaper adoption. A specific statement of the model is given in chapter 2.

CHAPTER II

THE MODEL

The model which is to be used to analyze the rate of diffusion of the reaper in Canada is formally set out in the first section of this chapter. The threshold size concept is then expressed graphically, where the necessity for a rising long-run marginal cost curve becomes apparent. Following this, some diagrammatic illustrations of the importance of the shape of the farm size distribution are given. Finally, the method by which predictions of the rate of reaper adoption are to be obtained from the model is explained.

1. The Basic Model

The frequency distribution for small grain acreage per farm is:-

(1) $F = f(x) = f(\mu_x, \sigma_x, \ldots)$ where x = small grain acreage per farm.

where F is the number of farms of any given size. Using David's "threshold size" assumption, the proportion of farms using reapers (R) can be derived from (1) by:-

(2) $R = \int_{S_T}^{\infty} f(x).\ dx$ where S_T = the threshold farm size.

For a normal distribution equation (2) can be represented graphically by:-

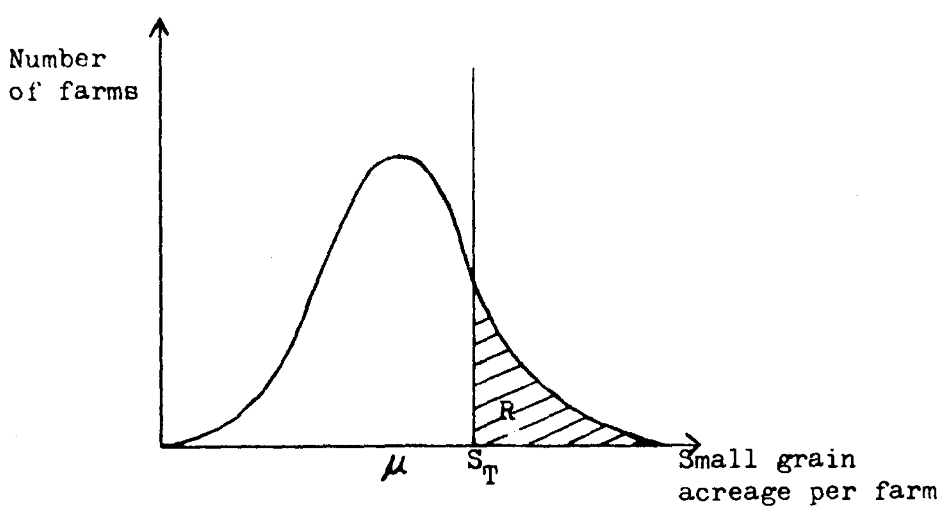

Figure 3. Graphical representation of the predicted proportion of farms using reapers.

With the above information we could also derive the total acreage harvested by reaper (A_R) by integrating the cumulative frequency function associated with (1), i.e. $F(x) = \int_{-\infty}^{x} f(x).\ dx$, over the relevant range:-

$$(3)\quad A_R = A(1 - \int_0^{S} F(x).\ dx)$$ where A = total acreage under small grains

Thus, for any given farm size frequency distribution[1] and values of A and S_T we can estimate (a) the proportion of farms possessing reapers and (b) the total small grain acreage harvested with reapers. It should be noted that the variable A, as well as entering into equation (3), also affects f(x), since μ_x is equal to A divided by the total number of farms.

The threshold farm size in acres of small grains to be harvested is defined as that size where:-

$$(4)\quad c = \sum_{i=1}^{S_T} L_{s_i} \cdot w$$ i = 1, ..., S_T designates the acre in the sequence of acres harvested.

where L_s = the number of man-days of labour dispensed with by mechanization, per acre harvested, w = the money cost to the farmer of a man-day of harvest labour, c = the annual money cost of a reaper to the farmer. Assuming linear cost functions for the two processes (cradling and mechanical reaping) over the relevant range, i.e. constant returns to scale, (4) can be rewritten:-

$$(5)\quad c = S_T \cdot L_s \cdot w$$

Thus:-

$$(6)\quad S_T = \frac{c}{L_s \cdot w}$$

[1] To be precise we should say "frequency distribution of small grain acreage per farm". Since constant reference is to be made to this distribution, the shorter title of "farm size distribution" will be used in all cases where no confusion arises. Similarly, S_T is referred to as "threshold farm size" rather than the more precise, but more awkward, "threshold small grain acreage."

Expressions (4) - (6) represent the farmer's purchase decision under conditions of perfect knowledge and static expectations (David 1966, p. 28-9). He compares the annual cost of a reaper with the reduction in his annual wage bill resulting from reaper usage and, if the cost is less than the wage saving (i.e. his farm is larger than S_T), then he buys a reaper. When the equalities of (4) - (6) hold, the farmer is indifferent on cost grounds between purchase and no purchase.

David's formulation of the annual money cost of a reaper is:-

$$(7) \quad c = (d + 0.5\, r)\, C$$

Where C = the purchase price of a reaper, d = the rate of depreciation, r = the rate of interest. Of the variables in (7), C and r are exogenous and d may or may not be exogenous:-

$$(8) \quad d = \max \begin{cases} d_1 \\ d_2 \end{cases}$$

when d_1 is a technologically given rate (e.g. assuming linear evaporation d_1 is the reciprocal of the life of a reaper) and d_2 is an economic rate depending on farmers' time horizons (and hence related to r).[2]

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[2]The formulation of annual reaper costs could be improved by including expected maintenance costs, M*. If quality improved as the number of reapers increased, this would impart a multiplier effect into the model. This would be a source of reverse causality, since the number of reapers affects the value of S_T.

On the other hand, any quality improvement effects may have been offset in the short and medium-term by inelasticity of supply of mechanics. The problem in quantifying M* is the lack of data. The relevant information would be (a) how many times prospective purchasers expected their reapers to break down and (b) how much they expected the average repair bill to be. None of this information is available. This is presumably why David ignored M* in specifying equation (7), and we will follow his lead. The consequence of this ommission is that our values of S_T will be lower than if M* were included. The discrepancy may not be large, however, because by 1850 reapers were fairly robust and M* should have been low. Furthermore, some repairs could have been carried out by the farmer himself in the off-season when his opportunity cost was low.

2. The Determination of Total Acreage

The linear short-run cost functions assumed for equation (5) can be represented graphically as:-

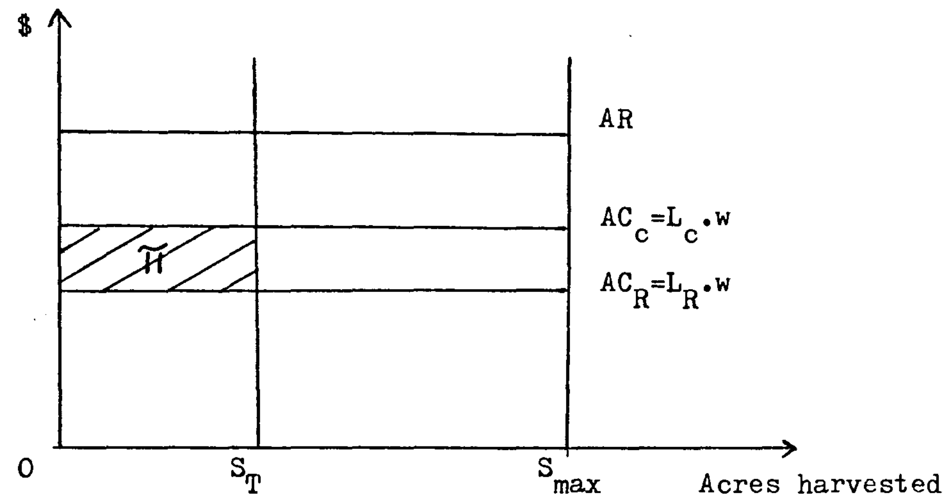

Figure 4. Assumed Short-run Labour Costs for Harvesting Small Grains; Graphical Representation of the Threshold Farm Size.

where AR = average revenue from an acre of small grains = the price of small grains multiplied by the yield per acre, L_c = number of man-days required per acre using cradling, L_R = number of man-days required per acre using reapers, AC_c = labour costs per acre harvested using cradling, AC_R = labour costs per acre harvested by reaper. When the shaded area (π = the difference in wage bills between the two techniques) is greater than c then the reaper can be introduced with profit. For a farm of size S_T, as in Figure 4, the shaded area exactly equals the annual money cost of a reaper, i.e. $\pi = c$. Conversely, the farm size where $\pi = c$ is defined as S_T.

The obvious question arising from Figure 4 is why don't farmers just increase their grain acreage to S_{max} (the maximum acreage which can be harvested with one reaper) or some multiple of S_{max}, thus obtaining maximum profits? The answer must be that there were other costs involved in producing small grains, and that these costs were increasing over some range. One explanation is that expansion leads to the use of inferior lands with higher unit costs resulting from poorer location, fertility, etc. Alternatively there might be rising long-run costs associated with increasing the size of farms, such as transactions costs associated with land purchase or costs related to the physical clearing of land (e.g. the setting up of a backwoods farm was estimated to cost £100 minimum, Jones p. 67). In either case, if we are to explain farm sizes below S_{max} in a situation of horizontal average revenue curves, then the expansion costs must be increasing over the relevant range.[2a]

If this upward-sloping long-run marginal cost curve exists, then it is a rational response to an increase in small grain prices to expand the acreage under small grains. Similarly, if the cost of clearing new land falls, then we may expect some conversion of unimproved land to small grain cultivation. Any increased small grain acreage will consist of improving land, which at the old prices yielded an expected stream of profits whose present value was less than the expansion costs, and the increase will continue so long as land exists for which the present value of the expected profit stream is greater than these costs, i.e. until MC = MR. This condition is set out more formally in chapter 4.

3. The Distributional Effects of Increased Acreage

After an increase in the price of small grains or a reduction in the costs of preparing land for grain production; there exists an equilibrium total small grain acreage greater than the old total acreage, but so far we have no way of explaining how this increased acreage will be distributed between

[2a]The point of intersection of the LRMC curve and the AR curve determines the acreage sown with small grains, i.e. the farmer's position on the horizontal axis of Figure 4. The LRMC curve cannot be drawn in Figure 4 because that figure refers only to harvesting costs in a single season, whereas the LRMC curve includes all production costs.

farms.[3] The importance of this question can be seen in Figure 5, which illustrates three possible ways in which increased total acreage may affect the farm size distribution. In 5(A) the number of farms above the threshold size is unchanged, while in 5(C) it is increased tremendously for the same change in total acreage.

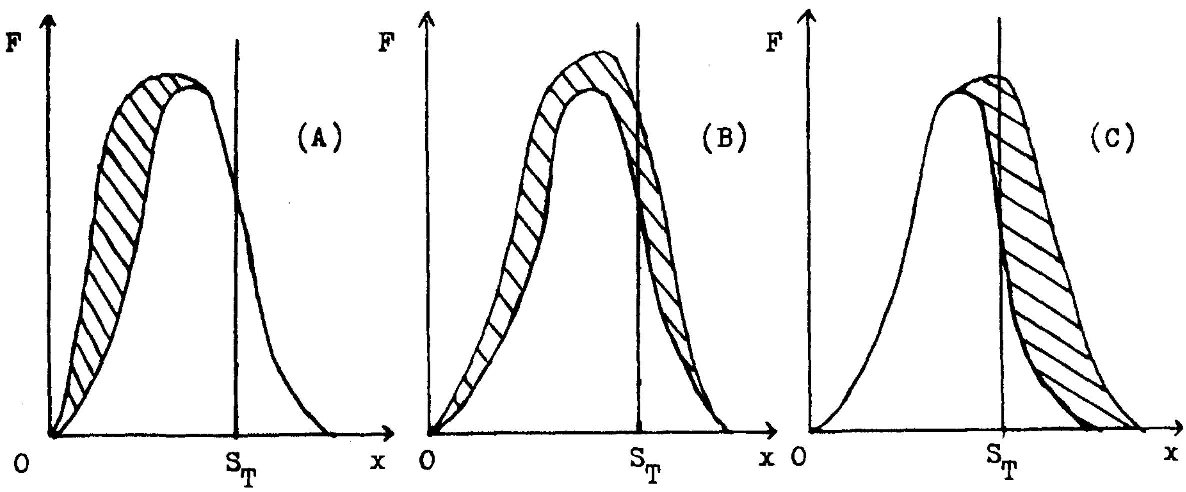

Figure 5. Alternative possible effects on the farm size distribution of an increase in small grain acreage.[4]

An increase in total small grain acreage may result from the creation of new farms or from a rise in the size of existing farms or from some mixture of these two forces. A rise in the number of farms, N, depends on the availability of potential farmers, i.e. it is linked to net migration and alternative opportunities in the economy. Also, we would expect new farms to start off on a small scale, i.e. as represented by 5(A). The fact that between 1850 and 1870 average farm size ($\mu_x = A/N$) increased and net migration was negative suggests that growth of existing farms was more impor-

[3]The equilibrium acreage obtains when the cost of bringing the marginal acre of land into small grains production is equal to the net present value of the expected profit stream from that acre.

[4]As in Figure 1 the use of an initial normal distribution is purely illustrative of the general form f(x).

tant than new farms in this period.

This leads on to the question of whether large and small farms would react in the same way to an incentive to bring new land into cultivation. Arguments can be made on both sides of the question. Since no conclusive decision is arrived at, these arguments will be treated in summary fashion. One view is that large farms have greater credit availability and are thus better placed to act. An alternative approach is to look at tenure arrangements. In Ontario farmers were usually freeholders, with tenancy fairly rare except by installment buyers and on clergy lands (cf. ch. 5.4). There was some sharecropping on new lands, usually by professional land-clearers and owners with purely speculative motives (i.e. a short-term arrangement). Thus there appears to have been little opportunity for large landowners to increase their holdings for the purpose of renting out. Since there will be diseconomies of scale in running a large farm oneself (especially in periods of shortages of wage labour), this implies that there was little incentive for large farms to expand much. Furthermore, farmers would wish to expand to adjacent land and there may have been no fixed pattern of farms of any particular size having unimproved land next to them.

The outcome of this discussion of the effect of increased total acreage on the shape of f(x) is uncertain. We have rejected the most likely explanation of an effect like that of 5(A), i.e. new entrants. Anyway, we know that the increase in acreage in Ontario 1850–70 was accompanied by a rise in μ_x. We have given plausible arguments for 5(C), i.e. access to credit, or for something approaching 5(B). Thus, although we cannot specify a priori a simple shift in one or two moments of f(x) in response to a change in total acreage, we have argued for a link between a change in A and a change in the number of farms of size greater than S_T. We will return to this question briefly in chapter 4. We are not, however, attempting to predict changes in concentration of ownership, and our final approach to the problem is empirical, i.e. the existing farm size distributions in 1850, 1860 and 1870 are taken as data (chapter 5.4). When these distributions are approximated by a continuous distribution (chapter 6), it is found that the median farm size increases through the period while farm size concentration remains unchanged, at least by some measures.[5] These conclusions are consistent with the reasoning of this section.

4. The Method of Estimation

Once total acreage has been determined, the equilibrium proportion of this to be harvested by reapers is also known for given values of S_T and $f(x)$ from equation (3). Since labour requirements per acre with and without reapers are technically fixed, the demand for harvest labour is determined. A disequilibrium situation will arise if at the expected wage (i.e. that used in calculating (4) - (6)) this demand is not equal to the supply of labour. This possibility is ruled out by assuming that the agricultural sector faced an infinitely elastic supply of labour at a wage rate determined elsewhere (cf. Appendix).

Since disequilibrium situations in the labour market are now ruled out, the number of reapers introduced between two years can be predicted from equation (2). The value of S_T can be calculated for each year and applied to

[5] Since a lognormal distribution with the same σ^2, (but differing μ) is used for each year, the Lorenz coefficient of concentration remains constant. On the other hand, the Gini coefficient, for example, also depends on the arithmetic mean of income and thus indicates increasing concentration 1850-70 (Aitchison & Brown p. 111-5). No commonly used measure would indicate reduced concentration (i.e. a pattern resembling 5(A) is ruled out).

the f(x) of that year to obtain a value of R, and the total number of reapers in each year will be N.R. The predicted values of NR will be designated R^*_t . It should be noted that a precise specification of the determinants of A is not necessary; the important point is that A is determined exogenously to the model.

The usefulness of this model is that, if it does have predictive power with respect to Ontario in the 1860s, then it permits separation of causal factors, or at least tests of sensitivity of R^*_t to different independent variables. This is done by posing questions such as: what would R^*_t have been in 1870 if f(x) had not changed since 1860? These counterfactual questions can be applied to three groups of variables: factor prices (c,w), technical change (reflected in L_s) and total acreage (whose changes shift f(x)).

CHAPTER III

RENTALS AND COOPERATION

Of crucial importance to our model is the assumption of no renting or cooperative purchase of reapers. In a frictionless world the problem of the indivisibility of a capital good hampering its diffusion would be overcome by one or both of these expediencies. Since our model's behavioural assumption is one of farmers' rationality, then we must explain what frictions existed in Ontario to make such expediencies non-rational.

Since reaper rental institutions would loom large in rural life, we would expect that if they existed mention would be made of them in the many county histories, settlers' guides, etc. written in mid-nineteenth century Ontario. There is no such evidence of the existence of a reaper rental market in Ontario 1850-70. One limitation on contract reaping would appear to have been the short duration of the harvest season, which only lasted about a fortnight. Such an enterprise could scarcely have been a principal employment for anyone, and if it were a sideline one would expect that high profits would be required to cover the costs of storage, etc. and of peak workload being at the period of highest opportunity cost of labour. Profits were, however, unlikely to be high because of the difficulty of moving the early reapers, which weighed over half a ton, between farms, and also because of possibly high transactions costs (although since there were no such firms in existence we cannot establish how high these would have been).

More surprising is the absence of any evidence of cooperation between farmers in the use of reapers. This may to some extent be spurious, because chroniclers may not have noticed that reapers were jointly owned or, if they did notice, may not have considered this fact to be noteworthy. Such activities did occur in the United States, e.g. a "long list of cooperative purchases" has been compiled from the McCormick papers (quoted in Davis p. 87, although the extent of "long" is not made clear),[1] but similar records are not readily available for Canada.

One problem for two farmers planning to share a reaper is that there is great advantage to having first use, because the farmer who has second use will be faced with more overripe grain which is prone to shattering. Any pecuniary compensation principle or profit-sharing would be difficult to calculate. On the other hand, if the sum of the two farms' acreage was sufficiently far above the threshold farm size, then the saving from having use of a reaper would provide considerable extra profits, however rough and ready the sharing procedure. Also the question arises of why the simple risk-sharing procedure of taking first use in alternate years was not adopted. This leads on to the problem of the long-term nature of an asset with an expected life of ten years, which necessitated a long-term cooperation agreement to which farmers might not have wished to commit themselves. Such a motivation does, however, seem rather unlikely; there is evidence in the remainder of the century of cooperation over other types of machinery, e.g. the combine, and over grain elevators, which belies the idea of farmers insisting on individual ownership of all factors of production. Finally it is possible that credit arrangements were more difficult to arrange in the case of two (or more) cooperating farmers; even if this was not the case with McCormick (see above), it may have been true with the smaller scale Canadian manufacturers.

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[1] In view of the fact that Davis uses this evidence to make the strong assertion that David's "extremely facile analysis" has "little historical reality", it is amazingly ill-documented. No specific cases are quoted, and we are left with many unanswered questions, e.g. (a) where in the McCormick papers is this list drawn from? (b) how many cooperative purchases were found and what were the precise arrangements? (c) were the cooperators geographically concentrated in any particular area?

None of the above arguments appear to be major deterrents to cooperation. A more critical element can be introduced by bringing a spatial dimension into the discussion. This follows from the cumbersome nature of the early reapers, which was mentioned above. A contemporary description of an English version of the McCormick reaper characterizes it as:-

> "... unwieldy, and requires much time and labour in taking to pieces for removal from field to field or from farm to farm". (W. Wright, p. 127 quoted in David 1971, p. 152).

In view of the short harvesting season time was of the essence; the more time that was wasted in moving the reaper from one cooperator to another, the less the benefits of cooperation.[1a] In general, as the distance between cooperators increased, so would the costs of cooperation.

Thus the ideal situation for cooperation was between adjacent farmers. If it was profitable for a farmer with 50 acres of small grains to buy a reaper, there seems no logical reason why it shouldn't also be profitable for two adjacent farmers with 25 acres each to buy one. There is, however, no reason to expect this ideal situation to be especially common. Land settlement patterns are not so orderly that the large farms in a village are together, the medium-sized farms are together and the small farms are together; they are much more haphazardly distributed. Furthermore, the set of potential cooperators will not be all farms with small grain acreage less than S_T, because below a certain acreage farmers will not consider it worth their while to get involved in cooperation.[2] The ideal conditions then exist where

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[2] The assumption is that transactions costs increase with the number of cooperators. Thus it was less profitable for a large number of small farms to cooperate than for a few medium-sized farms. In general, we will consider the ideal conditions to exist where two farmers could successfully cooperate, and they are of approximately equal size.

[1a] The harvesting season was generally no longer than ten days (Rogin p. 78n.) and even within this short period the grain was extremely vulnerable to bad weather and shattering (cf. p. 55 <u>infra</u>). This is in contrast to other parts of the production process where timing was not so critical.

potential cooperators are located sufficiently close together for cooperation costs not to exceed cooperation benefits.

If these ideal conditions were common, then there appears to be no reason why cooperation should not have occurred, making reaper services divisible and our model inappropriate. If they were uncommon, then our estimates of the number of reapers will be biassed downwards[3] but the method will retain validity. The question of prevalence of ideal conditions is clearly an empirical one, the answer to which will depend on the size of cooperation costs, the range of farm sizes within which potential cooperators are believed to fall and the spatial distribution of farms.

The York County Sample

In order to check some of the above hypotheses about the spatial distribution of farms, a sample was taken. The earliest maps suitable for our purpose are those of Belden and others which cover the counties of Ontario and which were published from 1875 onwards (May). For this reason it was desirable to select a county whose improved acreage and number of landowners didn't change greatly between the 1850s and the 1870s. York fits this bill admirably; acreage sown increased in the 1850s but not by as much as in the rest of Upper Canada, reflecting the relatively well-established nature of farming in that county, and by 1860 most of the county was settled. In the

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[3]The total number of reapers, NR, consists of those which are purchased by individual farmers, IP, plus those which are purchased by two or more farmers and by rental institutions, CP:-

$$NR = IP + CP$$

Since our estimates, R^*_t, are derived from assumptions about the individual farmers' decision-making process, they will only be estimates of IP. Thus, even if we have specified the decision-making process accurately and the data are perfect, our estimates will understate the total number of reapers by CP.

absence of any major change in the number of landholders, it can be argued that the landholding pattern displayed in the Miles Atlas of York in 1878 approximated the pattern of the years around 1860. A further reason for choosing York as the sample county is that it was the largest small grains producer during the period of study. Thus, if cooperation was not feasible in the relatively densely populated and high producing York County, then it would be unlikely to be feasible anywhere in Ontario.

The design of the sample was aimed at obtaining a random selection of landowners. York county in 1878 consisted of ten townships, each of which was divided into concessions which were further subdivided into lots, the standard inland lot being of one hundred acres. All lots in the county outside of Toronto and its suburbs were serially numbered, and the first thirteen numbers from a table of random numbers were used to select the sample. Of these thirteen lots, three were unsuitable for our purposes (two were located in villages, and thus split into small town lots; and one was right on the edge of the county). In the ten remaining lots there were twenty-six landowners (Table I).

The first hypothesis to be tested is that "land settlement patterns are not so orderly that the large farms are together, the medium-sized farms are together and the small farms are together; they are much more haphazardly distributed." For each landowner, adjacent farms were grouped by size according to the census groupings (Table II) and the size distribution of adjacent farms was then compared to the county farm size distribution of the 1871 census (Table III). If the hypothesis were true there should be no bias in the adjacent farm groupings; in particular there should be no tendency for the group within which the base farm falls to be larger than its county-wide percentage, e.g. around a 40 acre farm there should not be more than 26.82%

of the adjacent farms in the 10–50 acre category.[4] In order to test this, a statistic Z_i was computed whose value is unity when the percentage of adjacent farms to the ith. farm in the same size class as the ith. farm is greater than the expected percentage (i.e. the aggregate percentage for the county) and whose value is zero otherwise (Hoel p. 330–3). Since the Z_i are independent, their sum:–

$$u = \sum_{i=1}^{n} Z_i$$ where n = the number of farms in the sample

will be a binomial variable corresponding to n independent trials for which $p = \frac{1}{2}$. The null hypothesis is that $u = n/2$, i.e. farms are haphazardly distributed, while the alternative hypothesis is $u > n/2$. Thus a one-tail test

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[4] A more formal statement of the haphazard distribution hypothesis runs as follows. The set of farms in York county, [X], has m members. The subset, $[J_i]$, contains all farms adjacent to the ith farm, X_i, and has j members, i.e.

$$J_{i_1}^{k}, \ldots, J_{i_j}^{k} \in X_1^{k}, \ldots, X_m^{k}$$

The superscript k denotes which census size group the farm occupies, k = 10–50, 50–100, 100–200, > 200. Thus $J_{5_3}^{10-50}$ refers to the third farm adjacent to the farm X_5 and this farm has between 10 and 50 acres; the $J_{5_3}^{10-50}$ is also a member of the [X].

If the ith. farm is in the rth. size group, i.e. k = r for X_i^k, then we can define A_i as all J_i^k for which k = r and B as all X^k for which k = r. Thus A_i/j is the proportion of farms adjacent to the ith. farm which are in the same size group as the ith. farm, and B/m is the proportion of all farms in the population (i.e. York county) which are in that size group. The null hypothesis is then:–

$$\sum_{i=1}^{n} \left(A_i/j - B/m \right) = 0$$ where n = the number of farms in the sample

i.e. the expected difference between the sample proportion and the population proportion is zero.

For farms on the class boundaries the two neighbouring classes were consolidated, e.g. for a 50 acre farm the relevant size group was taken to be 10–100 acres.

is required and, at the 95% level of significance, the critical value of u is 17.2 when n = 26 (using the normal approximation for the binomial). In our sample u = 17, so the null hypothesis was not rejected.[5]

Although the above test supports the haphazard spatial distribution assertion, upon closer examination a definite pattern to the Z_i values is apparent. All seventeen of the unity values apply to farms of 50 acres and less, while none of the nine zero values apply to farms under 50 acres. Thus the smallest farms do tend to have more of their own kind surrounding them than would be expected, while the medium-sized and large farms have fewer adjacent equivalent-sized farms than expected.[6] The significance of this in the context of reaper cooperation is that, since only the very largest farms had reapers in 1860, the potential cooperators would come from the medium-sized and large strata of farms. Yet it was these farms which would encounter the most difficulty in finding like-sized neighbours to join them in the enterprise.

Thus the "haphazard distribution" hypothesis must be modified, but the modification is in a direction favourable to predicting low incidence of cooperation over reapers. For the small farms, cooperating in the use of a reaper was not a feasible proposition at this time, because the more cooperators the more cumbersome the arranging. Yet over the set of likely potential cooperators the problem of finding an adjacent equivalent-sized farm was most marked.

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[5] Clearly, however, it would have been rejected at the 99% level of significance.

[6] Under the assumptions stated in chapter 5, the threshold size in 1860 was slightly less than 250 acres total acreage. This had fallen to 122 acres by 1870. "Small" farms are defined as ones of less than 60 acres, i.e. two of them cooperating would not be of the 1870 threshold size. "Medium-sized" farms are of 60–125 acres, i.e. two medium farms could have considered co-operation in 1870 but not in 1860. "Large" farms are of more than 125 acres.

The Huron and Carleton County Samples

The question may be asked whether a sample taken from York county is a "representative" sample, and so, as a test of the conclusions based on the York county sample, further samples were taken from Huron and Carleton counties. In the 1850s Huron county was on the frontier of Canadian grain production and in this expansionary period total occupiers of land increased from 2,922 in 1850 to 6,815 in 1860. By the 1860s Huron was the largest wheat producing county and was rivalling York in total grain production. It is also a useful contrast to York in that the farm size distribution was slightly different, Huron having a larger proportion of farms of 100 acres and less throughout the period. This is probably a reflection of the recent settlement where farmers obtained one lot or two shared a lot, and there had been few large land grants (cf. the military grants in the early part of the century when York was being surveyed) and little time for consolidation to have occurred. The drawback to using a sample from Huron county is that a source published in 1879 is less applicable to the 1850-70 period in a county undergoing change than in a more stable environment. The other sample presents some opposite facets of Ontario agriculture. Carleton county is in the eastern part of the province, its grain production was relatively stable 1850-70, and by the 1860s, it had a relatively large proportion of farms of over 100 acres.

The source for Huron county was the Belden atlas of 1879, and the data are given in Table IV. The value of u is 16 and thus the "haphazard distribution" hypothesis is again not rejected. On the other hand, the pattern of the Z values is the opposite of that in York county. Of the nine farms of less than 100 acres eight had Z values of zero, while fifteen of the remaining farms had Z values of unity. Thus it is the medium-sized and large farms which have more adjacent equivalent-sized farms than expected - a conclusion more favourable to cooperation than that from York county.

The Carleton county source was also in 1879 Belden atlas. Of the twenty-six farms in the sample exactly half had Z values of unity (Table V), so that the null hypothesis would not be rejected at any level of significance. Unlike the other two samples there is no clear-cut pattern to these Z values, apart from some slight tendency for smaller farms to have zero values.

Geographical Conditions

The above analysis is useful so far as it goes, but it is limited by the failure of the county atlases to delineate geographical features which are relevant to this study. Proximity may have been a major prerequisite for profitable cooperation, but the crucial point is that the time taken to move a reaper between the cooperating farms had to be short. Thus, even if two farms were adjacent and of suitable size for cooperating, if the boundary between them was a river then the costs of cooperation might be high. In the above samples we were able to take account of lakes, but not of rivers, swamps or rocky ridges. A further facet of this problem is that the atlases give no idea of which part of a landholding is under crops. Clearly, if all of a farmer's grain is in the eastern extremity of his holding, it is more profitable to cooperate with a neighbour to the east than with one to the west.

The ideal geographical situation for cooperation is then one where the land is uniformly fertile and uninterrupted by irregular disruptive geographical features. This is not always the situation in Ontario, even below the Laurentian Shield. There are a large number of lakes and rivers in southern Ontario, especially in the central section. The western section, which has the most fertile soil, is split by patches of open rock, of which the most dramatic is the Niagara escarpment which runs from the U.S. border to the

Georgian Bay. The other significant physiological feature of this area is the horseshoe moraines running through Huron, Bruce and Grey counties, whose chief landform components are (a) irregular, stony knobs and ridges and (b) bedded sand and gravel terraces and swampy valley floors (Chapman and Putnam, p. 198). The eastern part of the province had the least fertile soil and lowest grain yields, and it too was subject to geographical difficulties which inhibited transport, e.g. the Ottawa valley around Carleton county consisted of clay plain interrupted by rocky escarpments (Chapman and Putnam p. 353; cf. Innis and Lower p. 527, quoted in the next chapter).

Conclusions

Although there doesn't appear to have been any compelling reason for the absence of cooperation over reapers in Ontario 1850-70, the spatial aspect suggests that there were some difficulties. In particular the hypothesis that farms were not distributed such that similar-sized farms were clustered together was supported in all three sample counties. In the York sample, which contained only inland lots from one of the most uniformly fertile counties in Ontario and should thus have been relatively well-placed for cooperation, the problem of finding an adjacent equivalent-sized farm in the relevant range was most marked. In Huron county this problem was least severe, but in the 1850s and 1860s there would have been many gaps in the landholding pattern which no longer existed in 1879. Finally, in the Carleton sample, which had the most clear-cut support for the "haphazard distribution" hypothesis, there was some tendency for the distribution of adjacent farms to favour cooperation in the range of potential cooperators, but here the geographical factors were least favourable.

The conclusion that conditions were not ideal for cooperation in these counties suggests that ideal conditions were not prevalent in Ontario as a whole. In the light of the brevity of the harvest season (cf. p. 27) this provides some explanation for the frequent mention in the contemporary literature of the cumbersome nature of reapers (since this design feature becomes important as a critical barrier to cooperation) and of the absence of any mention of cooperation actually taking place in Ontario.

The case must not, however, be overstated. The most relevant point in this chapter for the rest of the thesis is the lack of empirical evidence of cooperation. This is a strong argument, even though our attempts to explain the phenomenon are far from conclusive. The county samples do no more than suggest why, given the cumbersome reapers and the short harvest season, cooperation might have been uncommon. Geographical obstacles may also have ruled out some potential cooperators, although especially in the south west this was no major problem. If cooperation did in fact exist then our estimates of the number of reapers will be underestimates, but so long as cooperation was uncommon then the method of obtaining these estimates remains valid.

TABLE I. The Farms in the York County Sample

Township	Concession & Lot Number		Landholder	Holding
Vaughan	II	35	S. Thompson	50 acres
			M. Mortson	25 acres
			J. Beynon	25 acres
Markham	VII	10	P. Reesor	40 acres
			T. Robinson	85 acres
			A. Barker	25 acres
Markham	IX	13	W. Foster	100 acres
East Gwillimbury	III	23	M. Doan	50 acres
			W. Richardson	90 acres
			J. Cowison	125 acres
King	I	4	T. Mortson	50 acres
			J. Thompson	50 acres
King	IX	10	J. Cherry	150 acres
			O. Sullivan	25 acres
			J. McKenzie	12½ acres
			H. Allison	12½ acres
Vaughan	VII	8	Woodbridge Village	
King	I	13	T. Clancey	50 acres
			G. Kaizer	40 acres
			J. McCoy	30 acres
Whitechurch	VII	34	Montezuima Brothers	50 acres
			C. Spofford	50 acres
Georgina	III	24	Too close to edge of map (not all adjacent farms are known).	
East Gwillimbury	V	28	S. Cole	25 acres
			E. Stiles	25 acres
			G. Stiles	50 acres
King	V	3	Lake and Laskay village.	
King	VIII	23	W. McDevitt	75 acres
			W. Proctor	175 acres

NOTE: The lots occupied by Woodbridge and Laskay villages were ignored because they were subdivided into numerous town lots.

Source: Miles & Co.: Illustrated Historical Atlas of the County of York (Toronto, 1878).

TABLE II. The Distribution by acreage of farms adjacent to the sample farms (York county)

Farmer	Acreage	Acreage of Adjacent Farms: 10-50 acres		50-100 acres		100-200 acres		over 200 acres		Zi
S. Thompson	50	4	(57%)	1.5	(21%)	1.5	(21%)	0		1
M. Mortson	25	1.5	(38%)	2	(50%)	0.5	(13%)	0		1
J. Beynon	25	1.5	(30%)	2.5	(50%)	1	(20%)	0		1
P. Reesor	40	1.5	(30%)	3.5	(70%)	0		0		1
T. Robinson	85	4	(67%)	2	(33%)	0		0		0
A. Barker	25	1	(33%)	2	(67%)	0		0		1
W. Foster	100	1.5	(21%)	3.5	(50%)	1	(14%)	1	(14%)	0
M. Doan	50	4	(57%)	1	(14%)	2	(29%)	0		0
W. Richardson	90	5.5	(69%)	1.5	(19%)	1	(13%)	0		0
J. Cowison	125	7.5	(54%)	6.5	(46%)	0		0		0
T. Mortson	50	2.5	(42%)	3.5	(58%)	0		0		1
J. Thompson	50	3	(43%)	2	(29%)	2	(29%)	0		0
J. Cherry	150	7	(59%)	4	(33%)	1	(8%)	0		0
O. Sullivan	25	3.5	(50%)	2	(29%)	1.5	(21%)	0		1
J. McKenzie	12½	3	(75%)	0.5	(13%)	0.5	(13%)	0		1
H. Allison	12½	3	(60%)	0.5	(10%)	1.5	(30%)	0		1
T. Clancey	50	4.5	(75%)	1.5	(25%)	0		0		1
G. Kaizer	40	5	(83%)	1	(17%)	0		0		1
J. McCoy	30	3.5	(50%)	2	(29%)	1.5	(21%)	0		1
Monteziuma Bros.	50	4	(57%)	2.5	(35%)	0.5	(7%)	0		1
C. Spofford	50	4	(57%)	2.5	(35%)	0.5	(7%)	0		1
S. Cole	25	3	(50%)	3	(50%)	0		0		1
E. Stiles	25	2.5	(42%)	2.5	(42%)	1	(17%)	0		1
G. Stiles	50	4	(50%)	2	(25%)	1	(13%)	1	(13%)	1
W. McDevitt	75	1	(14%)	2.5	(35%)	3.5	(50%)	0		0
W. Proctor	175	8.5	(47%)	8.5	(47%)	1	(6%)	0		0

Source: as for Table I.

TABLE III. Occupiers of land in York County by size of holding, 1870.

	Number	Percentage of total
10-50 acres	1313	26.82%
50-100 acres	2235	45.66%
100-200 acres	1152	23.53%
over 200	195	3.58%
Total	6321	

Source: 1870-1 Census of Canada, vol. 3, p. 34.

Note: Holdings of less than 10 acres are omitted, since these are primarily town lots and not relevant to a study of grain cultivation.

TABLE IV. The Distribution by acreage of farms adjacent to the sample farms (Huron county).

Location	Farmer	Acreage	Acreage of Adjacent Farms: 10–50 acres	50–100 acres	100–200 acres	over 200 acres	Zi
Howick XIII 23	W. Giles	100	2.5 (25%)	4 (40%)	3.5 (35%)	0	1
Stanley VI 5	J. Jarrot	50	0.5 (8%)	2 (33%)	2.5 (42%)	1 (17%)	0
	J.G. Smith	50	0.5 (10%)	1.5 (30%)	2.5 (50%)	0.5 (10%)	0
Stephen XXI 4	F. Ramsey	140	2 (20%)	5.5 (55%)	2.5 (25%)	0	1
Hullett XII 1	A. Smith	75	1 (20%)	2.5 (50%)	1.5 (30%)	0	0
	W. Smith	25	1.5 (30%)	1 (20%)	2.5 (50%)	0	1
Ashfield VI 10	T. Pentland	100	1 (13%)	3 (38%)	3.5 (44%)	0.5 (6%)	1
	J. Kennedy	100	0	3 (50%)	2.5 (42%)	0.5 (8%)	1
Morris VII 17	W. McColl	100	0	2.5 (36%)	4 (57%)	0.5 (7%)	1
	A. Nichol	100	0	3 (43%)	3.5 (50%)	0.5 (7%)	1
Hullett XIV 41	A. Lautenschlaeger	125	1.5 (19%)	2 (25%)	4.5 (56%)	0	1
Turnberry A 4	W. Parks	50	0	2.5 (47%)	3.5 (58%)	0	0
	F. Wright	120	0.5 (6%)	2.5 (31%)	4.5 (56%)	0.5 (6%)	1
Grey V 6	T. Smith	298	2.5 (19%)	6 (46%)	4.5 (35%)	0	0
Howick XI 15	J. Akins	100	0.5 (7%)	5 (72%)	1.5 (21%)	0	1
Turnberry VIII 16	W. Johnston	200	1 (13%)	2 (25%)	4.5 (56%)	0.5 (6%)	1
Grey VII 9	A. Lamont	100	1.5 (15%)	6.5 (65%)	2 (20%)	0	1
McKillop XII 26	F. McCullough	100	2 (25%)	4.5 (56%)	1.5 (19%)	0	1
Turnberry 1st 22	T. Hislop	100	1.5 (25%)	2.5 (42%)	2 (33%)	0	1
Stanley L.R. 22	J.S. Homer	146	3.5 (44%)	3.5 (44%)	1 (13%)	0	0
	P. Sherrette	33	0	3 (75%)	1 (25%)	0	0
Hay XII 4	F. Shrader	50	1.5 (38%)	1 (25%)	1.5 (38%)	0	0
	G. Schellich	50	0.5 (13%)	1 (25%)	2.5 (63%)	0	0
Tuckersmith V 10	J. Ranke	100	1.5 (19%)	4.5 (56%)	2 (25%)	0	1
Turnberry IX 25	G. Wade	101	0.5 (10%)	2 (40%)	2 (40%)	0.5 (10%)	1
Turnberry V 11	G. Forgie	93	1 (14%)	3.5 (50%)	2.5 (36%)	0	0

Source: H. Belden & Co.: Historical Atlas of Huron County Ontario (Toronto, 1879)

Table V. The Distribution by acreage of farms adjacent to the sample farms (Carleton county).

Location	Farmer	Acreage	Acreage of Adjacent Farms: 10–50 acres		50–100 acres		100–200 acres		over 200 acres		Zi
Fitzroy III 16	W. Hare	100	0		1.5	(30%)	2.5	(50%)	1	(20%)	1
	J. Elliot	395	2	(10%)	11	(53%)	8	(38%)	0		0
Gloucester VII 14 (O.F.)	N. Anderson	200	1.5	(13%)	6	(50%)	4.5	(38%)	0		1
	J. Clarke	100	0		3	(43%)	3.5	(50%)	0.5	(7%)	1
Huntley VII 3	J.W. Loux	100	0		1	(25%)	2	(50%)	1	(25%)	1
	J. Huston	200	0		3	(43%)	3	(43%)	1	(14%)	1
Gloucester V 10 (O.F.)	J. White	125	0.5	(6%)	4.5	(56%)	2	(25%)	1	(13%)	1
	F.B. Haley	75	0		0.5	(13%)	2.5	(63%)	1	(25%)	0
Marlborough V 7	J. Pierce	125	3.5	(39%)	4	(44%)	1.5	(17%)	0		0
	R. Hyland	50	1.5	(25%)	2.5	(42%)	2	(33%)	0		0
	J. Hyland	50	1	(14%)	3	(43%)	3	(43%)	0		0
March VII 24	A. Monk	118	0		0		1	(25%)	3	(75%)	1
	H. Pinkey	610	0		0		1.5	(38%)	2.5	(63%)	1
N. Gower A 18	W.H. Brownlee	120	1.5	(25%)	3.5	(58%)	1	(17%)	0		0
	J. O'Callaghan	60	1.5	(38%)	0.5	(13%)	2	(50%)	0		0
Osgoode VI 6	W.J. Wallace	100	0		3	(43%)	3	(43%)	1	(14%)	1
	J. Wallace	100	1	(13%)	3.5	(44%)	2.5	(31%)	1	(13%)	1
Osgoode IX 8	J. Higgins	100	0		3.5	(50%)	3.5	(50%)	0		1
	W. Higgins	100	0		2	(33%)	2	(33%)	2	(33%)	0
Torbolton I 14	T. Hodgins	100	0.5	(7%)	2	(29%)	4	(57%)	0.5	(7%)	1
	D. Wilson	100	0		2	(33%)	3	(50%)	1	(17%)	1
Nepean I 10	R. Halfpenny	100	1.5	(21%)	3	(43%)	1.5	(21%)	1	(14%)	0
	W. Craig	50	0.5	(8%)	3.5	(58%)	1	(17%)	1	(17%)	0
	S. Craig	50	0.5	(10%)	2	(40%)	1.5	(30%)	1	(20%)	0
N. Gower IV 20	B. McEwen	79	1	(25%)	1.5	(38%)	0.5	(13%)	1	(25%)	0
	J. Craig	367	1	(8%)	7	(58%)	4	(33%)	0		0

Source: H. Belden & Co.: Historical Atlas of Carleton County Ontario (Toronto, 1879)

Table VI. Occupiers of land in Huron and Carleton counties by size of holdings in 1870.

	10-50 acres	50-100 acres	100-200 acres	over 200 acres	Total
Huron					
(a) Number	1,309	2,523	802	81	4,715
(b) Percentage	27.76%	53.51%	17.01%	1.72%	
Carleton					
(a) Number	599	1,179	591	243	2,612
(b) Percentage	22.93%	45.14%	22.63%	9.30%	

Source: 1870-1 Census of Canada Vol. 3, p. 29, 45.

Note: Holdings of less than 10 acres are omitted.

CHAPTER IV

THE SIZE OF FARMS

In the model used here, the diffusion of the reaper is the consequence of a kind of scissors process; increased numbers of reapers result from a reduced threshold size or a change in the farm size distribution or from both of these movements occurring simultaneously.[1] In the previous chapter we examined a basic issue for the validity of the threshold concept and in the next chapter the details of calculating the threshold size are considered. In the present chapter we will look at the other blade of the scissors, i.e. farm sizes.

Data on acreage under small grains and the distribution of farm sizes are given in the next chapter. Here we are concerned with whether it is valid to treat these values as exogenous or whether they are determined, in whole or in part, by other variables in the model (our procedure of separating the effects of various explanatory variables on reaper adoption assumes that these variables are independent of one another and that the direction of causality is from these variables to reapers and not vice versa). Two aspects of this question will be discussed:-

1. why did farmers face an upward-sloping long-run marginal cost curve which dissuaded them from expanding their acreage to S_{max} (cf. chapter 2.2)?
2. what were the forces leading to the increase in small grains acreage in Ontario 1850-70?

[1] The three sets of explanatory variables of chapter 2 can be compared to two blades of a pair of scissors because factor prices and technical change both determine the threshold size, $S_T = \left(\frac{c}{w}\right) \cdot \left(\frac{1}{L_s}\right)$

1. The Slope of the Long-Run Marginal Cost Curve

The condition for bringing an extra acre of land into small grains production is that the net present value of the expected profit stream from that acre be positive. The expected annual revenue is equal to the expected small grains yield in bushels (Y^*) multiplied by the expected price per bushel to the farmer (P_g^*), and the expected annual profit is the expected revenue minus estimated annual production costs for that acre (AC_g^*). Future profits should be appropriately discounted and the total present value is the sum of the discounted profit flow up to the farmer's time horizon, T. The net present value is this sum minus the costs of purchasing and clearing that acre, K. Thus the marginal condition for the jth acre may be represented formally as:-

$$(9) \quad K_j = \sum_{t=1}^{T} \left[Y_j^* \cdot P_{g_j}^* - AC_{g_j}^* \right]_t \cdot \left(\frac{1}{1+i} \right)^t$$

where i = the farmer's rate of discount.

Clearly the values of the variables in this decision rule will not be identical for every acre in Ontario, in particular Y^*, K and P_g^* will vary. Yields on all small grains varied greatly across Ontario (cf. the annual reports of the Ontario Commissioner of Agriculture in Ontario Sessional Papers). In the 1850s Crown lands were still readily available at a fixed price. The first to be settled would be those lands with the best conjuncture of low clearing costs, high potential yields and proximity to markets. Then settlers would buy lands with less and less favourable combinations of clearing costs, yields and location, until the marginal condition exactly obtained. The effect of diminishing fertility of the marginal unimproved land was apparent in the early 1860s, e.g. the minister of agriculture reported in 1863 that:-

> "The Clergy, School and Crown lands of the Western Peninsula ... are mostly sold, the few lots that remain are generally of inferior quality. The new townships between the Ottawa and Lake Huron con-

> tain much good land, but they are separated from the settled townships ... Moreover, the good land in these new townships is composed of small tracts, here and there, separated from each other by rocky ridges, swamps and lakes ... These unfavourable circumstances have induced the better class of settlers in Upper Canada to seek, at the hands of private owners, for lands of a better quality and more desirable location, though the price and terms of sale are more onerous than for the lands of the Crown." (quoted in Innis and Lower, p. 527)

Thus the expected yields from the remaining Crown lands had become sufficiently low, considering their distance from the market, for the purchase of private lands to be an alternative for the "better class of settler". Since improved land was a scarce resource, the aggregate supply curve would be upward-sloping and, in the aggregate, expansion costs would be increasing.

Similar arguments can be applied to the individual farmer wishing to increase his landholdings. An additional consideration here is that a farmer will primarily try to expand his holdings to adjacent land. First he will purchase adjacent Crown lands with the most favourable combination of clearing costs, yield and proximity, then less favourable Crown lands, until privately owned improved land becomes competitive with these. All the time he can pick land of differing K and Y* and this is what gives him a rising long-run marginal cost curve, because these combinations become progressively less and less favourable as his acreage increases.

2. Increases in Small Grains Acreage

Between 1850 and 1870 small grains acreage in Ontario almost tripled (cf. Table IX). In terms of equation (9) this increased acreage can be explained by the fact that K and AC^*_g fell while P_g^* rose during this period. The spread of better farming practices may also have contributed, but there is no evidence of major improvements in yields between 1851 (by which date Red Fife wheat had become the major variety sown in Canada, Reaman p. 83-4) and the 1870s. Likewise there is no evidence that lengthening of farmers' time horizons or reduction of their rate of discount occurred.

Inclusion of reduction of K as a cause of increased small grains acreage does not conflict with the argument of the previous section; it is clearly possible for land-clearing costs to be reduced across the board without affecting the relative difficulty of clearing different areas. We have already noted that in sylvan Ontario land-clearance represented no small cost (Jones, p. 67). This cost was considerably reduced by the use of stump-pullers, which were introduced in 1850-1. Recent estimates for forested areas of the eastern United States have the median labour cost of land clearing falling from 33 man-days per acre to 25 as a result of this innovation (Primack). Unfortunately, we have no data on the rate of diffusion of stump-pullers in Ontario, which might have been slow because of the need for many improvements over the rudimentary initial models. Thus we have little idea of the quantitative impact of this innovation onthe value of K, and hence on total small grain acreage, up to 1870.

Movements in P_g^* would depend primarily on changes in the current price of small grains. In 1850 wheat was the major small grain in Ontario (cf. Table VII). The Toronto price of fall wheat rose from an 1851 range of 3s. - 4s.3d. to an 1855 range of 8s.1d. - 11s.3d. The price fell to 4s.7d. in the worst month of 1857 but then picked up again through 1859. The price of the second small grain, oats, increased even faster, trebling between 1851 and 1856 (Taylor and Michell, p. 59-60). The American Civil War was disappointing for Canadian wheat farmers in that it did not produce the expected boom in wheat prices (because rapid mid-West growth increased U.S. supply), but it did see a high American demand for oats whose price rose from 28¢ in 1861 to 43¢ in 1863. Also there was an increase in U.S. demand for barley as beer consumption rose sixteenfold between 1861 and 1865 (because of increased whiskey tax and German immigration), leading to Toronto barley prices being over 60¢ every year 1862-70 (cf. 48¢ in 1861). Furthermore, Canadian barley was considered superior to American and thus was not hit by the abrogation of Reciprocity. In the years after 1865 wheat prices, which had fallen to 96¢ in 1864, rose to a new high of $1.80 in 1867 - a high not repeated until the Great War. In sum, Canadian grain prices were buoyant through the 1850s and 1860s, primarily because of external events such as the Crimean War, the U.S. Civil War, increased (and price inelastic) U.S. demand for Canadian barley and bad wheat harvests in Europe 1866-7.[2]

Since P_g* represents the expected price to the farmer, it would be increasing over this period even faster than the Toronto prices might suggest. The reason for this is the transportation improvements occurring at this time, which reduced shipment costs to the market. The importance of this was well recognized at the time, e.g. the commissioner of public works' report of 1859 stated that:-

> "With reference especially to grain, the great article of transport, being both bulky in its nature, and low in value in the Districts surrounding the great lakes where it is produced, cheapness of Transport is peculiarly important, and is becoming yearly more so, as the regions of production get more and more remote from the place of consumption." (quoted in Innis and Lower, p. 470n)

Contemporaries' major energies were, however, directed to the trunk routes, above all in competing with American west-east routes; a contest in which the St. Lawrence route met with little success, as the canal system failed to attract

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[2] It is assumed that Canadian grain prices are determined on the world market, where Canadian supply was a sufficiently small proportion of the whole not to affect the price. Thus the variable P_g* was a determinant of the sowing decision but was itself independent of Ontario grain production in this year, last year or any other time period.

traffic from the Erie Canal and, so far as grain was concerned, the Grand Trunk railway was no cheaper than the canals up to 1871 (Innis and Lower, p. 492-3). Since any reductions in shipment costs from Toronto would be picked up in the Toronto prices (if they were to benefit the farmers at all), these trunk routes are not our main concern. More significant to us was the increase in local railway lines as feeders from the country areas to the cities and ports. In 1850 there were no railways in Upper Canada, but by 1870 there were over two thousand miles of track in operation (Trout). The potential effects of this railway construction can be illustrated by a sample calculation; with average rail rates of 3¢ per ton-mile and overland freight costing 15¢ per ton-mile, to a farmer fifty miles into the interior the arrival of the railway is equivalent to an increase in the price of wheat of 20¢ per bushel. This gain in price may have been greater than the average, if farmers were less than fifty miles from a port or if farmers still had to use other means of transport to get their grain to the railway station. Nevertheless, the coming of the railway did increase P_g^* on many acres in Ontario.

At the same time as the farmer's expected revenue was increasing his cultivation costs were falling, primarily because of mechanization of harvesting and post-harvest operations. An attempt at quantifying such improvements in U.S. labour productivity has been made (Parker and Klein), and, given their geographical similarities, the estimates for the northeastern United States (i.e. New England, New York, New Jersey and Pennsylvania) may give a rough approximation of conditions in Ontario. For the "premechanized" period (1830-60) the average labour requirements per bushel of wheat were 1.32 hours for preharvest operations (ploughing, sowing and harrowing), 1.03 for harvesting operations and 0.73 for postharvest operations (threshing and winnowing) for a total of 3.08 hours. For oats the corresponding figures were 0.50, 0.45 and 0.40 for a total of 1.35 hours. By 1890-1910 these labour requirements had fallen to 0.66, 0.17 and 0.19 with a total of 1.02 for wheat and 0.31, 0.11 and 0.23 with a total of 0.65 for oats. Even if these figures do apply to Ontario it should be noted that they overstate the magnitude of the reduction in average costs because some of the relevant innovations were introduced after 1870 and because agricultural wages rose 1850-70 (see below).

So far we have assumed that all potential small grains land had no significant opportunity cost. This would not be true if the farmer saw his crops as substitutable one for another, in which case the price and production costs of small grains relative to other crops would be the relevant variables, rather than the absolute price and costs of small grains. In mid-century Ontario, however, the commercially produced crops were almost entirely small grains. This is clear in exports, where small grains and their products valued $750,000 and no other crop $1000 in 1849 (W.H. Smith vol. I, p. cxviii), and there is no evidence of a substantial domestic market in any other crop. Thus we have a picture of the Ontario farmer as part subsistence farmer, producing vegetables for himself and food for his livestock, and part cash crop producer, with little substitution between cash crops and subsistence crop production; e.g. he would shift from wheat to barley production if the relative price of these two crops changed sufficiently, but not from peas to wheat.[3]

Thus the major facts responsible for the increased small grains acreage in Ontario 1850-70 were improved land-clearing techniques, increased

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[3] This conclusion is in line with studies on present day less developed countries which have found very low price/acreage elasticities for most crops, but higher elasticities for the few cash crops (e.g. Krishna).

grain prices and reduced costs of production. It would be desirable at this stage to estimate the relative importance of these three causal factors, but here we encounter data problems. A saving of some eight hours labour per acre cleared using stump-pullers would appear to be significant, but we do not know how widespread stump-pullers were by 1870. Similarly the significance of the increased grain prices is hard to quantify, because, apart from the technical difficulties of creating a single price index, we have no information on farmers' time horizons or discount rates. The problem with the railways is that, while they affected most of the grain-growing regions of the province, their effects would differ between farms, thus making the concept of an "average" increase in P_g^* because of railway construction rather tenuous. Nevertheless it would appear that all of the foregoing factors were quantitatively important.

More crucial in the present context is the effect of reduced costs of production following the introduction of the reaper. The argument that the reaper reduced average costs, thus increasing the optimal acreage under small grains, is logically undeniable and is the most serious source of doubt on the validity of our procedure of separating the causes of reaper adoption. Thus it is essential to make some judgment of the quantitative importance of this cause of increased acreage in order to assess how destructive it is to our model.

According to the Parker-Klein estimates premechanized harvesting operations required 1.03 hours of labour per bushel of wheat. Of the harvesting labour requirements, reaping and raking took less time than binding and stocking (Hutchinson I, p. 73n), thus the absolute maximum that the reaper could save was half an hour's labour per bushel of wheat. The reaper, however, still required some labour (even with the self-rake reaper one sixth of the old labour force was needed, ch. 5.1) and incurred some capital cost. Assuming that the reaping and raking costs per bushel of wheat with a mechanical reaper were the equivalent of a quarter of an hour's labour in 1870, then using the wage rates of chapter 5.3 we find that these costs fell from 0.5 x 12.5 = 6.25c. in 1850 to 0.25 x 15 = 3.75c. in 1870 (assuming a ten hour work day), i.e. a reduction of 2.5c. per bushel. Since the short-run average cost curves are assumed horizontal for both cradling and mechanical reaping, after the introduction of the reaper the LRMC curve remains upward-sloping. The introduction of the reaper did shift the LRMC curve to the right, but, if the reduction in AC_g* is compared to the concurrent increases in P_g*, it can be seen that the shift in the LRMC curve caused by this factor is only a small part of the total movement.[4] Thus, as an explanation of increased small grains acreage, the reduction in average costs following the introduction of the reaper is relatively minor.

Even though reaper availability does not have a great effect on total acreage, it is relevant to ask whether it might change the shape of the distribution of that acreage, for this too is a possible source of reverse causality. A plausible argument is, since the reaper owner has lower harvesting costs on all acres once his farm is larger than the threshold size, he has greater incentive to expand his acreage than the small farmer. On the other hand, since the quantitative significance of this cost differential is small compared to the other variables affecting the sowing decision (see previous paragraph), this added incentive would not be very great. For any individual farmer seek-

[4]Even if the capital costs per bushel were minimal the total costs per bushel in 1870 would have been 0.1 x 15 = 1.5¢, implying a reduction in AC_g of 4.75¢ per bushel. At the other extreme, if reaping and raking costs were the equivalent of 25 minutes labour in 1870, the reduction in AC_g would have been precisely zero. Any of these reductions are small compared to the increase of more than a dollar in Toronto wheat prices between 1850 and 1870, the increase in the price received by the farmer after the building of railways or the reduction in preparation costs following the introduction of patented stump-pullers.

ing to expand his acreage this kind of consideration could easily be more than offset by the problem of obtaining adjacent land. This would appear to be sufficient explanation of the absence of any major trend towards concentration of land-ownership following the introduction of the reaper in Ontario.

3. Conclusions

We can now state the main conclusions to the questions asked at the beginning of this chapter. Since differing pieces of land entailed different clearing costs and had varying degrees of fertility and distance from the market, expansion costs were in the aggregate increasing. This was also true for the individual farmer, and the already established farmer had the additional problem of finding adjacent land. Thus the long-run marginal cost curve was upward-sloping in the aggregate and for individual farmers.

In the 1850-70 period, this cost curve was shifting to the right because of improved land-clearing techniques, especially the development of patented stump-pullers, and at the same time expected profits from small grains production were increasing because of favourable price movements and, to a lesser extent, reduced costs. Since all of these changes did not affect all acres equally, the shape of the curve would also have changed, but the argument that the slope was positive remains intact. The movement of the LRMC curve led to many previously sub-marginal acres becoming profitable, and hence to a large increase in total acreage.

There is a causal link between reaper availability and acreage under small grains. Thus, if factor prices lead to reaper adoption which leads to greater acreage under small grains and there is no other reason why the increase in acreage occurred, our model would mistakenly ascribe some causal importance to the increase in acreage. It was found, however, that in Ontario between

1850 and 1870 there were other determinants of total acreage and, compared to these, the availability of reapers was quantitatively a minor factor.[5] Thus our method of separating factor prices from scale of operations as independent explanatory variables of reaper adoption remains viable.

[5]This conclusion is consistent with the findings of a recent study by Shen. He proposes a model based on:

> "the assumption of a definite and irreversible order in the search and deliberation and decisions by producers with regard to dynamic input and output changes. Specifically primacy in descending order is assigned to the decision variables: scale, technology and (followed in a tie) substitution and efficiency" (Shen p. 265-6),

which he tests against cross-sectional data from Massachusetts manufacturing plants, and after some juggling he concludes that this model gives a good explanation of technology diffusion. His model is directly comparable to our treatment of the Ontario farmer's decision-making process. We have concluded that given the parameters (cost of clearing land, expected yield from that land and output price) the farmer determines his scale of operations. For the second decision of choice of technique his parameters are now the attributes of alternative techniques facing him (in terms of physical productivity), factor prices and scale of operations. Once he has chosen between a reaper and cradling he has no choice over factor substitution (because there are fixed proportions within each technique), but efficiency may vary between farmers if X -efficiency exists. We concentrate on the second decision, choice of technique, and take the scale of operations as datum (determined by exogenous forces) and assume that inter-farmer variations in efficiency do not affect the choice of technique, which is the assumption made by Shen.

CHAPTER V

DATA

Data are presented here for (a) labour saving, (b) the annual cost of a reaper, (c) the wage rate, (d) total acreage, number of farms and farm size distribution, and (e) number of reapers. The years studied are restricted to 1850, 1860 and 1870 because the decennial censuses are the only source of data on numbers and size of farms.[1]

1. Labour Saving

L_s is the number of man-days of labour dispensed with by mechanization, per acre harvested:-

$$L_s = \frac{m - q}{n}$$

where n = number of acres cut by a reaper in a day, m = number of men needed to cradle n acres in a day, q = number of operators per reaper.

With this formulation we follow David in considering the only private economic benefit from the adoption of a reaper to have been a saving of cradling labour. The possibility of gains from increased output per acre or from saving of labour at a later stage of production is considered at the end of this section.

In the 1850s McCormick reapers were claimed to cut 15–20 acres per day, but this was working full speed and with a change of horses at noon (Hutchinson, Vol. 1, p. 336). Assessing the fairly extensive U.S. evidence for the period (including the 1860 Census), Rogin concludes that the average

[1] It could be argued that the years for which we possess data are 1851, 1861, 1871, rather than 1850, 1860 and 1870. The censuses cover the twelve months up to the census date, which in the last case, for example, was 1st April 1871. Such magnitudes as acreage under crops would refer to the previous harvest, e.g. 1870, but the stock of reapers would be that held on the census date. On this last point, however, there was little purchasing of reapers over the winter, so that the April 1871 figure would approximate the end of 1870 figure.

performance in a twelve hour day of both the hand-rake and self-rake reapers was 10-12 acres (Rogin, p. 134-5). There is little evidence to suggest that reapers' performance in Canada was much different. Denison states that Wood's Reaper as made by Massey "could cut twelve to fifteen acres of grain a day," but it isn't clear whether this represents a maximum or a normal performance.

Rogin's summary of U.S. evidence on cradling, mainly taken from the eastern states, was that "There appears ... to have been a norm of performance for the country as a whole which approximated two acres (per man day)," (Rogin, p. 128). This seems to emphasize the lower estimates quoted by him, but since these are from New York they may be the most applicable for Southern Ontario. Also, since the stand of wheat was relatively heavy in Ontario, the lower estimates are again the more probable. If $m = \frac{n}{2}$, then $L_s = \frac{1}{2} - \frac{q}{n}$.

The self-rake reaper, introduced in 1854 but first produced commercially in Canada in 1861 by Massey, had no effect on n, but reduced the number of operators from two to one. Thus, if we introduce subscripts, 1 referring to hand-rake reapers and 2 to self-rake reapers, then $q_1 = 2$ and $q_2 = 1$. If n = 12, then:-

$$L_{s_1} = \frac{1}{2} - \frac{1}{6} = \frac{1}{3} \qquad L_{s_2} = \frac{1}{2} - \frac{1}{12} = \frac{5}{12}$$

by taking n = 10 and n = 15 we can also set upper and lower bounds:-

$$0.3 < L_{s_1} < 0.36$$
$$0.4 < L_{s_2} < 0.43$$

There is some reason to believe that these estimates of L_s are low. First, there was less shattering of grain per acre where the reaper was used. Second, fewer binders were used after the reaper was introduced. These two considerations will be discussed in turn.

McCormick claimed that a bushel per acre of wheat was lost when the cradle was used instead of a reaper (Hutchinson I, p. 336). For much of Ontario this would mean that an extra acre would have to be cradled in a day to obtain the same output as a reaper, i.e. m would be $\frac{n+1}{2}$ instead of $n/2$. On the other hand, much of this shattering was of overripe grain, because the harvesting was slower when cradling was used. Thus, the shattering could have been reduced in pre-reaper times by hiring more men for a shorter period. With an elastic labour supply this would not increase costs and considerable doubt is cast on McCormick's claim.

A saving of up to three binders per day has been claimed for the reaper (see McCormick's letter to the "Albany Cultivator" of Jan. 1851, quoted Hutchinson I, p. 73), although the common estimate is a saving of two binders (Rogin p. 136). This can be expressed in a revised form of equation (5), viz:-

$$(5a)\ c = S_T\ (L_{s_c} \cdot w_c + L_{s_b} \cdot w_b)$$

where: $L_{s_c} \cdot w_c = L_s \cdot w$, L_{s_b} = savings in binders per acre by not using cradlers, w_b = daily wage of a binder. The cause of the savings in binders is that the reaper left the grain lying in swath for the binders who followed the machine, while with cradling the binders followed a much less ordered pattern and made more leisurely progress. The key factor in reducing the number of binders was the increased pace of work, rather than any technical considerations per se. Before the introduction of the reaper farmers could have made the same labour economies by adopting the "binder station" system, but this was not generally done because the use of women and children was precluded under this system by the pace of work (Rogin, p. 103n). If the two binders made redundant by the advent of the reaper were family members with low opportunity costs, then the last term in equation 5a (i.e. $L_{s_b} \cdot w_b$) will approach zero. The fact that the reaper forced the introduction of a system not previously undertaken under conditions of choice suggests that this "saving" may even have been a cost to the farmer, rather than providing any monetary economies. This would be the case if he utilized more than two non-adult-male family members in binding before obtaining a reaper.

2. <u>The annual cost of a reaper</u>

Data on the purchase price of a reaper (C) are scattered and not necessarily uniform; prices in any year could vary for different farmers depending upon the particular model bought, the distance it had to be transported and the arrangements made for payment. Paucity of data prevents us from being scrupulous about these conditions. First let us summarize the Canadian prices quoted in the literature. In 1855 the Manny hand-rake reaper produced by Massey:-

> ..."sold for $130 with steel cutter bar, $120 with wood, and included as extras one set of knives, two blades, two guards, one pinion and one wrench." (Denison, p. 32).

In 1857 domestically produced McCormick-style machines were selling in Canada for $125-130, while McCormick's own productwas offered there at $160 (Hutchinson, Vol 2, p. 647). In the 1862 Massey catalogue both Wood's self-rake and the Manny hand-rake were offered at $130 (Denison, p. 50). At the 1876 Select Committee of the House of Commons Inquiry, F.T. Frost of Frost & Wood gave the price of a combined reaper at Prescott with twelve months credit as $125 (Denison, p. 64). The overall impression is one of a pretty stable price of $125-130. Since the years 1873-6 saw generally falling prices, we will use $130 as the value of C for both 1860 and 1870. Since there were no Canadian producers in 1850, this year provides some difficulty. According to David the price of McCormick reapers in the U.S.A. was about $20 less in 1850 than in 1857, which in conjunction with the 1857 price given above suggests a Canadian selling price of $140. We will use this <u>"faute de meilleur"</u>, but it should be borne in mind that an unknown quantity of reapers was available at lower prices in Canada as a result of dumping following the U.S. patent wars (Phillips, pp. 10, 40).

In the 1850s reapers had "an average life of nine or ten years" (Hutchinson Vol 1, p. 311), the larger figure presumably applying to good care and normal use:-

> "With good care the reaper would harvest one hundred acres per year for ten years" (Hutchinson, Vol 1, p. 73)

There is some doubt as to whether "good care" was prevalent; American farmers tended to leave reapers where they were last used regardless of weather conditions (Hutchinson, Vol 1, p. 365) and it is unlikely that Canadian farmers of the time were any more careful. Potentially more damage to the threshold hypothesis would be caused if the reapers' life could be extended by less intensive use, but there is no evidence to suggest that this was the case. This expected life span obtained through to the 1870s:-

> "... a machine even at that time (the 1870s) lasted very close to ten years" (Rogin, p. 95)

Thus, the annual straight-line depreciation rate, d_1, through the period 1850-70 was 0.1. There is no evidence that machines were abandoned before the end of their physical lives, at least not until the advent of the harvester in the 1870s. Thus the economic rate of depreciation or obsolescence, d_2, was no greater than the physical rate.

An appropriate rate of interest to use would be the charges made by the reaper companies for credit. Even if the farmer could earn a higher return elsewhere, this represents the farmers' opportunity cost since he could buy the reaper on credit and then invest the freed capital in the more lucrative avenue. Unfortunately, however, we have no data on what this rate was in Canada. McCormick charged 6% through the 1850s (Hutchinson, Vol 1, pp. 337,

369) and this is the rate used by David in his American study. To use this rate for Ontario 1850-70 begs many questions about the general trend of interest rates in Canada. The interest rate on government bonds was 5.4% in 1868 (Innis and Lower, p. 809), but this may have been a peak, since it declined to 3.8% by 1885. As a first approximation then we use r = 0.06. This rate may be too high, but we defend its use on the grounds that changes in r will not affect our conclusions very radically (cf. ch. 6.2).

3. The wage rate

There are three problems in trying to obtain the money cost to the farmer of a man-day of harvest labour:-

1. farm labour was often paid on a monthly basis, with or without board, which reduced the daily cost to the farmer if the labourer worked for the whole month. Since the harvest season only lasted ten days, however, extra labour would be hired then at a daily wage rate. Presumably the reduction in man-days used following the introduction of a reaper was primarily at the expense of this daily labour.

2. skill differentials existed between agricultural workers and expert cradlers would earn more than, say, binders.

3. agricultural labour is seasonal. Thus summer wage rates are considerably higher than winter ones.

Thus, we require data on the daily cost of an expert cradler at harvest time, and must beware of data relating to average farm wages since such data will provide an underestimate.

Agricultural wage rates are quoted in many of the county reports in the appendices to the annual reports of the Ontario Commissioner of Agriculture of the early 1870s. (in Ontario Sessional Papers). Here there is a great deal of uniformity in summer daily wage rates, which are quoted at $1.50 except in some counties in the extreme east (notably Glengarry where the quoted rates are $1-1.25). In 1867 the Immigration Agent at Kingston reported farm labour scarce even at $1.25-1.50 a day (Denison, p. 59). These sources suggest that in 1870 farmers hiring cradlers by the day would have to pay a rate of around $1.50.

As we go back intime data becomes less plentiful. For 1860, we will use an 1859 observation that "expert cradlers were plentiful at $1.25 a day" (quoted in Denison, p. 59). This accords with the general impression that the 1860s were a period of rising wages in agriculture (cf. ch. 1, pp. 8-10).

Jones, in summarizing the scattered references to wages in the mid century, concludes that from the 1820s until the late 1850s "the worker by the day received from 50 cents to $1.00, or $1.25 if he was an expert cradler" (Jones, p. 55 n.). It is unlikely that this specific rate would apply to every year, but in view of the pioneer nature of Ontario agriculture to 1850 the concept of a regional labour market is much more hazy than in 1860 or 1870 and it would be unrealistic to expect a standard provincial wage rate anyway.

4. Total acreage, number of farms and farm size distribution

The above data on labour saving, reaper costs and wage rates permit calculation of the threshold size for each year. In this section data are presented on the distribution of small grain acreage per farm. Good estimates of average small grain acreage are available. The major problem lies in finding the distributions around these means. Since a major innovative feature of the present study is comparison of S_T with the whole distribution rather than just with the mean, this is clearly an important issue.

The decennial censuses provide data on the total area in farms, improved land under crops and, for 1850 and 1860, acreage sown of individual crops. These figures are given in Table VII, where the bottom line gives total acreage under the principal small grains ($\doteq$ A). For 1870, A was estimated on the assumption that small grain acreage represented the same proportion of improved land under crops as it had done in 1860.

Table VII. Area in farms and total acreage under small grains, Ontario 1850–70

	1850	1860	1870
Total area in farms	9,825,915	13,354,907	16,161,676
Improved land under crops	2,282,928	4,101,902	6,537,438
(1) wheat	798,275	1,386,366	
(2) oats	413,058	678,337	
(3) barley	30,129	118,910	
(4) rye	49,066	70,376	
Σ(1) - (4)	1,290,528	2,253,989	

Sources: Censuses: (a) 1851–2, Vol. 2, p. 60–2;
(b) 1860–1, Vol. 2, p. 90–2;
(c) 1870–1, Vol. 3, p. 49

From the same sources we find that the total number of occupied farms in Ontario was 99,906 in 1851, 131,983 in 1861 and 172,258 in 1871. In the light of an earlier statement (in ch. 2.3) it is interesting to note that the 1871 figure is disaggregated according to tenure and only 27,340 of these farms were tenant-operated. These figures provide upper bounds for the number of farms growing small grains (N), and under the assumption that all farms grew some small grains they are approximate measures of N. Under this assumption average small grain acreage per farm, $A \div N = \mu_x$, is easily calculated. For the three years 1850, 1860 and 1870, μ_x is equal to 12.92 acres, 17.08 acres and 20.85 acres respectively.

No data exist on the distribution of small grain acreage per farm, f(x). The censuses do, however, provide grouped data on total acreage per farm (Table VIII (a)). In order to convert this to a distribution of small grain acreage the simplest assumption was made, i.e. all farms were assumed to devote the same proportion of their total acreage to cultivation of small grains. For each year a discrete form of f(x) was obtained by multiplying the class limits of Table VIII (a) by μ_x / μ_y, where μ_y is total area in farms divided by N.[2] The estimates are given in Table VIII (b).

Table VIII. Farm size distributions for Ontario 1850-70.

(a) Total acreage

	1850	1860	1870
Number of farms of 10 acres and under	9,746	4,424	19,954
Number of farms of 10-20 acres	2,671	2,675	} 38,882
Number of farms of 20-50 acres	19,143	26,630	
Number of farms of 50-100 acres	47,427	64,891	71,884
Number of farms of 100-200 acres	17,515	28,336	33,984
Number of farms above 200 acres	3,404	5,027	7,574
Total number of farms (N)	99,906	131,983	172,258

(b) Small grain acreage

1850		1860		1870	
Small grain acreage	Number of farms	Small grain acreage	Number of farms	Small grain acreage	Number of farms
1.31 acres	9,746	1.69 acres	4,424	2.22 acres	19,954
1.31-2.63 acres	2,671	1.69-3.38 acres	2,675	2.22-4.45 acres	} 38,882
2.63-6.57 "	19,143	3.38-8.44 "	26,630	4.45-11.12 "	
6.57-13.14 "	47,427	8.44-16.88 "	64,891	11.12-22.23 "	71,884
13.14-26.27 "	17,515	16.88-33.76 "	28,336	22.23-44.46 "	33,984
26.27 "	3,404	33.76 "	5,027	44.46 "	7,574

Sources: (a) Censuses as in Table VII;
(b) See text.

[2] The multipliers are (i) for 1850 12.92 ÷ 98.35 = 0.131, (ii) for 1860 17.08 ÷ 101.19 = 0.169, and (iii) for 1870 20.85 ÷ 93.82 = 0.222.

5. Number of Reapers

The first statement of the stock of reapers in Canada is in the 1870-1 Census (Vol. III, p. 110-3). This gives the total number of reapers and mowers in Ontario as 36,874; in Quebec, 5,149; in New Brunswick, 869; and in Nova Scotia, 1,312. Thus the Canadian total was 44,204. Since these figures include mowers, they represent maximum values for the number of reapers (R), but the prevalence of combined reaper/mowers by this time implies that R would not have been much lower than the figures quoted.

Annual investment in agricultural implements rose by 550% in the 1860s (ch. 1, p.2). In view of the continual growth of this investment 1850-70, the 1870 stock of implements will be an even greater multiple of the 1860 stock. Thus in 1860 we would expect there to have been less than 5,000 reapers in Ontario. No domestic output data are available for 1850, but the number of reapers produced could not have been more than a handful. Some American machines were imported, but their numbers cannot have been great in view of the sluggish response of potential Canadian manufacturers. Thus the number of reapers in Ontario in 1850 must have been small.

6. Overview of the data

The data to be used in estimating reaper adoption are collected in Table IX. Sources of these data were discussed above, but mention may be made here of the major weaknesses of the data. The figures for the purchase price of a reaper and for cradlers' wages are markedly worse for 1850 than for 1860 and 1870, but it must be remembered that the 1860s are the period of primary interest. A more important problem is the choice of a suitable rate of interest, to which no satisfactory solution was found because of the scarcity of data on Canadian interest rates. If the selected rate of 6% is too high, some idea of the possible extent of bias is given by the fact that if the rate were 4% then S_{T_1} would be 40.32 in 1850 and 31.2 in 1870 (i.e. S_{T_1} would be reduced by 7.7% in each case). Thus our estimated number of reapers may be too low in all years. More important in explaining the rate of diffusion is that we don't know if, and in what direction, the relevant rate of interest changed in this period.

The census data on acreage are as good as might be expected of any historical data. The major weakness for our purposes is the need to assume that small grains acreage was distributed in the same way as total acreage. We will return to this problem in the next chapter.

Table IX. Summary of data for Ontario 1850-70

	1850	1860	1870
L_{s_1}	1/3	1/3	1/3
L_{s_2}	-	-	5/12
C	140	130	130
d_1	0.1	0.1	0.1
d_2	-	-	-
r	0.06	0.06	0.06
$c = (d+.5r)C$	18.2	16.9	16.9
w	1.25	1.25	1.5
c/w	14.56	13.52	11.26
$S_{T_1} = \frac{c}{L_{s_1} . w}$	43.68	40.56	33.8
$S_{T_2} = \frac{c}{L_{s_2} . w}$	-	-	27.04
A	1,290,528	2,253,989	3,592,331
N	99,906	131,983	172,258
μ_x	12.92	17.08	20.85

Sources: See text.

Notes: L_{s_1} = number of man-days of labour dispensed with by the hand-rake reaper, per acre harvested, L_{s_2} = the same for the self-rake reaper, C = the purchase price of a reaper, d, = the technological rate of depreciation = the reciprocal of the life of a reaper, r = the rate of interest, c = the annual money cost of a reaper to the farmer, w = the wage rate, S_{T_1} = the threshold farm size for the hand-rake reaper, S_{T_2} = the same for the self-rake reaper, A = total small grain acreage, N = the number of farms, μ_x = average small grain acreage per farm = A/N .

CHAPTER VI

RESULTS

The results obtained in this chapter fall into two categories. Firstly, there are the estimates of the number of reapers in 1850, 1860 and 1870. These are, in principle, testable against the actual numbers in these years. Secondly, there are the counterfactual estimates which give insight into the relative importance of the different causal factors. As a preliminary to obtaining these results it is necessary to specify a continuous farm size distribution. Once the estimates have been derived, we will compare our results with those of David.

1. Fitting a continuous function

We are already in a position to obtain an idea of the order of magnitude of the predicted number of reapers, R_t^*. These preliminary figures illustrate why a continuous form of f(x) is required. Applying the values of S_T calculated in chapter 5 (Table IX) to the small grain acreage distribution of Table VIII(b) gives values for R_t^* of less than 3,404 for 1850, less than 5,027 for 1860, and between 7,574 and 41,558 for 1870. All of these values are consistent with the actual number of reapers, but the class divisions are so broad that the estimates are of little value. A continuous farm size distribution would permit integration of the function over the range S_T to ∞ and would provide single-valued estimates of R_t^* rather than range estimates (cf. chapter 2). Thus we will attempt to fit a continuous function to the grouped data of Table VIII(b).

A major problem in the curve fitting is the selection of criteria for judging goodness of fit. The small number of groups for each year give too few degrees of freedom for standard statistical tests, e.g. chi square, to be of assistance. Thus instead of taking large numbers of theoretical frequency functions and seeking a statistically significant fit we adopt a more ad hoc two-stage procedure. First a statement is made of the general forms we might expect the farm size distribution to have on a priori grounds. Having done this we will select the particular members of these families of distributions which best approximate the small grain acreage distributions in Table VIII(b) for each year.

It is clear from Table VIII that we are dealing with a skewed frequency function. The most commonly used skewed functions with respect to economic variables have been lognormal and Pareto distributions.[1] Explanation of the generation of such functional forms has presented a major difficulty. The basis for most generation models has been the law of proportionate effect (Gibrat's Law):-

> A variate subject to a process of change is said to obey the law of proportionate effect if the change in the variate at any step in the process is a random proportion of the previous value of the variate,

thus:-

$$X_j - X_{j-1} = e_j X_{j-1}$$

where e_j is a random term, i.e. the set $[e_j]$ is mutually independent and independent of the set $[X_j]$. This leads to a lognormal distribution. The problem with this generation theory is that the longer the law of proportionate effect works for, the greater the standard deviation becomes; a phenomenon

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[1] General surveys of these approaches are Aitchison & Brown and Mandelbrot. For an application of the lognormal to the distribution of firms see Hart & Prais and the comments on their paper (Journal of the Royal Statistical Society 1956, p. 181-90). Quandt estimated lognormal and Pareto distributions for 30 U.S. industries and found the former generally provided a superior fit of the actual firm size distribution. Recent applications of both distributions to income data are Schultz and Metcalf. The lognormal appears in an agricultural context in G. Wright's study of wealth, farm value and improved acreage in the antebellium American South.

not commonly observed. For example, if the distribution of incomes is a consequence of the working of the law of proportionate effect, then income inequality (as measured by, for example, Gini or Lorenz coefficients) should be increasing over time. Modifications have been made to the crude proportionate effect theory leading to the genesis of a Pareto distribution (Champernowne) or a lognormal distribution with constant standard deviation (Kalecki). These modifications have, however, an ad hoc air about them[2]. and the lack of a satisfactory generation theory is a deterrent to the use of the lognormal and Pareto distributions. On the other hand, no alternative skewed function possesses a generation theory suitable to the Ontario farm size distribution.

The common use of Pareto and lognormal distributions to describe economic variables, despite the lack of a satisfactory generation theory, is explained by three compensating advantages which are generally possessed by these distributions. The first advantage is the ease with which they can be handled in statistical analysis. The second is that economic significance can be attached to the parameters of these distributions. Finally, they have given good approximations to the data in a large number of cases, e.g. the distribution of inheritances, incomes, bank deposits, firms, industrial profits, city size. Although no logical argument can be given for why Ontario farm sizes should have followed a Pareto or lognormal distribution, the general and accepted use of these functions with respect to economic phenomena suggests that they are the most relevant. Even though we do not know the generation process underlying the distributions of income, firms and farm sizes, it seems plausible that, if the same functional form is generated for

[2]For criticisms of Champernowne's model see Quandt p. 418-9.

the first two, it might also be generated for the latter, although the sole attempt to test this hypothesis against historical data was inconclusive (G. Wright).

Unlike the normal distribution, the shape of a lognormal distribution depends upon the origin as well as the mean and standard deviation and the explicit assumption of the two-parameter lognormal that the origin is zero is not appropriate to the present study. The problem is that the bottom group in the census data on landholdings, i.e. 10 acres or less, contains many township lots which are not relevant to a study of farm sizes. Thus the lower bound of the distribution, δ, is set at the upper limit of the bottom groups of Table VIII (b); i.e. for 1850 $\delta = 1.31$, for 1860 $\delta = 1.69$ and for 1870 $\delta = 2.2$. Even if this excludes some farms from the analysis, these will be small farms outside the commercial sector.

The first functional form to be considered is then where log $(x-\delta)$ is normally distributed with mean μ and standard deviation σ. Since the median of $(x-\delta)$ is equal to e^{μ}, estimates of μ could be made from the small grains acreage distributions in Table VIII (b); for 1850 $\mu = 2.1$, for 1860 $\mu = 2.4$ and for 1870 $\mu = 2.7$. A standard deviation of 0.6 was used for each year since this gave the best approximation to the data of Table VIII (b).[3] A comparison of some cumulative frequencies generated by the lognormal function and the data of Table VIII (b) is given in Table X.[4] If the small grains acreage distributions given in Table VIII approximate the actual distributions, then the fitted function has a regular bias, i.e. the proportion of farms in

[3] A test of the sensitivity of the results to this assumption is made below (ch. 6.4).

[4] Under a chi square test generated frequencies would be found to be significantly different from the actual frequencies. There is, however, some doubt as to whether such a test is relevant. Since the generation of the distribution is a stochastic process, our hypothesis is not that small grain

Table X. Comparison of cumulative frequencies of small grain acreage obtained from (a) the small grain acreage distributions of Table VIII and (b) the postulated lognormal frequency functions.

(i) 1850

x	1-F(x)	
	(a)	(b)
6.57	75.81%	76.80%
13.14	23.21%	29.00%
26.27	3.78%	3.12%

(ii) 1860

x	1-F(x)	
	(a)	(b)
8.44	77.02%	79.30%
16.88	26.15%	29.65%
33.76	3.94%	3.77%

(iii) 1870

x	1-F(x)	
	(a)	(b)
11.12	74.48%	80.40%
22.23	27.28%	30.85%
44.46	4.97%	4.10%

Notes and sources: The first column, headed x, is small grain acreage per farm. F(x) is the cumulative frequency function, i.e. the proportion of farms with small grain acreage less than x. Thus the columns headed 1-F(x) represent the proportion of farms with small grain acreage greater than x. Column (a) is derived directly from Table VIII, e.g. the bottom figure for 1850 (3.78%) is equal to the number of farms with small grain acreage greater than 26.27 acres (3,404) divided by the total number of farms with small grain acreage greater than 1.31 acres (90,160).[5] Column (b) are estimates of 1-F(x) derived from the lognormal distributions specified in the text, i.e. for 1850 $\delta = 1.31$, $\mu = 2.1$, $\sigma = 0.6$, for 1860 $\delta = 1.69$, $\mu = 2.4$, $\sigma = 0.6$ and for 1870 $\delta = 2.22$, $\mu = 2.7$, $\sigma = 0.6$.

acreage was lognormally distributed, but that it approximated a lognormal distribution. The null hypothesis of the chi square test is that the actual distribution was precisely lognormal, but on a priori grounds alone we do not expect this null hypothesis to be accepted. If general, we know for any distribution generated by a stochastic process that the null hypothesis of a chi square test is inappropriate (cf. A. Stuart's comment in the Journal of the Royal Statistical Society 1956, p. 185).

[5] The purpose of the exclusion of the smallest group of farms is to keep the "direct" estimates comparable with the lognormal estimates.

the central region of the distribution is overstated. This is important because it is the area in the upper tail (above S_T) which predicts the number of reapers. Thus any estimates of the number of reapers, R_t^* derived from the lognormal functions will be biassed downwards.

The alternative functional form selected on a priori grounds is the Pareto distribution. This has a reputation from income distribution studies of fitting the upper tail of these distributions better than the lognormal and thus appears at first sight the more suitable choice for the present study. The Pareto function used here is defined by two parameters: minimum farm size, x_o, and α. Thus:-

$$F(x) = \left(x_o / x\right)^{\alpha}$$

and the arithmetic mean is:-

$$\bar{x} = \alpha \cdot x_o \big/ (\alpha - 1)$$

(Klein p. 150-4). For alternative values of x_o the value of α could be calculated from our prior knowledge of the mean (Table IX). The best fits were obtained when x_o was set equal to the upper bound of the third group of Table VIII (b), i.e. x_o was 6.57 in 1850, 8.44 in 1860 and 11.12 in 1870. The value of α rose through the period, reflecting increased mean acreage.[6] The cumulative frequencies generated by the Pareto functions understate the proportion of farms in the central regions, i.e. their bias is the exact opposite of that of the lognormal functions, and, more important, they were further away from the actual distributions.[7]

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[6] This can also be interpreted as a measure of increased concentration (cf. p. 23n).

[7] A table analagous to Table X can be constructed for the best-fitting Pareto distributions, i.e. for 1850 $x_o = 6.57$, $\alpha = 1.596$, for 1860 $x_o = 8.44$, $\alpha = 1.66$, and for 1870 $x_o = 11.12$, $\alpha = 1.645$.

1850			1860			1870		
x	(a)	(b)	x	(a)	(b)	x	(a)	(b)
13.14	30.61%	33.08%	16.88	33.96%	31.49%	22.23	36.64%	31.95%
26.27	4.98%	10.94%	33.76	5.12%	9.91%	44.46	6.68%	10.23%

Since neither of the two functional forms gives bias-free results,[8] the lognormal is used on the grounds of providing the better fit to the data of Table VIII (b). It can be seen, however, that this goodness of fit, as illustrated in Table X, would not be found significant under a chi square test. The estimates in the next section must be interpreted in this light. We do not have an accurate representation of the farm size distribution. We have instead assumed that small grain acreage approximated a lognormal distribution and that, if this is the case, the parameters in 1851, 1861 and 1871 were close to those given above. This puts into context the assumption made in the last chapter that small grain acreage was distributed in the same way as total farm acreage. The assumed distribution is used to derive reasonable estimates of μ, σ and δ independently of our model. It is found below (p. 79-81) that alternative values of μ and σ do not significantly alter our conclusions. Thus, criticisms of this assumption are not destructive to our results; the real question is whether small grain acreage approximated a lognormal distribution.

2. The estimates of reaper adoption.

Estimates of the number of reapers in each year, R_t^*, can now be made. The threshold farm sizes are taken from Table IX and the number of farms above the threshold can be calculated from the relevant lognormal distribution. The problem then arises of how to evaluate the significance of these estimates.

As in the previous section, the use of accepted statistical tests

[8] Estimates of R_t^* obtained from the fitted lognormal distributions will be biassed downwards, while estimates from the fitted Pareto distributions will have an upward bias.

is hampered by lack of degrees of freedom. In this case we have just one firm figure, that of 1870, against which the estimates can be tested. For the other two years, 1850 and 1860, we cnly know the range within which the actual number falls. Furthermore, although at each step the most plausible data was used, some possible biasses have already been noted. The major sources of bias should be stated before evaluating the estimates. First of all, the one "actual" figure of the number of reapers which we possess, 36,874 in 1870, is itself an overstatement because it includes mowers. Secondly, the postulated frequency function is one which understates the number of farms in the upper tail, thus yielding underestimates of R_t^*. Thirdly, any reapers shared by two or more sub-threshold-size farms will not be included in R_t^*. Fourthly, the most obvious weakness in the data used to calculate S_T is the rate of interest, which is probably too high. It is also possible that L_s should be higher than we allow, because of the increased output via reduced shattering. These last two factors suggest that the calculated threshold size may be too high. Thus, all four biasses work in the same direction, i.e. towards increasing the amount by which our R_{70}^* will be below the census figure if our model accurately describes the farmer's decision process. The first two of these biasses are undoubtedly present, so that even if we have calculated S_T exactly our estimate will be below the actual number of reapers, which in turn will be below the census figure. The calculation of S_T may be close to the truth, but it is sensitive even to small inaccuracies with respect to the rate of interest and L_s, especially the latter; e.g. if we were to assume that use of a reaper did save a bushel of wheat per acre and the relevant rate of interest was 5% then S_{T_2} is reduced from 27.04 to 23.55.

The conclusion from the previous paragraph is that it is difficult to conduct a comprehensive test on the results for 1870. We know that R_{70}^*

should be somewhere below 36,874 if our model is a correct specification and our data are accurate, but we do not know how far R_{70}^* may fall below this figure without invalidating our approach. A more clearly defined test of our estimates is that they should follow the time path outlined in chapters 1 and 5.5 i.e. a slow increase (in absolute terms) from a low base 1850–60 followed by a rapid increase 1860–70. If the estimates succeed in picking this up, then we have some support for the model's applicability to the problem at hand. Furthermore, if our model did generate an S-shaped diffusion path, this would be in itself an important contribution to the diffusion literature (cf. p. 12).

The estimated number of reapers is 270 in 1850, 2,283 in 1860 and 30,080 in 1870. The last estimate is 18% below the census figure. This is a considerable variation even allowing for the expected downward bias. The estimate is, however, sensitive to small changes in some of the variables, e.g. the recalculated S_{T_2} figure of 23.55 given above would yield an R_{70}^* value greater than 36,874; the point is that all the biasses in our specification and data are downwards, but it only requires small adjustments at some of the possible sources of error to offset this bias completely.

The major triumph of the model is that, although the estimates may be lower than the actual figures, they do follow the S-shaped pattern of diffusion suggested in chapter 5.5. If we refer to the values of c/w and μ_x in Table IX, it is clear that predictions based on either of these variables alone could not have foreseen the actual rate of diffusion. Changes in factor prices suggest an increasing capital/labour ratio throughout the period, with some quickening in the rate of change in the 1860s, but nothing so dramatic as what actually occurred. If the scale of operations determine factor intensity, then changes in average farm sizes even imply a slowing down in the rate of farm mechanization in the 1860s.

In sum, our estimates of the number of reapers in Ontario 1850–70 cannot be considered accurate predictions in the strict statistical sense of the words. They do, however, form a diffusion pattern similar to that which actually occurred, which is more than any unicausal explanation or linear regression based on factor prices and/or scale of operations (average farm size) could have done. This primarily follows from the introduction of the size distribution of innovating units into the analysis. The success of our model in predicting the diffusion pattern suggests that it can provide a useful parable of Canadian reaper adoption.

3. The counterfactual estimates.

In this section counterfactual questions are asked about the course of reaper diffusion in the absence of changes in factor prices or farm sizes. This permits separation of these different causal factors and some judgement can then be made of their relative importance.[9]

The estimates of reaper adoption given in the previous section and the counterfactual estimates both appear in Table XI. The method of deriving these figures was presented in chapter 2 and can be illustrated with respect to the first element in Table XI. The area under a lognormal distribution with parameters $\delta = 1.31$, $\mu = 2.1$, $\sigma = 0.6$ to the right of 43.68 (the 1850 threshold size) contains 0.3% of the total area under the curve. Since there

[9] For this procedure to be valid, the effects of the biasses mentioned above should be neutral, i.e. those biasses understating the effects of changes in S_T (underestimates of r and L_s) must be the same size as those understating the effects of changes in farm sizes (misrepresentation of f(x)). This is unlikely to be the case, but, since there are biasses operating on both variables, it is impossible to decide in which direction the net bias works. The assumption of zero net bias is made.

TABLE XI. **Simulated values of R^* where the farm size distribution is represented by three-parameter lognormal distributions with $\sigma = 0.6$.**

Threshold Size \ Farm Sizes	1850 f(x)	1860 f(x)	1870 f(x)
	[$\delta = 1.31, \mu = 2.1, \sigma = 0.6$]	[$\delta = 1.69, \mu = 2.4, \sigma = 0.6$]	[$\delta = 2.22, \mu = 2.7, \sigma = 0.6$]
1850 S_{T_1}	270	1,658	6,671
1860 S_{T_1}	397	2,283	8,742
1870 S_{T_1}	956	4,770	15,946
S_{T_2}	2,515	10,524	30,080

Notes and Sources: f(x) = the frequency distribution of small grain acreage per farm. In this table f(x) is assumed to be a three parameter lognormal distribution. The parameters of f(x) at the head of each column were obtained in the text (p.68). S_{T_1} = threshold farm size for using a hand-rake reaper. S_{T_2} = threshold farm size for using a self-rake reaper. Values of S_T are taken from Table IX.

are 90,160 farms included in the total distribution for 1850, this area represents 270 farms. The assumption of our model is that all farms above the threshold size (and none below it) possess a reaper, so the estimated number of reapers in 1850 is 270. Similarly, estimates of R_{60}^* and R_{70}^* can be obtained by applying the respective threshold sizes to the relevant farm size distribution. All three of these estimates, $R_{50}^* = 270$, $R_{60}^* = 2,283$ and $R_{70}^* = 30,080$, were presented and discussed in the previous section.

The remaining elements of Table XI are the counterfactual estimates. They represent estimates of what the number of reapers would have been had circumstances been different from those which actually obtained. Thus, they are not testable even in principle. They are, however, useful in separating the influence of the different causal factors: technical change, factor prices and scale of operations. Conceptually, the exercise may be thought of as a controlled application of the ceteris paribus method of economic analysis.

Each row of Table XI presents a picture of what the time profile of reaper diffusion would have been had factor prices and technical conditions (and hence the threshold size) remained constant. If the threshold size had remained at its 1850 level throughout the period, then increasing farm sizes alone would have led to 6,401 more reapers being in use in 1870 than in 1850.

The columns of Table XI present the opposite situation, i.e. what would have happened to the rate of diffusion had farm sizes remained unchanged. Since the first three rows of the table are in terms of the threshold size with the hand-rake reaper, S_{T_1}, they exclude the effects of technical change and any variation within the first three rows of a column can be ascribed to changes in factor prices. Thus, if farms had remained at their 1850 sizes while the wage-rental ratio increased to its 1870 level, then in the absence of any technical change the number of reapers in use would have increased from

270 to 956.

The final piece of information which can be gleaned from this table is the effect on reaper adoption of technical change in the form of the replacement of the hand-rake reaper by the self-rake reaper. In our model these two techniques give two different threshold sizes for each year: S_{T_1} and S_{T_2}, the latter being associated with the more efficient self-rake reaper (hence $S_{T_2} < S_{T_1}$). The effect on reaper adoption of the new technique can be seen from a comparison of the bottom two rows of Table XI, e.g. had the self-rake reaper not been available in 1870 the number of reapers would have been 15,946 rather than 30,080.

Having dealt with the mechanics of constructing and reading Table XI we will now draw some conclusions from it. In interpreting the table three points stand out; these will be dealt with in turn.

The introduction of the self-rake reaper, increasing L_S and S_T, accounts for half of the increase in reapers between 1860 and 1870. Without the self-rake reaper the increase would have been 13,663 instead of 27,797. Much of the literature on diffusion of technical change has been concerned with explaining the "lag" between invention and innovation (cf. ch. 1, p. 11). This emphasis may be misplaced, however, because of the imperfection of most "inventions". Only after improvements do they become practical, and, as in this case there may be no time lag between the improvement and its introduction. Thus, emphasis on the "eureka" stage of a new technique, although traditional may not have much economic significance, unless we have an economic explanation of why improvements to the basic invention occur (for further discussion of this topic see Rosenberg).

Despite the dramatic effect of the introduction of the self-rake reaper in 1860s, other factors were important in determining the rate of reaper diffusion. Even without the self-rake reaper the increase in the number of reapers 1860-70 would have been sevenfold, and even if the self-rake reaper had existed in 1850 the number of reapers operating then would have been small. Comparison of the relative importance of changes in factor prices and in scale of operations can be made from the square matrix formed by the first three rows of Table XI. For example, changes in farm sizes alone induced an increase in the number of reapers between 1850 and 1870 of 6,401 whereas changes in factor prices alone led to an increase of 686 reapers in the same period. Since the elements north-east of the main diagonal are greater than those to the south-west of it (and by large amounts), this gives support to Kaldor's contention that size of market is more important than factor prices in explaining the adoption of more capital-intensive techniques.

The effects of changes in factor price or total acreage are not linear. Thus the 1850-70 change in factor prices leads to a far greater absolute change in R^* when acreage is held constant at the 1870 level than if it were held at the 1850 level (cf. columns 1 and 3 of Table XI) Similarly the change in acreage has greater effect on R^* if factor prices are held at their 1870 ratio rather than their 1850 ratio (cf. rows 1 and 3 of Table XI). In sum there is a critical region within which changes in either factor prices or farms' acreage have greater effect on the choice of technique than they had earlier. This non-linearity arises from postulating a non-rectangular distribution of innovating units, which is clearly a reasonable assumption applicable to most cases of innovation. It is the same non-linearity which produces the S-shaped diffusion pattern dealt with in the previous section.

4. Changing the parameters of the lognormal distributions.

In order to obtain the parameters of the lognormal distributions used above, it was assumed that small grain acreage was distributed in the same way as total acreage (cf. p.68). This assumption was chosen on the grounds that it was easily applicable and independent of the model. It can, however, be criticized. If farmers grow one cash crop (small grains) and a collection of subsistence crops, then it may be argued that a greater proportion of total acreage will be devoted to the cash crop on large farms than on small farms.

Within the family of lognormal distributions this alternative assumption implies a higher mean (i.e. a higher median small grain acreage) and a lower standard deviation. In order to test the sensitivity of our results to such changes Table XI was reestimated with $\sigma = 0.5$ and higher values of μ.[10] These new simulations are presented in Table XII.

In comparing these new estimates with the original figures in Table XI some small changes are evident. The value of R_t^* for 1870 is 4% higher, and closer to the census figure. On the other hand, the value of R_t^* for 1850 is 6% lower, and appears less likely than the original estimate. The overall tendency of this change in the parameters is to increase the estimated pace of diffusion; the S-shaped diffusion path remains, but the S is more compressed. So far as the counterfactual estimates are concerned, the revised parameters have increased the importance ascribed to the self-rake reaper at the expense of changes in factor prices and median farm size. The scale of operations remains more important than relative factor prices and to a greater degree than in the original estimates.

[10] The displacement parameter, δ, remained unchanged because no reasonable alternative hypothesis as to its values presents itself.

TABLE XII. Simulated values of R^* with alternative parameters in the lognormal distributions.

Threshold Size \ Farm Sizes	1850 (fx)	1860 f(x)	1870 f(x)
	[$\delta = 1.31, \mu = 2.2, \sigma = 0.5$]	[$\delta = 1.69, \mu = 2.5, \sigma = 0.5$]	[$\delta = 2.22, \mu = 2.8, \sigma = 0.5$]
1850 S_{T_1}	90	867	4,904
1860 S_{T_1}	144	1,301	6,915
1870 S_{T_1}	469	3,355	14,560
S_{T_2}	1,631	9,082	31,375

Notes and sources: as for Table XI.

The conclusion is that changing the parameters of the lognormal distribution has little effect on our results. It may be argued that altering σ by 20% and μ by 5% still does not represent a reasonable assumption about the actual small grain distribution. The point, however, is that even if the changes were larger or smaller they would not alter our qualitative conclusions; the predicted diffusion path would remain S-shaped and scale of operations would remain more important than relative factor prices.

5. Comparison of our results with David's results.

In this section our results are compared with those of David's study of the "major small grain counties" of Illinois between 1849-50 and 1859-60. This comparison highlights the importance of introducing the farm size distribution into the analysis.

David found that the threshold size fell from 46.5 acres to 35.1 acres while the average small grain acreage increased from 25 to 30 acres. He considered this to provide an empirical foundation for the plausibility of his model (David 1966, p. 24). The gap $S_T - \mu_x$ is reduced by 75% but, if the standard deviation of the farm size distribution was small, the number of farms above the threshold size may not have increased very much. Without knowledge of the shape of the distribution it is impossible to determine the quantitative significance for the number of farms above S_T of a given reduction in the gap between S_T and μ_x. Thus, when David tells us that the gap was reduced by 75% in this period, we do not know whether this reduction was, in terms of its effect on the number of farms above S_T, large or small. This means that we do not know whether David's model adequately describes the phenomenon under study or not. In contrast, our more completely specified model makes numerical estimates of the predicted number of reapers, which can be compared with the actual situation.

A more important criticism of David's work concerns his attempt to determine the relative importance of the different causes of rapid diffusion. Here, his incomplete specification not only prevents accurate quantification, but may lead to qualitative error. The conclusion which he arrives at from the above data is that:-

> "... the estimated increase in average small grain acreage was responsible for less than a third of the subsequent reduction of the gap existing between threshold size and average acreage at the opening of the decade. Moreover, among the Midwestern states experiencing rapid settlement during the 1850s, Illinois was singular in the magnitude of the expansion of its average farm size. Elsewhere in the Midwest, the relative rise in farm wage rates is likely to have played a still greater role in bringing the basic reaping machine into general use during the decade preceding the Civil War." (David 1966, p. 25)

David has ascribed numerical values to his conclusions (changes in factor prices are more than twice as important as changes in average farm size), but his results depend upon a very restrictive assumption.

Our Ontario 1850-70 results have some similarity to David's Illinois results; S_T falls from 43.7 to 27.0 acres while average small grain acreage rises from 12.9 to 20.9 acres. Thus, approximately one third of the reduction of the gap $S_T - \mu_x$ is due to increased acreage and two thirds is due to falling threshold size, although in this case the latter reduction is due to technical improvement (i.e. introduction of the self-rake reaper) as well as increased wage-rental ratio. Even if the effect of the self-rake reaper were omitted, however, changes in factor prices appear more important than increased farm size on the gap reduction criterion. By introducing the whole farm size distribution, rather than just the mean, we obtained different conclusions. The change in the threshold size between 1850 and 1870 would have increased the number of reapers by 672% if farm sizes had not changed, whereas the change in farm sizes between 1850 and 1870 would have led to a

2,370% increase ceteris paribus. If we consider the 1860s alone reduction in the threshold size is the dominant effect, but only because of the introduction of the self-rake reaper. During the 1850s, the 1860s and the 1850-70 period as a whole, the changes in factor prices now appear less important than the change in the scale of operations.[11] Thus David's methodology would have produced a qualitatively wrong answer to the question of which of these two explanatory variables was the more important in Ontario.

The weakness of David's method of determining the relative importance of the causal factors is that it implicitly assumes a symmetrical farm size distribution with constant standard deviation. This was not the case in Ontario and, although there are no data on the distribution of small grain acreage in antebellum Illinois, this assumption of a symmetrical farm size distribution seems unlikely to apply there.[12] If the farm size distribution is not symmetrical then it is not generally true that a reduction of S_T by k acres is equivalent in its effect upon reaper adoption to an increase in μ_x of k acres, even if σ_x remains constant. If farms are, for example, lognormally distributed, then an increase in μ_x does not just shift the distribution to the right, but alters the shape of the distribution (Aitchison & Brown p. 10). In the lognormal case, if average farm size increases by the same amount as the threshold farm size falls, the former will have a greater

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[11] The argument that the self-rake reaper, a labour-saving improvement, was introduced in response to changes in relative factor prices and thus all shifts in S_T should be ascribed to changed factor prices is rejected. Since the improvement reduced labour requirements without incurring any costs, a competitive Canadian implement industry would borrow it from the U.S.A. as quickly as possible. The fact that the self-rake reaper was introduced in Canada seven years after its introduction in the U.S.A. is to be explained by institutional arrangements regarding patents rather than by Canadian factor prices (Denison p. 47).

[12] For some general considerations as to why we might expect a skewed distribution see p.67-8 above.

effect on reaper adoption (cf. Figure 6 (b)). This explains why in the Ontario case it was possible for changed factor prices to reduce S_T by more than the increase in average farm size, and yet the latter was the more significant causal factor.

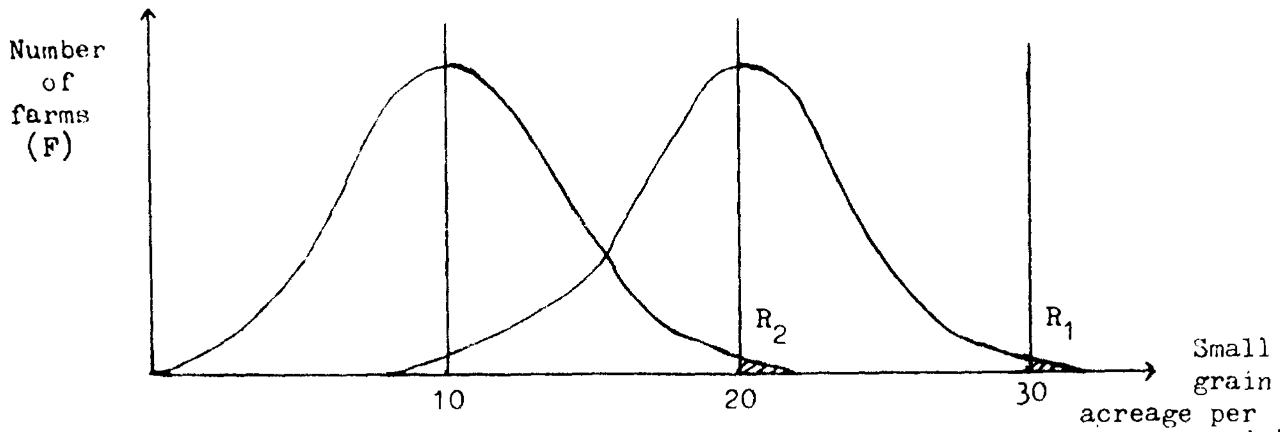
David's conclusion that changes in factor prices were more than twice as important as changes in average farm size in explaining the rapid diffusion of reapers in Illinois in the 1850s is thus seen to rest on the shaky assumption of a symmetrical farm size distribution. Under the more likely assumption of a skewed distribution, the emphasis on factor prices would be less, although without specifying the precise distribution we do not know by how much.

An idea of the quantitative importance of the assumption of an a-symmetrical farm size distribution in the Ontario case may be gained from a comparison between our results and the results which would have been obtained if a distribution consistent with David's implicit assumption had been used. In Appendix 2 values of R^* comparable to the results in Table XI are derived from a normal distribution with constant standard deviation.[13] The estimates obtained from this symmetrical distribution indicate that changing factor prices were more important than changing scale of operations in explaining reaper adoption. Thus, as was mentioned above, David's methodology produces a qualitatively wrong result in the Ontario case. The surprising thing to emerge from the concrete example of a normal farm size distribution is just how clearly the David method points to the wrong conclusion. In the 1860s,

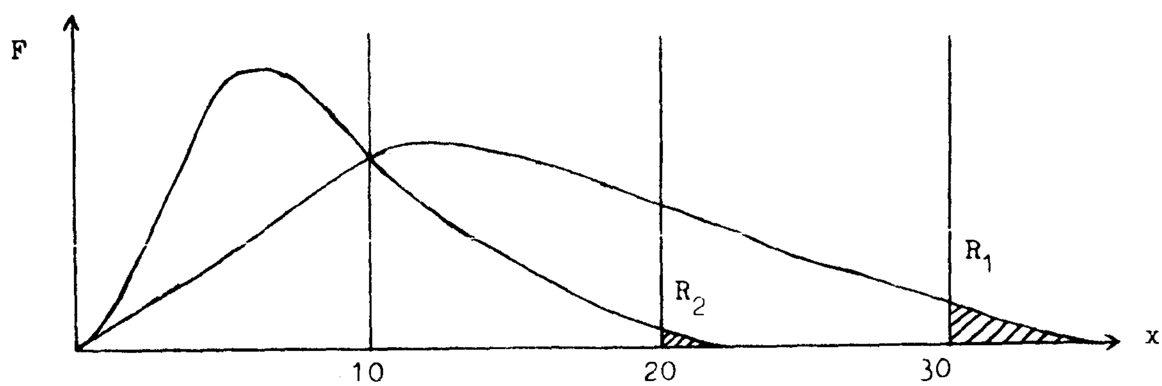
[13] Although there are other symmetrical distributions, e.g. the rectangular distribution, the normal is the only one which appears plausible. The mean, average small grain acreage per farm, is known from the census data. The standard deviation is assumed constant, because a varying standard deviation is inconsistent with David's gap reduction criterion.

Figure 6. Effects on reaper adoption of equal changes in μ_x or S_T with alternative farm size distributions.

(a) Normal distribution with constant σ_x.



(b) Lognormal distribution with constant σ.



Notes: In an initial situation of μ_x = 10 and S_T = 30, the proportion of farms greater than the threshold size, R, is negligible in both cases. If μ_x increases by ten acres so that μ_x = 20 and S_T = 30, then the proportion of farms above S_T is R_1. If instead S_T falls by ten acres so that μ_x = 10 and S_T = 20, then the proportion of farms above S_T is R_2. In the normal distribution case $R_1 = R_2$, i.e. the effect on reaper adoption of a ten acre increase in μ_x is identical to that of a ten acre reduction in S_T. If the lognormal case $R_1 > R_2$, i.e. the effect of a ten acre increase in μ_x is greater than that of a ten acre reduction in S_T.

for example, with the lognormal distribution R^* increased from 2,283 to 8,742 when farm sizes changed ceteris paribus, but R^* only increased to 4,770 when factor prices changed ceteris paribus. For the same period the normal distribution version gave an increase in R^* from 172 to 999 when farm sizes changed ceteris paribus and to 2,824 when factor prices changed ceteris paribus, which suggests a significantly greater importance should be ascribed to the factor price changes![14]

In sum, it can be said that the incomplete specification of David's model leaves it open to some serious criticisms. Firstly, as it stands David's model is not testable. It provides no guide as to how large a reduction in the gap between S_T and μ_x is necessary to explain a given increase in the number of reapers. Secondly, David's model cannot indicate the relative importance of the causal factors, because there is a bias in favour of factor prices. Thus his conclusion as to the pre-eminent role of changes in factor prices in explaining the rate of reaper diffusion must be considered not proven. In contrast, our model does provide estimates of the increase in the number of reapers following changes in S_T or $f(x)$, which can be compared with the actual figures, and our findings on the relative importance of the causal factors, while not so clear-cut as to state that one is twice as important as another, have a firmer theoretical base than David's.

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[14]The figures are obtained from Table XI and Table AII.

CHAPTER VII

CONCLUSIONS

This study has been concerned with investigation and assessment of the relative importance of economic factors affecting the decision of Ontario farmers to use mechanical reapers. The literature on Canadian economic development and on the diffusion of technical change was reviewed. This literature pointed to factor prices, the scale of operations and technical change as the relevant variables in explaining the rate of reaper diffusion. The issues that this raised for the present study were twofold. First, how far do these economic variables succeed in explaining the observed diffusion pattern, especially the time lag between availability and widespread adoption which yielded the familiar S-shaped pattern? Second, what weights should be given to each of these three explanatory variables?

A model developed by David was used as a starting point for the present study. David's model introduced the concept of a threshold farm size, above which it was profitable to use a reaper, and explained reaper adoption in terms of reductions in the threshold size or increases in average farm size. The threshold size is determined by relative factor prices and the technical specifications of the alternative harvesting techniques. Our principal extension of David's model was to explicitly state a farm size distribution, rather than just using average farm size. This extension permitted quantitative estimates of the rate of reaper adoption to be made. Thus our model indicated the quantitative significance for reaper adoption of changes in the threshold size or farm sizes, whereas David's model gives no guide as to how large such changes must be to cause a significant increase in reaper diffusion. Furthermore it was shown that without our extension David's model could produce qualitatively wrong results regarding the relative importance of the explanatory variables.

There are two major caveats to the applicability of our model. If there was cooperation between farmers over use of reapers, then our estimates of reaper adoption will be too low. If there was a reverse chain of causality between reapers and farm sizes, then our separation of causal factors will be invalid. These problems are examined in chapters 3 and 4. The major argument against the existence of cooperation is that there is no empirical evidence of such practices. The lack of such evidence suggests that transactions costs were high, and it was hypothesised that this was a result of the spatial distribution of farms and the geography of Ontario. Some rudimentary tests based on county samples supported this hypothesis. The reduction in average costs following the introduction of the reaper did provide an incentive for increasing farm size, but this was of little quantitative significance compared to the other factors which were encouraging increased acreage at this time. Thus neither of these objections is refuted, but both were found to be of little quantitative significance.

The data and results are presented in chapters 5 and 6. The data contained some weaknesses, especially with respect to the rate of interest and the distribution of small grain acreage. The fitting of an easily manipulable frequency function to the observed farm size distributions also reduced the probability that our model would make accurate estimates of the actual number of reapers. In the light of these problems the estimates obtained in chapter 6 provided reasonable approximations of the actual figures. In particular, the success of the model in reproducing the S-shaped diffusion path led us to conclude that the model provided a useful parable of the diffusion process.

The conclusions regarding causal factors in the rate of reaper adoption are threefold. First, the reaper of the 1860s was a different product to that of the 1850s and the labour-saving improvement which had taken place accounts for half of the increase in the number of reapers between 1860 and 1870. This suggests that if the self-rake reaper had been available earlier then diffusion would have been faster in the 1850s, although the bottom row of Table XI indicates that the diffusion path would have remained S-shaped.

Second, the increase in acreage which occurred between 1850 and 1870 was a more important causal factor than the increase in the wage-rental ratio. This is the opposite conclusion to that of David for the American Midwest and this reversal appears to result from the incomplete specification of his model, which omits all parameters of the farm size distribution other than the mean. If the explanatory variables are divided into demand and supply effects, the former being changes in farmers' demand for reapers because of changes in the final product market and the latter being changes in the supply of factors (either changes in their availability and price or in their technical specifications), it is not clear which is the more important. Over the whole 1850-70 period the demand effect is the more important, but over the 1860s alone the supply effect predominates.

Third, given changes in factor prices and farm sizes do not have the same effect on reaper adoption at different times. There is a critical region, depending on the shape of the farm size distribution, where the slope of the frequency function becomes steeper and previously insignificant changes in factor prices or average farm size have a much greater effect on the number of reapers adopted than previously.

It was suggested in chapter 1 that the increased rate of reaper diffusion in the 1860s was an important component part of a critical transition period in Canada's economic development. Explanation of the component may throw light on the broader phenomenon. The proximate causes of the increased diffusion rate were, in order of importance, (i) the development of the self-rake reaper, (ii) increased grain prices and reduced costs of clearing land, which led to increased small grains acreage, and (iii) a change in relative factor prices following an increase in agricultural wage rates. The picture is one of a series of simultaneous external stimuli to mechanization, e.g. inventions imported from the U.S.A. (the self-rake reaper, stump-pullers) and the American Civil War (affecting the grain market and possibly the labour market). These stimuli did, however, have a powerful effect only because Canadian agriculture was at the critical region mentioned in the previous paragraph. Thus the question of cause is not so clear, because changes in the 1850s (and earlier) when the price of reapers fell and grain prices rose were essential prerequisites for the increase in the pace of reaper adoption in the 1860s. A conclusion, based on the 1860s, that supply effects were preeminent has to be changed when the 1850s are included.

One of the phenomena to be explained was the slowness of the Canadian farmer in adopting the mechanical reaper relative to his American counterpart. The argument has been made in the literature that the Canadian entrepreneur is less dynamic, and this would be sufficient explanation of his comparative tardiness in reaper adoption. The success of our model in explaining the adoption of the new technique in Canada in terms of economic variables casts doubt on this argument. To complete the counterargument the model should be applied to the American case in order to identify the critical differences between the two countries' experiences.

The current case study also suggests some conjectures about the general process of diffusion of technical change. The first problem raised is semantic, but very important. If technical change is defined as anything which alters the shape of the isoquant map, then the development of the self-rake reaper was clearly technical change. It is, however, closely related to the hand-rake reaper which preceded it and it appears foolish to treat the two as completely separate phenomena. One of our findings is that this improvement was significant in increasing the rate of reaper adoption and we know that it increased the capital-labour ratio, but we have no explanation of why the improvement occurred when it did, and there is nothing in the diffusion literature to help us on this point.

Microeconomic theory, including the literature on induced technical change, has traditionally emphasized the role of factor prices in determining factor proportions. Our results suggest that the criticisms of Young and Kaldor, who consider the scale of operations to be more important than factor prices in practice, are well-founded in this particular case. The tools of this study should be applicable to other cases of technical change whose introduction involved an element of fixed cost, and it would be a useful exercise to test the generality of this conclusion about the importance of scale considerations.

Finally, our model provides a satisfactory explanation of the S-shaped diffusion pattern. The basis for this explanation is the introduction of the size distribution of adopting agents into the analysis. The S-shape would be obtained from many unimodal theoretical frequency functions. Lognormal and normal functions were fitted to the farm size distribution in the present study and the lognormal produced an S-shape whose slope closely resembled that of the actual diffusion path. Analysis utilizing the size distribution of adopting units sheds new light on the diffusion process and, in view of the fact that firms in many industries are lognormally distributed, this method of analysis has potentially wide applicability.

APPENDIX 1

THE DETERMINATION OF THE AGRICULTURAL WAGE RATE

In our model we assume that the agricultural wage rate is determined exogenously. In this appendix we will offer two possible rationalisations of this assumption. The first of these is based on the model used by Chambers and Gordon to analyse a later period in Canadian development, while for the second we look at the possible existence of an integrated North American labour market.

In its simplest form the Chambers-Gordon model has two sectors, gadgets and agriculture, in each of which the wage rate is equated to the marginal value product. If there are constant returns in gadgets (MPP_L = a constant) and the price of gadgets is determined by the world gadget price (adjusted for tariffs and transport costs), then the demand for gadget labour is infinitely elastic at a wage rate equal to the fixed price multiplied by the MPP_L. Assuming labour mobility, this wage rate will also obtain in agriculture. The agricultural MPP_L curve is negatively sloped, because of diminishing returns to land, and the size of the agricultural labour force is determined by the MVP = w intersection. Labour in gadgets is the rest of the labour force willing to work for wage w.

Thus the gadget sector determines the agricultural wage rate unless labour productivity in agriculture becomes so great that the gadget sector disappears completely. For an industry to qualify as part of the gadget sector (i.e. having infinitely elastic demand for labour) it must have the following attributes:-

1. the price of the final product is fixed externally,
2. the supply of other inputs is perfectly elastic to the industry,
3. there are constant returns to scale.

The last point will be ignored because it is hard to prove or disprove.

Possible candidates for an 1870 gadget sector are listed in Table AI. Theoretically there is no minimum size for such an industry, but we have excluded some small industries (of less than 500 workers) on the grounds that they may not be integral parts of the national labour market.

Table AI. Possible gadget industries in 1870

		Labour Force	Domestic Output	Imports
1	Iron & steel products	10,632	$14.6m.	
1a	Sewing machines	966		$7.1m.
1b	Agricultural implements	2,546		Negligible
2	Textiles	2,214	$22.6m.	
2a	Clothing	16,830		$19.7m.
2b	Boots & shoes	18,719	$16.1m.	Indistinguishable
3	Carriages & wagons	7,798		Negligible
4	Malt liquors	918	$ 2.1m.	Indistinguishable
		60,623		

Source: 1871 Census of Canada and K.W. Taylor & H. Michell: "Statistical Contributions to Canadian Economic History vol. II"

Of these candidates, it appears that agricultural implements and carriages and wagons are ineligible because their price is not regulated by competing imports; this would presumably be a result of significant natural protection for bulk products. Imports of boots and shoes and malt liquors are not given separately in Taylor's summary of imports, but in both cases there is some query because the products rely on agricultural inputs. The real question here, however, is how significant these demands are in relation to agricultural output, i.e. would a change in boot and shoe output affect agricultural prices?

Even if these are excluded we are still left with iron and steel products (including sewing machines) and textiles and clothing as possible members of the gadget sector. I see no unanswerable criticism of this, although two possible grounds for doubt exist. Firstly, they are both rather heterogenous groups and the categories produced domestically may not be the same as those which are imported. Secondly, there is the question of size; is it realistic to expect a sector with 30,000 workers to determine the wage rate throughout an economy with a labour force of over a million?

As an alternative to the agricultural wage rate being determined in a competing domestic sector, we can also consider the possibility of it being determined in the same sector in a competing country. In the absence of migration controls, we should perhaps treat the North American labour market as a single entity, and clearly this market will be dominated by the U.S.A. Thus the Canadian farmer wishing to employ harvest labour will be constrained by the U.S. wage rate (adjusted by some differential reflecting removal costs). Any increase in the excess supply of labour, eg. because of increased immigration, will not result in lower wages, but will be balanced by increased emigration to the U.S.A.

The major problem in testing this second theory is the choice of time horizon. In the short-run (eg. within one harvest season) there was not even a fully integrated Canadian market; wages varied between counties because of imperfect labour mobility. On the other hand, if the long-run is long enough some kind of North American equilibrium appears inevitable. The question is: how fast was a new equilibrium reached after a disequilibrium appeared? Was it sufficiently fast to make this assumption accord with our ten-year time periods?

Thus the crucial question is the degree of integration of national and continental labour markets (even the Chambers-Gordon model requires labour mobility within the regional market). It would be desirable if we could conduct some empirical test of this, eg. using spectral analysis in a similar way to the Granger-Elliot study of English wheat markets. Unfortunately, however, the Ontario wage data of this period are too scattered to provide much confidence in the successful application of such techniques. Thus the acceptance of either of these theories of an exogenous agricultural wage is a matter for debate, where the central question is were these labour markets "sufficiently" well integrated?

APPENDIX 2

ESTIMATED NUMBER OF REAPERS USING A SYMMETRICAL FARM SIZE DISTRIBUTION

In the last section of chapter 6 David's implicit assumption that the farm size distribution was symmetrical was criticized because it could lead to incorrect results as to the relative importance of the causal factors. Here we will test whether using a symmetrical distribution alters the conclusions which we obtained for Ontario from a non-symmetrical distribution.

The assumption is made that small grain acreage per farm was normally distributed. The mean of this distribution, μ_x, is known for each year from Table IX. The standard deviation was chosen which gave an accurate prediction of the number of reapers in 1870. The choice of standard deviation should not affect our conclusions, although this particular choice is the one most sympathetic to the view that use of a normal distribution could produce reasonable results. The estimates obtained from the normal distribution are given in Table AII.

Table AII. Simulated values of R* using a normal distribution with constant standard deviation.

Threshold Size \ Farm Sizes		1850 f(x) $\mu_x = 12.92, \sigma_x = 7.8$	1860 f(x) $\mu_x = 17.08, \sigma_x = 7.8$	1870 f(x) $\mu_x = 20.85, \sigma_x = 7.8$
1850	S_{T_1}	0	40	293
1860	S_{T_1}	20	172	999
1870	S_{T_1}	370	2,824	8,355
	S_{T_2}	3,507	13,304	36,874

The normal distribution gives an S-shaped diffusion path, but a very steep one, i.e. reapers are not present in Ontario in 1850 but are adopted very rapidly in the 1860s. The 1850 and 1860 values of R* are too low to be reasonable, but this may just reflect use of the wrong σ_x for these years. More important is the way in which changes in factor prices now appear more important than changes in average farm size. This is especially so when the hypothetical estimates in cells 3.2 and 2.3 of Table AII are compared. Thus the statement made in chapter 6 that implicit assumption of a symmetrical distribution leads to exaggeration of the importance of changes in factor prices vis-à-vis changes in farm size is supported in the Ontario case.

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