The Coming of the Reaper

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Recent work in economic history, focusing on technological change and on the diffusion of various innovations, has contributed much to our reconstruction of the past. One of the more intriguing problems in this subject has been that of the diffusion of the reaper. Although patents were independently granted to McCormick and Hussey in the early 1830s, it was not until the 1850s that sales grew rapidly. In a celebrated article, Paul David [6] explained the delay in adoption as a function of the price of a reaper relative to that of the labor it would replace. This paper questions the robustness of his explanation. It makes two points. The reaper manufacturer could not hope to make large sales until the farmer could "afford" to buy a reaper. Illinois wheat output serves to illustrate the importance of this point. Second, a farmer would not buy a reaper until he was confident that the machine could perform when he needed it. The manufacturer needed a "sound" product.

I.

Economists argue that a firm will adopt an innovation if it believes that the expected profit when using the device in the optimal fashion will exceed profit from continuing production using the existing but older technology also in its optimal fashion. Symbolically,

$$(1) \quad \pi_R^* = (O_R^* P^*) C_R,$$

expected profits using a reaper equal expected gross revenue ($O_R^*P^*$) less the cost of the reaper (C_R).[1] Also,

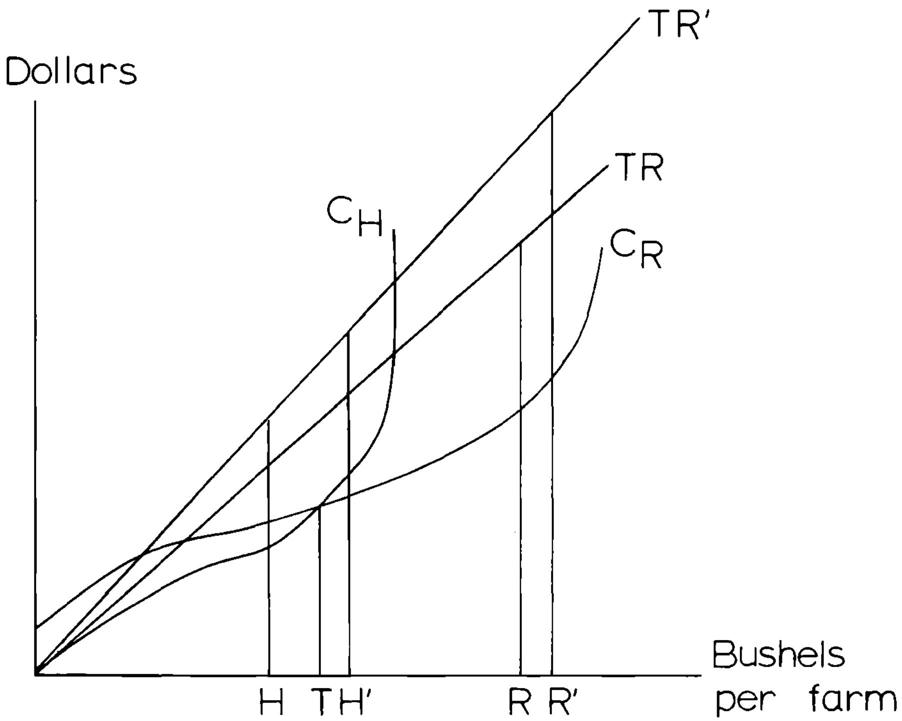
(2) $\pi^* = (o_H^* p^*) - c_H$

expected profits using hand harvest techniques equal gross revenue ($c_H^* p^*$) less costs of hand harvesting (c_H). Diffusion of the reaper is then a function of $\pi_R^* - \pi_H^*$ with a positive first derivative if the function is continuous and differentiable over the relevant range. So,

(3) Sale of reapers = $f[p^*(o_R^* - o_H^*) - (c_R - c_H)]$.[2]

This is our basic equation which is pictured graphically in the chart.

THRESHOLD FARM SIZE, TOTAL REVENUE, AND SALES OF REAPERS



Profits will be maximized at the point where a tangent to the cost of harvesting is parallel to the total revenue line. With the original total revenue, profit is maximized at *H* using hand harvest techniques and *R* using a reaper. If total revenue increases, the profit-maximizing positions will move out to *H'* and *R'* respectively. There is a point *R* (the threshold) where the two harvesting techniques cost the same. As the chart is drawn, it would clearly pay the farmer to expand his output from *H* to *R* because the cost functions are nonlinear, yet he might not do so because other costs, of land breaking and fencing, for example, which are not included in the costs shown on the chart, might lower his expected profit below that at *H*. In addition it would take some time to expand acreage if land breaking and fencing were required. In order to determine when a farmer might decide to buy a reaper, it is necessary to look at revenue and costs in detail.

II.

Total revenue is the product of the price of wheat times the yield times the number of acres sown to wheat. Let us consider each of these variables in turn. The average of the July-August spring wheat price at Chicago for the years 1850 to 1853 was only 55 cents per bushel, whereas the average for the following four years was $1.09 per bushel. This observation has led many agricultural historians such as Paul Gates [9, p. 287] to argue that "Illinois, Wisconsin, Iowa, and Minnesota farmers enjoyed real prosperity and were in a position to buy and pay for reapers."[3] Another test would be to compare the relative price of corn with that of wheat. If the relative price of wheat rose, there would be substitution toward wheat. There was a tendency for this ratio to fall during the middle 1850s, perhaps inducing at least a relative shift from corn to wheat production.

The prices we have been considering are Chicago prices, which would be higher than actual farm prices; but the 1850s were years of rapid railway expansion, so interior prices would have been rising relative to Chicago prices. This means the percentage increase of the farm price of spring wheat would be even greater than the Chicago price shows.

Equally important in understanding the diffusion of the reaper are possible changes in expected output $(O_R^* - O_H^*)$. There are several related points. An increase in expected output per acre would increase total revenue and cause a more rapid diffusion of the reaper.[4] In terms of the chart, *TR* moves to *TR'* because of an increase in yield instead of an increase in the price per bushel of wheat. The optimal move, using hand harvest techniques, would be from *H* to *H'* but because the cost functions are nonlinear and because the threshold point has been passed, it is cheaper to adopt a reaper and to expand to R'. This may be an important factor in explaining the specific way in which reaper sales increased.

There is some evidence that grain often went unharvested because of lack of help. This was a problem because the farmer did not know how many harvest hands would be available when he sowed his grain.[5] Another major problem the farmer faced was the marketing of grain. Unless he lived close to a waterway, the distance he could profitably wagon-haul a load of wheat was fairly limited. The 1850s marked the coming of the railroad to Illinois. The spreading of this network tended to have two effects. First, the farmer might expect it to raise the price he received for his grain by reducing his transport costs and thus encourage him to prepare to ship more to market, but, equally as important, it meant that farmers could ship a much greater amount of grain to market. In 1848 Illinois had 55 miles of railroad. By 1860 it had 2,760 with most of the increase coming between 1853 and 1856.

Some writers have suggested that the decision to purchase a reaper depended upon crop prospects. Thus William T. Hutchinson wrote [12, p. 366],[6]

> The number of sales depended upon the weather more than on other businesses, and a late spring, excessive rain or drought, or any other of the abnormal and uncontrollable circumstances to which the farmer was subjected, spelled a bad season for agent and manufacturer alike. Most grain-growers had no surplus in the bank and could not buy machinery unless there were prospects of a good crop and a fair market for grain. Nor would a salesman wish to press a machine upon a farmer who did not seem able to pay. A crop outlook that was discouraging late in April frequently became favorable within a month and under such circumstances more orders for reapers would be rushed to the factory than could be filled. Late shipments on slow canal-boats often arrived at their destination too late and Eastern agents in particular complained of tardy deliveries.

There is evidence that in some years McCormick did not supply all he could have sold.[7] Output and yield per acre are ex post measures and, as such, are only a proxy for prospective crop conditions. Nevertheless, they are informative. Table 1 shows Illinois output, yield, and early season prices, together with McCormick's national reaper sales. Although the test is not conclusive, since we are comparing Illinois data with national sales, it is seen that reaper sales and crop yields and prices do move together.

Finally, the decision to buy a reaper and to expand acreage

Table 1
ILLINOIS WHEAT OUTPUT, YIELD, PRICE PER BUSHEL, AND McCORMICK REAPER SALES, 1849-58

Year (1)	McCormick reaper sales (2)	Illinois output (1,000 bushels) (3)	Illinois bushels per acre (4)	March-April-May price spring wheat at Chicago (5)
1849	1,490	9,415	15.4	$ .57
1850	1,598	7,607	10.8	.76
1851	999	7,128	9.2	.52
1852	994	7,800	9.1	.37
1853	1,086	11,820	12.7	.62
1854	1,549	13,074	12.4	1.15
1855	2,524	22,323	17.7	1.40
1856	4,039	25,072	16.7	1.11
1857	3,937	32,827	19.3	.99
1858	3,917	19,606	10.6	.62

Sources: Column (1), [12, p. 369]; number of machines made less number on hand; Columns (2) and (3), [2, Table 17].

might have been one and the same decision. Improved farm land for the state of Illinois increased from 66.1 to 91.4 acres per farm between the 1850 and 1860 censuses. For the northern part of the state improved land increased from 58.1 to 98.9 acres per farm. In terms of the chart, this factor by itself would provide sufficient reason for expecting farmers to adopt a reaper, since they could expand from *H* to *R* and increase profits.

Unfortunately, actual acreage data are not available. In order to estimate acreage, it is necessary to estimate the yield and divide this into total output. The US Department of Agriculture estimated a yield of 11.3 bushels per acre for Illinois for the period 1866-75. Column (3) of Table 2 provides acreages per farm for the 1849 and 1859 crop year censuses for all counties that averaged more than 200 bushels of wheat per farm in 1859. The results are mixed, and no particular county appears representative.[8]

The immediate question is, how representative is this yield? There are two sources of information about 1859 yields, and they tend to be contradictory. First, using county data from the cen-

Table 2

ILLINOIS WHEAT ACREAGE PER FARM IN COUNTIES THAT AVERAGED MORE THAN 200 BUSHELS PER FARM IN 1859[a]

County (1)	Year (2)	(1866-75) 11.3 bushels per acre (3)	15.5 bushels per acre-1849 12.3 bushels per acre-1859 (4)	13 bushels per acre Parker (5)	16 bushels per acre Parker (6)	1859 assessor (yield) (7)	McCormick reapers (8)
Boone	1849	24.5	17.8	21.3	17.3		
	1859	21.0	19.3	18.3	14.8	20.5 (11.6)	66
Bureau	1849	20.5	14.9	17.8	14.5		
	1859	32.4	29.8	28.2	22.9	31.9 (11.5)	312
Carroll	1849	25.0	18.2	21.8	17.7		
	1859	33.6	30.8	29.2	23.7	26.7 (14.2)	124
Cass	1849	19.1	14.0	16.6	13.5		
	1859	18.3	16.8	15.9	12.9	18.3 (11.3)	101
De Kalb	1849	24.2	17.6	21.0	17.1		
	1859	34.3	31.5	29.8	24.2	31.2 (12.4)	72
Henderson	1849	25.7	18.7	22.3	18.1		
	1859	20.6	18.9	17.9	14.5	25.5 (9.1)	90
Henry	1849	19.2	14.0	16.7	13.6		
	1859	25.1	23.1	21.8	17.8	30.9 (9.2)	137
Jersey	1849	21.1	18.4	15.4	14.9		
	1859	22.7	20.9	19.7	16.0	22.5 (11.4)	135
Kane	1849	27.6	20.1	24.0	19.5		
	1859	20.1	18.4	17.4	14.1	16.7 (13.6)	45
Lee	1849	18.1	13.2	15.7	12.8		
	1859	33.5	30.8	29.1	23.7	22.1 (17.1)	135
McHenry	1849	25.5	18.6	22.2	18.0		
	1859	26.0	23.9	22.6	18.4	24.3 (12.1)	87

Table 2 *(continued)*

ILLINOIS WHEAT ACREAGE PER FARM IN COUNTIES THAT AVERAGED MORE THAN 200 BUSHELS PER FARM IN 1859[a]

County (1)	Year (2)	(1866-75) 11.3 bushels per acre (3)	15.5 bushels per acre-1849 12.3 bushels per acre-1859 (4)	13 bushels per acre Parker (5)	16 bushels per acre Parker (6)	1859 assessor (yield) (7)	McCormick reapers (8)
McLean[b]	1849	6.2	4.5	5.4	4.4		
	1859	18.9	17.4	16.4	13.4	30.1 (7.1)	32
Monroe[b]	1849	9.1	6.6	7.9	6.4		
	1859	20.1	18.5	17.5	14.2	12.4 (12.4)	37
Ogle	1849	24.2	21.0	17.6	17.1		
	1859	42.2	38.8	36.7	29.8	31.8 (15.0)	267
Pike[b]	1849	12.4	9.1	10.8	8.8		
	1859	17.9	16.4	15.5	12.6		208
Putnam	1849	24.8	17.5	21.5	18.1		
	1859	22.7	20.9	19.7	16.0	25.1 (10.2)	17
Rock Island[b]	1849	12.6	9.2	10.9	8.9		
	1859	19.3	17.7	16.8	13.6	18.0 (12.1)	225
St. Clair[b]	1849	10.1	7.4	8.8	7.1		
	1859	28.4	26.1	24.7	20.1	20.2 (15.9)	306
Scott[b]	1849	10.5	7.6	9.1	7.4		
	1859	20.4	18.7	17.7	14.4	21.5 (10.7)	36
Stark[b]	1849	14.0	10.2	12.2	9.9		
	1859	33.2	30.5	28.8	23.4	29.5 (12.7)	136
Stephenson[b]	1849	17.1	12.5	14.9	12.1		
	1859	36.4	33.5	31.6	25.7	26.1 (15.8)	85
Whiteside	1849	32.7	23.9	28.5			
	1859	31.1	28.5	27.0	21.9	25.4 (13.8)	235

Table 2 *(continued)*
ILLINOIS WHEAT ACREAGE PER FARM IN COUNTIES THAT AVERAGED MORE THAN 200 BUSHELS PER FARM IN 1859[a]

County (1)	Year (2)	(1866-75) 11.3 bushels per acre (3)	15.5 bushels per acre-1849 12.3 bushels per acre-1859 (4)	13 bushels per acre Parker (5)	16 bushels per acre Parker (6)	1859 assessor (yield) (7)	McCormick reapers (8)
Winnebago	1849	30.5	22.2	26.5	21.5		
	1859	34.7	31.9	30.1	24.5		65
Woodford[b]	1849	13.4	9.8	11.7	9.5		
	1859	17.8	16.3	15.5	12.6	24.5 (8.2)	35
State	1849	11.0	8.0	9.6	7.8		
	1859	14.6	13.5	12.8	10.4		

Sources: All total wheat outputs from the *Seventh Census* and *Eighth Census*. The number of farms for the *Seventh Census* may be found in *Compendium* to the *Seventh* (1850) *Census*, pp. 221-27 and the number of farms for 1859 from the *Eighth Census, Agriculture*, p. 197. The yield estimates may be found as follows: Column (3), USDA average 1866-75 used by David [6] for all calculations; Column (4), [2, p. 115]; Column (5), [18, p. 532]; Column (6), [18, p. 551]; Column (7), [2, pp. 245-47]; and Column (8), McCormick reaper sales for 1849, 1850, 1854, 1855, 1856, and 1857 [12, p. 469]. Note that these are the only years for which he provides data.

[a]Seven counties, Adams, Du Page, Kendall, Knox, Lake, Marshall, and Mercer harvested more than 200 bushels per farm in 1849, but fell below this figure in 1859.

[b]Less than 200 bushels per farm in 1849.

suses it is possible to apply regression analysis to estimate yields, making use of the total number of improved acres.[9] The results given here show wheat yields of 15.4 bushels per acre in 1849 and 12.3 bushels per acre in 1859. Both estimates are greater than the US Department of Agriculture's estimate of 11.3 bushels per acre. If these revised estimates are used, we find wheat acreages per farm of 8.0 and 13.5 acres, respectively, instead of 11.0 and 14.6 (using 11.3 bushels per acre). Column (4) of Table 2 provides county estimates.

On the other hand, Illinois assessors began to collect data for wheat and corn acreages in 1859. There are omissions, and in later years the state assessor complained about underenumeration, but if we accept the acreage estimates we can use the census returns to find yields. Column (7) of Table 2 provides these yields (in parentheses) for counties in which individual farms averaged over 200 bushels of wheat harvested.

Finally, although William Parker and Judith Klein [19, p. 532] flirted with the 11.3 bushels per acre average, they used 13.0 bushels per acre as their estimate of wheat output in the West, and in an appendix suggested that a more appropriate yield for Illinois might be 16.0 bushels per acre [19, p. 551]. Columns (6) and (7) of Table 2 provide these data.

Several points may be made about the interpretation of the data in Table 2. First, the lower our estimated yield, the higher is our estimated acreage for a given output and vice versa. Thus 11.3 acres gives the highest acreages for both censuses.[10] This is important since there is reason for believing that the 1866-75 yields are lower than earlier ones because of soil depletion.

Likewise, it should be noted that using any fixed yield shows a very small growth in average acreage. Since yields were not fixed, the use of a fixed yield is wholly inappropriate because it can give a misleading impression about actual yields and acreages.

III.

Costs were the next determining factor in the adoption of the reaper. The two main costs were the wages of harvest labor and the cost of a reaper. Paul David [6] developed a "threshold model (the point T in the chart) in order to explain the adoption of the reaper. He compared the periods 1849-53 and 1854-57. He assumed that output was independent of the method of harvesting, so that only costs would determine the harvesting method. He found that the price of labor rose relative to the price of a reaper during this period, so that the threshold (measured in acres) fell. Following his choice of data, the threshold declined from 46.5 acres for the first period to 35.1 acres for the second period. Though his argument is suggestive, it is not persuasive. The Appendix provides a discussion of the threshold and a closer look at reaper and labor costs. It is shown there that the threshold is fairly sensitive to the values chosen for the parameters. The threshold concept suffers from two shortcomings. First, output and revenue do not enter into the calculations. David does not even provide yearly data on sales of the reaper for the two periods. In fact, there is a strong correlation between reaper sales and time itself, that is, sales simply grow over time. This is because his first period was one of very poor wheat years in Illinois, whereas the second period was one of very good years. Table 1 makes this clear.

Second, labor costs are defined very narrowly in David's paper. It might be thought that the availability of labor would be reflected in the price of labor. Certainly if the supply of labor can be represented as a continuous function, this would be so, but there are references in the literature that indicate this may not be an appropriate assumption. David Schob [20, p. 167] reports from a farm diary in 1845, "Becker in tribulation about his crop! hands very scarce -- worth $1.50 in cash at what Mr. Schillaber gives and he monopolizes them." Another Illinois farmer reported that he swung the cradle for 27 consecutive days, because he could not find help and he decided to give up farming. Such a situation was exacerbated because farmers often planted more than they could harvest and hoped they could later find the help. This shortage was to be even more severe in years such as 1855 when the harvest was very heavy [20, p. 165; 11, p. 80; and 12, p. 208].

There were often complaints about the quality of farm labor, and James Campell, who became a state senator in New Jersey said, "The only object I had in view at first was to aid agriculture and place the farmer beyond the power of a set of drinking harvest hands with which we have been greatly annoyed" [12, pp. 355-56]. In such a case a backward bending supply curve of labor is conceivable. However, it is equally true that farm laborers as well as farmers themselves lacked mechanical aptitudes.[11] In spite of this there still might be reasons to prefer a reaper. If this appears to be irrational prejudice for machinery, keep in mind that cradling was demanding physical labor, performed during the hottest months of the year. The combination of heat and humidity particularly affected those persons who were subject to fevers and ague. Schob [20, pp. 179-80] reports that a "mutiny" occurred on the Indiana farm of Calvin Fletcher in 1839 because of the excessive heat. Fletcher also had problems in 1850 and 1853.[12] This is the type of situation the farmer could not plan for and, of course, his own illness or that of his farm hands might spell disaster. Such a probability would not be reflected in the price ratio or in a threshold, but it would provide a positive inducement to replace hand labor.

IV.

Central to my argument is the belief that the farmer was willing to purchase a reaper once a reliable one become available.[13] The last section showed that output prospects became increasingly more favorable as the 1850s progressed, but this does not explain why farmers did not purchase reapers in greater numbers before 1850. It is argued that a reliable reaper was not really available before that date.[14] We may consider this from the inventor-manufacturers' side as well as the farmers'.

The problems these early inventors faced should not be minimized. The farmer wanted an all-purpose machine that would cut grass as well as the small grains he might sow. However,

> some grasses are tall and large and easy to cut, others are short and wiry, and hard. Timothy grain stands well; clover is usually prostrate and tangles. The taller grasses sway in the wind, and incline away from the advancing machinery. Grainfields are weedy and sometimes difficult grasses are encountered in them. Rye is tall and wheat comparatively short. Both become tangled, lodged (lodging is the rule with heavy oats) and strawbroken at times. Overripe grain becomes so "fluffy" that good work cannot be done in harvesting it. Fractious teams and ignorant labor can also be added to the unfavorable conditions confronting inventors. [21, p. 12]

The manufacturers problem was that there were annoying defects to be worked out of the machines and new ideas could be given field tests only during the short harvest season.

> The story of the invention of the raker's seat illustrates the obstacles to be surmounted when changes in the construction of the reaper were necessary or a new appliance had to be added to its carefully balanced framework. The general form of seat desired and the most advantageous position for the riding rakeman could be readily determined, but a year of study was required with experimental construction work in the shops of Walnut Grove and Cincinnati, and trials in the grain of four states, before Cyrus McCormick finally discovered how this device could be utilized in the most convenient location without sacrificing the efficient operation of the other elements of the reaper.[15] [12, pp. 215-17]

McCormick's slow pace in the early years resulted from these sorts of problems. Although he sold two machines in 1840, they did not come up to expectations [12, p. 182]. He spent the next year experimenting and consequently sold none. Six machines were sold in 1842. "Early in the year he expected to make more for this harvest, but he finally 'concluded to wait another year's experience, and additional testimony from different parts of the state, before hazarding a great deal.'"[16] [12, p. 185]

A second problem, which David mentions [6], is that McCormick began his work in the East. But the hilly countryside of the East also caused more problems for the successful operation of a machine than did the more level Midwest. McCormick did not go West until 1844.

Equally as important, McCormick did not manufacture his own machines until 1848 but rather licensed others, who were not always as careful as he would have been and consequently were giving his product a bad name [12, p. 224]. Careless production proved disastrous to other manufacturers. For example, J. S. Wright received so many orders for the 1857 harvest that he used green lumber in the machines with the result that the hot sun warped and twisted them. The Panic of 1857 did the rest [11, p. 138]. C. W. Marsh [16, p. 87] also reported that he and his brother foolishly began producing harvesters in 1860 by having parts produced at various locations, only to find the machines poorly constructed and unsalable. He goes on to report a disastrous field trial,

> At the request of our customers we gave a public trial in a field of barley on the eve of the 4th of July and the machine failed to satisfy. It was our first experience in cutting and binding barley. The grain was thick and short; we could not get the machine low enough, binding was difficult and something broke. The trial was a failure and our customers "went back" on our orders.

All this suggests dating the beginning of the reaper industry from 1848 when McCormick moved to Chicago and took control of his production.

The farmer needed a machine that would work. This meant that McCormick would have to teach farmers how to use this "complicated" machine, since farmers were not used to such machinery [12, pp. 334-35]. If he decided to purchase a reaper but did not also hire the normal quota of harvest hands, he might lose a large part of his crop if his machine broke down. An improving machine would gradually convince farmers that the purchase of a reaper would be profitable. A comparison of Table 3 Parts (c) and (d) shows a large decline in the "threshold" if the machine could be improved to last 10 years instead of five, or if the farmer expected it to last longer than he had previously. McCormick supplied his agents and each reaper with spare parts.[17] In 1853 when a gear worked

Table 3
THRESHOLDS

(a) Interest rate of 6 percent and useful life of 10 years

Period 1		Period 2	
Daily wage	Threshold	Daily wage	Threshold
$1.00	59.0 acres	$1.87[a]	35.1 acres[a]
1.27[a]	46.5[a]	2.00	32.9
1.50	39.4	2.50	26.3

(b) Interest rate of 10 percent and useful life of 10 years

Period 1		Period 2	
Daily wage	Threshold	Daily wage	Threshold
$1.00	68.1 acres	$1.87	40.5 acres
1.27	53.6	2.00	37.9
1.50	45.4	2.50	30.3

(c) Interest rate of 6 percent and useful life of 5 years

Period 1		Period 2	
Daily wage	Threshold	Daily wage	Threshold
$1.00	104.5 acres	$1.87	62.1 acres
1.27	82.3	2.00	58.1
1.50	69.6	2.50	46.5

(d) Interest rate of 10 percent and useful life of 5 years

Period 1		Period 2	
Daily wage	Threshold	Daily wage	Threshold
$1.00	113.6 acres	$1.87	67.6 acres
1.27	82.3	2.00	63.2
1.50	75.7	2.50	50.5

Source: Calculated, based on Equation (3), L_s=0.273, based on 11 acres harvested per day and labor savings of three men. c_1=$124; C_2=$138.

[a]David's original data and threshold.

poorly, McCormick sent free replacements.[18] The point is that people were learning to trust McCormick and his machines.[19] Success likewise breeds success. McCormick's reaper won the highest award at the London Fair of 1851.[20] This served as effective advertising. The spread of agents (sometimes even one of the McCormick brothers stopped to chat with farmers) [12, pp. 389-91] also helped. The problems such a manufacturer faced may be compared with the problems foreign auto manufacturers have when they attempt to break into the American market -- lack of spare parts on hand and lack of an effective marketing organization.

VI.

In summary, this paper has looked at the many problems surfounding the adoption of the reaper. Particular attention was paid to various revenue factors and cost factors that are not easily quantifiable. It is suggested that the farmer was willing to buy a reaper as soon as a reliable machine became available and that this did not occur until after McCormick moved to Chicago in 1848. Various nonwage considerations also increased the demand for reapers, most important, the extreme heat and humidity in Illinois. Finally, the demand for reapers in an individual year depended upon the prospects for the coming crop and it was not until the middle 1850s that Illinois wheat output turned favorable.

APPENDIX

David reasoned [6, pp. 14-15] that there was a point (a threshold) at which the farmer was indifferent as between using a reaper and hiring cradlers. He argues that "mechanization of reaping spread through the agricultural sector as a result of an alteration in factor prices which accompanied the expansion of grain cultivation in the West..."

David's model sought to find that point (threshold) where the farmer was indifferent as between the two techniques. In order to do this, it is necessary to determine first the savings in labor cost at the threshold. Equation (1) defines the cost of two methods at the threshold and assumes they are linear thoughout the relevant range.

(1) $$c = S_t L_s w$$

where c = the annual rent of a reaper, S_t = threshold in acres,

L_s = labor saving per acre by using a reaper, and w = the wage rate paid to cradler. Equation (2) defines the annual rent on the machine,[21]

$$(2) \quad c = (d + 0.5r)\ C\ ,$$

where d = the depreciation rate - straight line, r = the interest rate, and C = the cost of a reaper. Combining Equations (1) and (2) we can solve for the threshold (S_t). Equation (3) defines the threshold,

$$(3) \quad S_t = [(d + 0.5r)/L_s](C/w).$$

In David's paper, this threshold was only influenced by the ratio (C/w).

David found that the price of labor rose relative to the price of a reaper from 1849-53 to 1854-57, so that the threshold fell. Following his choice of data, the threshold declined from 46.5 acres for the first period to 35.1 acres for the second period.[22]

David's analysis depends crucially on the values that are assigned to Equation (3) and what is allowed to fluctuate, that is, what the independent variable is. His independent variable was the ratio (C/w); therefore, we begin by looking at the wage rate.[23] Until recently very little wage data have actually been available. He used 85 cents for the daily wage for the first period 1849-53 based on the 1850 Census Report for Illinois [p. 36] and $1.25 for the period 1854-57. He adjusted this upward 50 percent to get the wage for cradlers, $1.27 and $1.87 for the two periods.[24]

The lack of wage information over an eight-year period leaves David's results somewhat in question. However, David Schob [20] has recently completed an outstanding Ph.D. thesis, "Agricultural Labor in the Midwest, 1815-1860," which adds much to our knowledge about wage rates during these years and enables us to enlarge upon David's conclusions.[25]

These reports suggested that the wage rates may have been somewhat higher than those David used, both initially and at the end of the period. This would have the effect of lowering the threshold for both time periods and perhaps increasing the relative difference between the two periods. Table 3 compares the threshold for cradler wages holding the other terms in Equation (3) at the values David assigned to them, that seem representative, based on Schob's work.[26]

Higher interest charges would raise the threshold. David asserted that he was using the rate McCormick charged the farmers, 6 percent, but a careful reading of Hutchinson's *Cyrus Hall McCormick* [13, p. 74] indicates 6 percent is not an appropriate rate to use.[27]

McCormick usually demanded cash on delivery equal to about one-third of the price of the implement. On the balance due after the first payment, he required that 6 percent interest be paid. If the notes were not met on time and the usury laws of a state allowed it, he demanded 10 percent for renewal secured by a mortgage on the farm or personal property.

Two-thirds of the total price at 6 percent for five months is the equivalent of about 10 percent per annum of the total price, which is what McCormick charged on overdue notes. Table 3(b) therefore is the equivalent of Table 3(a) with interest being charged at 10 percent instead of 6 percent. Notice, however, that this was the cost of borrowing. Many farmers, especially in southern Illinois, were more conservative and refused to buy unless they could pay cash [13, p. 69].

The appropriate interest for them was the opportunity cost of not lending the money out. Another consideration for the farmer was that McCormick did not require final payment until the first of December, whereas farm laborers had to be paid during the harvest season. If the cash was not available, then either they had to sell their grain immediately, probably at an unattractive price or else borrow the money at rates much higher than 10 percent.[28]

Finally, David used a depreciation rate based on a reaper life of 10 years, but Hutchinson reported [13, p. 471] a useful life of from 5 to 10 years.[29] A five-year useful life would double the straightline depreciation rate and greatly increase the threshold. Parts (c) and (d) of Table 3 recalculate the threshold, based on a five-year useful life. It should also be clear that the depreciation rate could be falling over time as the reaper improved and its useful life lengthened.

At this point, the revised data of Table 3 yields several thresholds, but it is difficult to know precisely which is the most valid. To be sure, they all indicate the threshold was falling, but considerable doubt may be expressed about choosing one and calling it *the* threshold. My own feeling is that something between Table 3(b) and 3(d) comes the closest to expressing a "true" threshold. All these thresholds are considerably higher than David's results.

NOTES

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1. This would include depreciation, interest costs, labor costs, and any repairs to the reaper.

2. Normally, O_R^* would be expected to be equal to O_H^*, but this need not be the case as is explained later.

3. In 1854, however, the boom in prices caused by the demands of the Crimean War, awakened the entire country to the possibilities of agriculture.... It was a simple proposition then: put in more wheat and buy a reaper, buy more land and put in more wheat.... With largely increased acreage and profitable returns per acre, farmers would have and could pay for the various implements and machines which were required for such increased acreage.

4. McCormick guaranteed that his 1842 reapers would save one bushel of wheat per acre, "ordinarily lost by shelling when the cradle was used." [12, p. 336]

5. [20, pp. 165-67]. The *Cleveland Leader* in 1857 reported (p. 169) "The only trouble seems to be getting labour in the fields. Farmers are unable to do all the work themselves, and they can not hire help for love or money." See also [12, p. 208]. "While on his trips to Ohio Valley, Cyrus wrote home of crops wasting for lack of labor to harvest them" [12, p. 246]. "Conditions were especially favorable (in the Chicago area in the late 1840s) in that wheat prices were attractive and many farmers held land suitable for wheat far in excess of what they could harvest by the cradle."

6. Forest Flippo [8, p. 52] emphasized the same set of factors. The sale of reapers was directly geared to crop prospects in each locality and farmers were reluctant to sign notes until they were reasonably sure of a crop to harvest (Harrison and Son, Newark, Illinois, to C. H. McCormick, 27 March 1855). Phelps and Bourland reported in 1849 that they "could have sold three to half a dozen more if we had them on hand just at the right time" (Phelps and Bourland to C. H. McCormick and Company, 24 July 1848).

7. See [12, p. 358; and 13, pp. 79, 80, 81, and 85]. In an agreement with Phelps and Bourland of Peoria, McCormick promised to pay $3 for all orders which he could not fill. Likewise, McCormick had difficulty filling Eastern orders, in part because of "inability in some seasons to supply the demand of the Middle West... At all times the factory office viewed the Atlantic seaboard principally as an outlet for surplus machines." In 1860, "McCormick's supply of reapers and mowers was again too small." "By late June [of 1861] angry farmers were told the McCormick supply of reapers and mowers was exhausted, and agents were ordered to sell only for cash." The following season McCormick "oversold about 500 machines."

8. A problem with this analysis is that we are comparing 1849 and 1859 acreages to suggest the amount of acres sowed throughout the decade. However, Margaret Beattie Bogue [4, p. 127] thinks farm size decreased after 1856, "the height of the wheat raising boom."

9. For 1849, the equation (t-statistics in parentheses) is

(4) $Y = 5{,}333 + 1.068x_1 + 0.034x_2 + 0.043x_3 + 0.065x_4,$

$$\quad\quad (6.76) \quad (18.13) \quad (2.86) \quad (5.63)$$

$R^2 = .92.$
D.F = .94.
where Y = "tilled" acreage, x_1 = tons of hay, x_2 = bushels of Indian corn, x_3 = bushels of oats, and x_4 = bushels of wheat. For 1859, the equation is

(5) $Y = 14{,}497 + 1.366x_1 + 0.040x_2 + 0.0161x_3 + 0.081x_4 .$

$$\quad\quad (5.99) \quad (14.42) \quad (.625) \quad (6.49)$$

$R^2 = .89.$
D.F = 97.
Equation (1) divided by 0.065 gives the wheat yield for 1849. This method is completely worked out in [3, pp. 67-75].

10. This type of analysis leads to one other problem. It appears that when a farmer had his best yields and was in a favorable position to afford a reaper, my estimates show he was planting fewer acres and had less need for a reaper. Since I believe that higher yields induced farmers to buy reapers, this is a serious shortcoming.

11. Clarence Danhof [5, p. 229n] observes

> Edward Ruffin, the distinguished Virginia farmer and agricultural editor, wrote in 1850 that although the reaper was in use in his neighborhood, 'because of their own ignorance of machinery, I have feared to attempt the use of reaping machines.' Such a lack of familiarity with mechanical devices and consequent inability to use them as intended by the manufacturer represented a serious difficulty not only in selling the machines but also in securing proper use and care.

12. Schob [20, p. 162] also reports on several other identical cases. The *Ohio Valley Farmer* I (June 1856), reported that exhaustion from heat and labor was common during the harvest. In 1842 at Spoon River in central Illinois, wheat harvesting was conducted in temperatures hovering about the 120° mark, and labor was scarce! John Muir [17, pp. 222-23] emphasizes the hard work involved.

> In those early days, long before the great labor-saving machines came to our help, almost everything connected with wheat-raising abounded in trying work...and it often seemed

> to me that our fierce, over-industrious way of getting the grain from the ground was too closely connected with grave-digging... We were called in the morning at four o'clock and seldom got to bed before nine, making a broiling, seething day seventeen hours long loaded with heavy work... In mowing and cradling, the most exhausting of all the farm work, I made matters worse by foolish ambition in keeping ahead of the hired men.

13. While substantial labor savings were early claimed, the question of cost advantages of harvesters was long debated. Comparisons with harvesting costs by hand labor were frequently made to the disadvantage of machine work, taking into account interest and depreciation. Others claimed that such doubts would be resolved with the machine's increasing perfection. Well before the question was clearly answered, however, significant numbers of individuals had seen the harvester's value as a substitute for labor that was frequently not available with certainty and in the amounts desired. [5, p. 233]

14. If adoption of the reaper can be judged as being slow, it was principally because of the technological immaturity of the machine. Once the farmers were assured of a satisfactory machine of reasonable reliability, their ability to adapt their operations and so secure a machine of their choice was the determining factor in adoption. [5, p. 233n]

15. David Landes [14, p. 87] makes the same point about the British Industrial Revolution.

> The many small gains [in the British textile factories] were just as important as the more spectacular initial advances. None of the inventions came to industry in full-blown perfection. Aside from the trials and errors of creation, there were innumerable adjustments and improvements -- before these primitive contrivances would work commercially. The first decades of industrialization saw a ceaseless war against breakdowns.

16. See also [12, pp. 324-25].

> A complete story of the mechanical evolution of the reaper between 1848 and 1855 would involve technicalities beyond the purpose of this narrative, but several changes of considerable importance were introduced which require mention. Scarcely a single element was left untouched. The main wheel was enlarged, the gearing was altered almost every year, the platform shortened and covered with zinc, the reel improved in detail, and a seat added for driver as well as raker....

17. It may be argued that his success was mainly due to marketing and business acumen which others lacked, particularly Obed Hussey who set up his plant in the East. In a somewhat related point Robert A. Lynn [15] suggests that the reaper industry was one of the earliest industries to sell on credit.

18. [12, pp. 363-64]. See also [8, p. 55].

> He regained lost favor with the farm public the following winter by sending out experienced mechanics from the factory to repair or replace, free, all offending parts in the machines.

19. Hutchinson [12, p. 323] writes

> It is a somewhat striking fact that in the face of growing competition and the appearance of the self-rake machine, Cyrus McCormick could charge more for his hand-rake reaper than any rival, and could not only hold his ground but lead the market and increase his output annually. He charged "all the traffic would bear."

20. One of the most famous and important reaper trials in history (the Exposition trials between McCormick and Hussey) may have been decided in part because McCormick had a mechanic who knew how to operate his machine and how to make adjustments under less than ideal conditions, whereas Hussey's mechanic did not. See [12, pp. 389-91].

21. It has sometimes been argued that one should look for evidence of actual rental of machines, or for joint purchase instead of approaching the problem in this fashion [17, pp. 87-88]. A. L. Olmstead in [18] has found many examples of this.

> Random samples of all McCormick sales in 1854 and 1859 show that in both years approximately one out of every four reaper sold was purchased jointly by two or more individuals. In the overwhelming majority of cases the individuals did not have the same last name... But in the newly settled states of the Midwest -- including Illinois, Iowa, and Wisconsin -- over thirty percent of all McCormick reapers were jointly purchased (p. 337).

Joint purchases reduce the threshold for any one farmer and destroy the usefulness of the threshold analysis. Olmstead also shows that contracting was widespread. One Iowa farmer reaped on six different farms and made eleven moves from one farm to another during a three-week period in the summer of 1855 (pp. 338-39). Another man made 21 moves between farms during the harvest of 1854 in Massachusetts (p. 341). Olmstead points out that these frequent moves were made to reduce risk, but he also quotes C. W. Marsh [16, p. 80] who reported that

> in 1856 in connection with a neighbor we purchased a Mann reaper... Next year we bought out our neighbor...

Apparently there could still be problems.

22. d = .10; r = .06; l_s = 0.273; w_2 = \$1.87; c_1 = \$124; and c_2 = \$138.

23. To be complete, we should also look at the price of the reaper. No threshold computations will be based upon different selling prices for the reaper but, of course, the price of the reaper would affect the threshold. With respect to the McCormick machine, [12, pp. 323-40] reports that

> the price of the McCormick reaper advanced from \$115 cash and freight charges in 1849 to \$130 with a maximum of \$5 for freight in 1854. But in the latter years most of the machines which were sold were combined reapers and mowers, and they were priced at \$155 in addition to the cost of transportation.

This compares with David's prices of \$124 and \$138 [6]. Furthermore,

> In the partnership contract with O. M. Dorman for the harvest of 1850, it was agreed to sell for \$120 in Ohio and Missouri, for \$105 along the Erie Canal, \$115 in Illinois. In other words, the company paid the freight of \$4 or \$5 by boat to Buffalo, and charged the

New York farmer $10 less than the Chicago price. Reapers were also sold in New York and Philadelphia on Chicago terms as late as 1855.

By concentrating on McCormick's sales we also create another problem. During this entire period, McCormick sold about one-quarter of all reapers in the country [12, p. 326]. We should therefore consider the price at which others were selling their machines. In the late 1840s Esterly asked $225 for his header; in the 1850s Manny asked $300 for his combined reaper-mower. See [11, pp. 313-32]. Anderson [1, p. 120] writes,

> The prices at which the machines sold varied but usually ranged from about $125 to $175 for reapers, with time payments in part. Headers sold for about $300.

24. For some times and places, this may be too low.

> That cradling was considered an art is evident from the fact that cradlers received better pay than ordinary farm hands. In some communities cradling was almost a trade by itself and a good cradler could demand and would receive two or three times as much pay as common laborers.

See "McCormick Reaper Centennial Source Material", p. 20, as reported in [11, p. 77].

25. The following is summarized from [19, pp. 133-38]. Reports from the 1830s indicate that harvest hands in Ohio received between 50 cents and 74 cents per day. Reports from Indiana and Michigan roughly coincide for these early years and extend into the 1840s. However, harvest wages in Illinois were higher. Morris Birkbeck hired harvest hands for 75 cents per day in the 1820s and John Mason Peck reported that cradlers received $1.50 to $2 per day in the 1830s. All this suggests that wages would have been higher on the frontier, as farm labor would not be in sufficient supply. Unfortunately for reaper manufacturers, the farmers in these areas would also lack the cash necessary to purchase a reaper. All reports indicate that day harvest rates rose rapidly in the late 1840s and early 1850s. In 1846 harvest hands in Indiana received $1.25 per day. Ten years later rakers received $1 per day, binders $1.50, and cradlers $2.50. Rumor suggests some cradlers received as much as $3 per day. Wages in Illinois also rose. Fred Gerhard [10, p. 296] reports $1.25 was paid for binding and shocking hands, while $1.50 per day was paid to stackers. In 1856 Matthew T. Scott paid harvest hands $1.25 per day, and two years later the *Chicago Democrat* reported harvest wages of $2.50 and $3 per day.

26. David also provides a threshold based on monthly wage rates that were 27 percent lower than the daily wage, but he suggests that it is more likely that the reaper would replace day

laborers [6, p. 37]. To that should be added Schob's finding that workers were often hired by the month to guarantee that they would be available during the harvest season. Schob [20, pp. 139-40] provides several examples:

> Competition for harvest hands became keen, a fact which both employer and employee recognized. Farmers therefore hired hands early in the season and agreed in advance to alter the monthly wage rate during the harvest months as an added incentive for reliable work and as an inducement to stay on the farm.

27. See also [12, pp. 362-63],

> When the agent sold a reaper he was expected to secure the signature of the farmer on a printed sales form stipulating that he would make a first payment when he received the machine, and remit the balance on December 1, with interest at 6% from July 1. Salesmen wrote to the company, complaining that rivals did not require so much formality and that many farmers were loath to bind themselves in this way. In fact, the regulation seems to have been honored as much in the breach as in its observance, for the correspondence reveals that frequently no cash was paid when the reaper was delivered and only after the harvest had begun did the agent go from purchaser to purchaser to secure their signatures to reaper notes.

28. See [13, p. 74]. It should be noted that the ratio of outstanding debt to sales at the end of each year was very low until the panic of 1857. See [12, p. 369].

29. Danhof in [5] quotes the editor of *Rural New Yorker* Vol. 12 (1861), p. 382, and Vol. 13 (1962), p. 390, who writes that a well-cared-for machine "should last at least eight years," but because of neglect, the average life was only two years. Consider what that would do to our threshold!

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