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Piece rates and learning: understanding work and production in the New England textile industry a century ago

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Piece rates and learning: understanding work and production in the New England textile industry a century ago.[1]

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Abstract

New data on individual worker's outputs show that New England ring spinners exhibited substantial on the job learning c. 1905. Despite this, variable capital-labour ratios meant high labour turnover reduced aggregate labour productivity only fractionally. The combination of variable capital-labour ratios and piece rates meant low average experience levels did not raise unit costs. This made firms willing to hire all comers, so immigrants readily found work. Equally firms were indifferent to labour turnover, so female workers could move between home and market work. As such piece rates were as an appropriate and successful labour market institution for this period.

[1] I would like to thank Dudley Baines, Jim Bessen, Jane Humphries, Mary Mackinnon, Bob Margo, Cristiano Ristuccia, Mark Stern, Joachim Voth and conference participants at seminars at the London School of Economics, the University of Oxford and the University of Cambridge and conference participants at the Business History Conference, Economic History Association and Economic History Society for helpful comments. The data collection was funded by grants from the Economic History Association's Arthur H Cole Grant-in-Aid, Department of Economics, Royal Holloway College, University of London and the Pasold Fund for textile research. I would particularly like to thank John Geoffrey Walker for designing a data input program that trebled my labour productivity in the archives, and the staff in Harvard Business School's Baker Library Historical Collections for their help with the records.

Introduction & literature

Economists' and economic historians' interest in worker learning goes back at least to Wright's article on airframe building, and to Arrow's theoretical paper, setting out a model in which productivity gains are a by-product of worker experience.[2] More specifically there is a large literature that looks at productivity in the New England textile industry before the Civil War. This is the period in which the earliest workforce – the daughters of Yankee farmers – was replaced by a permanently changing immigrant labour force.[3] The earliest works characterise this as a period of social and economic decline, arguing that 'the semi-idyllic conditions of the early New England cotton-mill have given way to a system brutalized by greed and the exigencies of modern industry', and moreover one in which productivity fell.[4] Davis and Stettler showed that whatever the social effects, productivity in fact increased in this period, despite what most previous historians had seen as a decline in labour quality. Davis and Stettler ascribed this to machinery improvements, such as the replacement of gears with belt drive.[5] David argued that job duration, as opposed to initial levels of conventionally-measured human capital was more important in the determination of labour productivity and, as such, the replacement of educated but short-staying Yankee women with less-educated but longer staying Irish immigrants represented a rise rather than a fall in human capital, and as such explains the rise

[2] T. P. Wright, "Factors Affecting the Cost of Airplanes," *Journal of the Aeronautical Sciences* 3 (1936).,Kenneth J. Arrow, "The Economic Implications of Learning by Doing," Review of Economic Studies (1962).

[3] Thomas Dublin, *Women at Work: The Transformations of Work and Community in Lowell, Massachusetts, 1826-1860* (New York and Guildford: Columbia University Press, 1979)., chapter 8.

[4] Annie Marion MacLean, *Wage-Earning Women*, ed. Richard T. Ely, *The Citizen's Library* (New York: The Macmillan Company, 1910)., p. 11, Edith Abbott, Women in Industry: A Study in American Economic History (New York and London: D. Appleton and Company, 1910)., pp. 143, Caroline F. Ware, *The Early New England Cotton Manufacture: A Study in Industrial Beginnings* (Cambridge, MA: The Riverside Press, 1931)., p. 232.

[5] Lance Davis, and Stettler, Louis, "The New England Textile Industry, 1825-60: Trends and Fluctuations," in *Output, Employment and Productivity in the United States after 1800*, ed. NBER (New York: Columbia University Press, 1966)., p. 230.

in productivity in this period.[6] This finding was strengthened by Lazonick and Brush, who showed that Lowell cotton workers' experience was an important determinant of labour productivity, in line with Saxonhouse's work on cotton spinners in Japan.[7] Nickless found evidence instead of rising capital to labour ratios, leading her to question the emphasis on skill formation.[8] This circle has been neatly squared by Bessen, who argues that it was because of greater levels of worker experience that mills could increase the capital labour ratio – the nature of learning was the ability to control more machinery.[9]

This plethora of material looking at productivity prior to the civil war contrasts with a drought of equivalent material for the period of industrial maturity. But whilst economic history may have neglected later New England cotton workers, social history has done better. Hareven's *Family Time and Industrial Time* looked at the interaction of family and market work for those working at the Amoskeag cotton mill, in Manchester, New Hampshire.[10] She found that a mill worker's 'typical career was short and punctuated by frequent interruptions.'[11] Just seven percent of workers had continuous careers of one year or more, sixty percent worked for less than one year in total, and thirty-three percent had over one year of total service, but with breaks.[12] Women were less prone to short-lived careers than men, and married women were more likely to have extensive careers, albeit ones characterised by often lengthy breaks in

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[6] Paul A. David, "The "Horndal Effect" in Lowell, 1934-1856: A Short-Run Learning Curve for Integrated Textile Mills," Explorations in Economic History 10 (1973).
[7] William Lazonick, and Brush, T, "The 'Horndal' Effect in Early US Manufacturing," *Explorations in Economic History* 22 (1985)., Gary R. Saxonhouse, "Productivity Change and Labor Absorption in Japanese Cotton Spinning 1891-1935," Quarterly Journal of Economics 91 (1977).
[8] Pamela J. Nickless, "A New Look at Productivity in the New England Cotton Textile Industry, 1830-1860," *Journal of Economic History* XXXIX, no. 4 (1979).
[9] James Bessen, "Technology and Learning by Factory Workers: The Stretch-out at Lowell, 1842," *Journal of Economic History* 63, no. 1 (2003)., pp. 6-9
[10] Tamara K. Hareven, *Family Time and Industrial Time: The Relationship between the Family and Work in a New England Industrial Community* (Cambridge, UK: Cambridge University Press, 1982).
[11] Ibid., p. 234.
[12] Ibid., p. 242.

service.[13] Hareven argues that the ready availability of work meant that 'many married women shuttled back and forth between the workplace and home', treating the mill 'as a kind of home base'.[14] In effect, the opportunity cost of time in the mill was domestic output forgone at home, and the opportunity cost of time at home was income forgone from not working in the mill. Nelson shows that Hareven's picture of high rates of labour turnover is representative of the American cotton industry more generally, with southern cotton firms having even higher rates of turnover.[15]

This paper proceeds as follows. We first describe the new data set of individual ring spinners wages that have been assembled. We then use the data set to show that workers' earnings did increase over time, and that this increase was caused by learning rather than by poor workers leaving the mill more quickly than the more able. We then look at the situation from the point of view of workers, showing that all workers who stayed on the job were able to learn, and to end up with similar, relatively high, levels of productivity. We show that while workers ended up with similar levels of productivity, their initial earnings in the mill were more varied. We use data derived from the Census to show that workers' initial earnings were positively but not perfectly correlated with their age, and argue that many older workers had prior experience of ring spinning. We reinforce this interpretation by showing that workers who took a break from ring spinning at this mill maintained their previous level of earnings on their return. Next we look at the situation from the point of view of the Lyman Mill. We show that the company varied the amount of capital given to workers according to their experience. As a result of this and the use of piece rates, the mill ensured that unit costs were unaffected by the levels of experience in the workforce at any time: put simply, the mill could replace one experienced worker

[13] Ibid., pp. 245-7.
[14] Ibid., pp. 198, 241.
[15] Daniel Nelson, *Managers and Workers: Origins of the Twentieth-Century Factory System in the United States, 1880-1920*, second ed. (Madison, Wisconsin: The University of Wisconsin Press, 1995)., p. 85.

with two inexperienced ones, giving each one half the number of machines and one half the pay that would be given to an experienced worker. We also run simulations of the effect on labour productivity at the Mill of both lowering quit rates to British levels, and raising them to those of the US South. Neither causes substantial changes in productivity, reflecting the fact that many of the new hires were, in fact, experienced ring spinners. We conclude with a discussion about the appropriateness of piece rates and a liberal hiring policy for immigrant female workers. We argue that this combination was appropriate for this labour force, since it meant that work was readily available, and that firms had no objections to workers moving between market and domestic work, but that it would not have been successful in the earlier era in which the workforce was made up of young Yankee women, who needed high initial earnings to cover the cost of living away from home.

Data

The data are drawn from the records of Lyman Mills, and cover the period 1903-1912. Lyman Mills was a large, integrated cotton textile firm, located in Holyoke, Massachusetts, a town associated as much with paper as with cotton, and today more famous as the birthplace of volleyball.[16] Following earlier unsuccessful cotton ventures, the Lyman corporation was founded in 1854, and expanded repeatedly in 1872, 1882 and 1891. Lyman Mills produced a wide range of goods, from coarse sheetings and heavy yarns to fine lawns and fancy goods. The company began to shed labour after the First World War, as machinery replaced workers. Still profitable, it entered liquidation in 1927, with the loss of 1050 jobs.[17]

Holyoke was notable for large-scale immigration. In 1900 41.4% of the population was foreign born, a figure exceeded by only seven other towns in the

[16] Constance McLaughlin Green, *Holyoke, Massachusetts : A Case History of the Industrial Revolution in America*, *Yale Historical Publications Miscellany* (New Haven: Yale University Press, 1939)., p. 227.
[17] Ibid., pp. 38, 56-65, 77, 238.

United States.[18] The first group to arrive in large numbers were the Irish, who were numerically overtaken by French Canadians by 1880. By 1900 these two groups remained the most important immigrant communities, but were supplemented by substantial numbers of Russians and Poles, as well as by Germans and Austrians.[19] The names on the payroll records show that Irish, French, Canadian and Slavic workers were well represented in the Lyman Mills. After the mule spinners were victorious in their protracted 1902/3 strike, there were no further strikes by any workers until 1916, with the mill following the lead of other more major textile centres in adjusting wages, a method of setting wages accepted by both sides.[20]

The surviving records of the Lyman Mills are extensive and include the payroll ledgers. There were ring spinners in more than one building, and each building kept its own records. Ring spinners in Mill One, which produced weft yarn, were paid piece rates, while those in other buildings, responsible for producing warp yarn, were paid day rates. Unobservable characteristics – notably yarn strength – are more important for warp yarn. The dataset collected for this paper covers those ring spinners paid piece rates. For these workers, the weekly payrolls give the spinner's name, hours worked, amount produced, rate paid per unit of production, and actual earnings, which equal output multiplied by the rate per piece, rounded to the nearest 5c. In total over 14,000 individual weekly observations were collected.[21]

Workers were paid different rates according to the count of yarn spun, with, for example, workers using waste cotton paid a higher rate per hank. The pay rate sheets, giving the rate of pay for different categories of yarn, survive only for two dates, May 20, 1907 and March 30, 1908.[22] These are, however, sufficient to rule out the possibility that different rates per worker reflect

[18] Ibid., p. 368.
[19] Ibid., p. 367.
[20] Ibid., p. 237.
[21] The payroll records held in Harvard Business School, Baker Library, Historical Collections, as Series LX and LAB in the Lyman Collection.
[22] Harvard Business School, Baker Library, Historical Collections, Lyman Collection, LO-1

different machine vintages or that more experienced workers were paid more per piece, perhaps to cover some sort of supervision of less experienced staff. The data also prove both possibilities false: the number of different piece rates varied over time, eliminating the possibility that piece rates were related to machinery vintages, and there is no correlation between worker experience and the rate paid per piece to that worker.

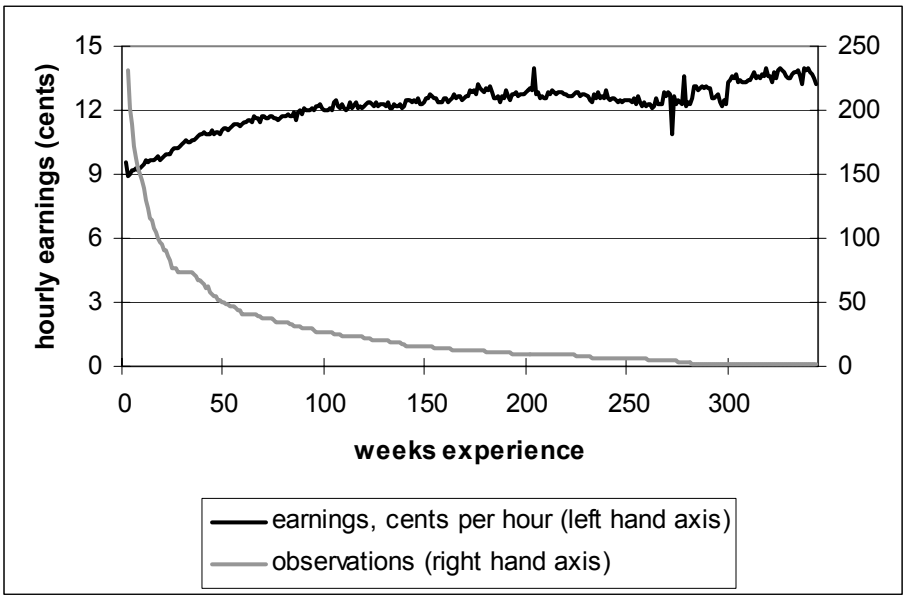
We know, therefore, that a wide variety of yarns were produced, both in any one week, and over time, but, except for one week in May 1907 and one in March 1908, we do not know the count of yarn to which each piece rate refers. We clearly cannot use the unadjusted quantity of yarn produced as a measure of a worker's productivity, since we know that different yarns required different labour inputs. Rather than using the workers' physical products, therefore, we use instead their 'revenue product', that is, output multiplied by piece rates. Revenue product can be contaminated by inflation, giving an upward or cyclical bias to any estimate of learning. The payroll records show that average hourly earnings rose in 1907, falling back thereafter, before rising again in 1911-12. Although it is possible, it is unlikely that workers were more productive in these periods. Green, in fact, notes that there was a short-lived wage rise early in 1907, withdrawn the following year, and the wage rates are higher for May 1907 than March 1908.[23] To avoid contaminating our productivity estimate with inflation, we deflate each worker's hourly earnings by the average revenue product for that week. This will eliminate inflation, but it also means that if in one week the workforce was more experienced than on average, with higher productivity, that additional productivity will be deflated away. This biases our learning by doing estimates downwards, although the magnitude is unlikely to be large.

[23] Green, Holyoke, Massachusetts., p. 237; Harvard Business School, Baker Library, Historical Collections, Lyman Collection, LO-1

Did learning by doing exist?

Figure 1 plots productivity, as measured by workers' deflated average revenue products, against experience. It shows that experienced workers produced more than inexperienced ones. Broadly speaking output increases from 9c per hour to 12c per hour over the first two years, with no significant learning beyond that point.[24]

Figure 1: Did experience matter?



There are two ways in which experience could be correlated with higher productivity. First, if workers learned on the job, experienced workers would have had higher output than inexperienced workers. We call this the learning hypothesis. Second, workers may have had innate but heterogeneous abilities as spinners uncorrelated with their abilities at other jobs. Less able and less well-paid workers would then have been more likely to quit. As a result experienced workers would have had higher productivity than new workers, because the former are a more productive subgroup of the latter. We call this the sorting hypothesis. The two hypothesis are not mutually exclusive: it would be possible

[24] Note also that sample size becomes very small when looking at very long service workers – there are, for example, only nine workers with more than four years service.

both for all workers to have learned on the job, and for the less able workers to have been more likely to quit.

Figure 1 shows that productivity rose with experience, so we know that at least one of these two hypotheses must be true. It does not, however, allow us to tell whether all workers were learning, poor workers were quitting, or both. Instead we distinguish between learning and sorting as follows. First, we divide workers joining the firm from 1904 onwards into four groups according to final job duration. The first group contains all workers who left with between 11 and 25 weeks service (53 workers), the second those who left after 26-50 weeks (27 workers), the third those who left after 51-100 weeks (22 workers) and the fourth those with more than 101 weeks service (27 workers). To test for learning, we take each group and examine their productivity over time within the period in which no worker left, that is to say we look at weeks 1-10 for the first group, weeks 1-25 for the second group and so on. Since no worker in each group left in the period under consideration, the sorting effect is eliminated: if average productivity in each group rose over time it can only be that the productivity of individual workers rises with experience (see figure 2a). For sorting, we look at the productivity of each group in the first ten weeks. If the sorting hypothesis were true, high initial earnings would be a good predictor of job duration (figure 2b).

The plot of productivity over time for workers within each equal-duration group, given in figure 2c, shows that workers did learn over time – although there is an initial fall for the first couple of weeks, all groups show evidence of learning thereafter. In contrast, figure 2d shows that there is no evidence for sorting: higher initial earnings do not predict longer job duration.

Figure 2a: Learning

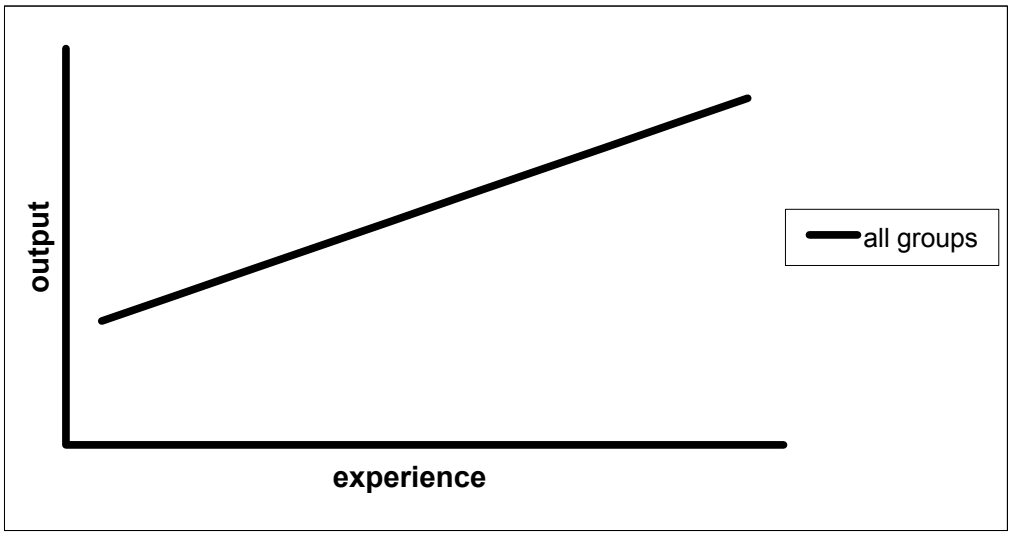


Figure 2b: Sorting

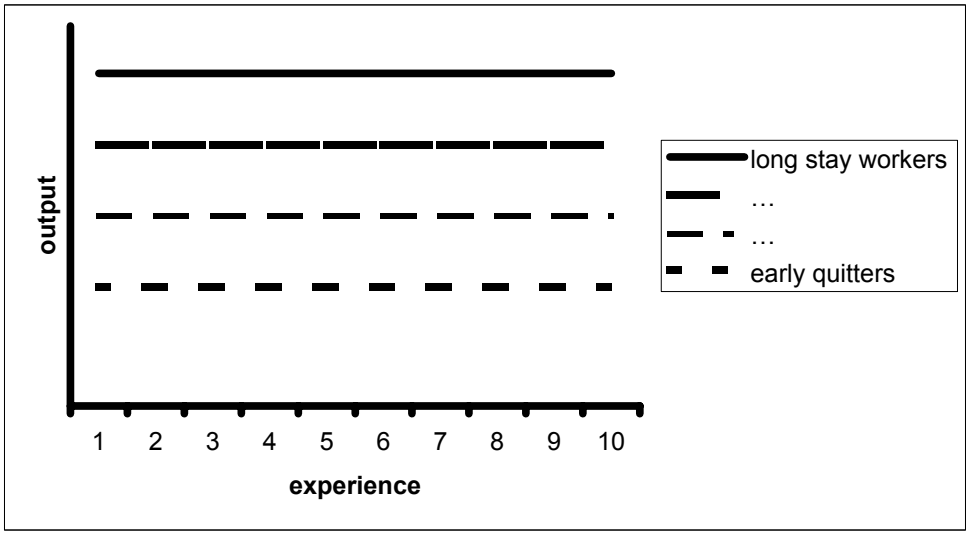
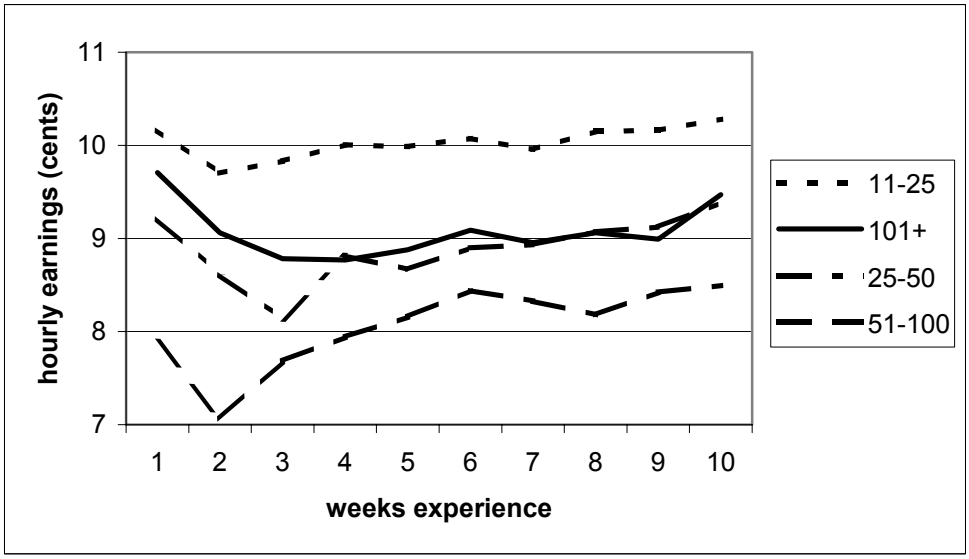


Figure 2c: Evidence for learning

Figure 2d: Evidence against sorting.



Learning and piece rates from workers' perspectives

In the previous section we showed that on the job learning means that, on average, workers increased their productivity and earnings in their first two years working as ring spinners. We also found no evidence that some workers did not

learn and therefore quit the mill. It may be, however, that some workers did not learn but decided to remain as ring spinners. This would be rational if low ability at ring spinning was correlated with low ability at other jobs. It was economically feasible for the firm to tolerate non-learning workers since the firm paid piece rates. The mill therefore had no incentive to replace workers who did not improve, and could instead allow them to continue in a 'low productivity – low wage' equilibrium. In this section we test whether it is the case that all workers learned, or whether the average learning trajectories given in figures 1 and 2c hide a group who did not, in fact, improve their productivity over time.

In order to do this, we look at workers individually. Figure 2c showed that there were no differences in learning experiences between different groups of workers, as divided by job duration. In this section, therefore, we limit ourselves to looking at the 27 long stay workers with two years' experience, to allow us to look at the full learning process. For each individual, we first regress productivity over time on experience alone, to test whether productivity did in fact rise over time for each worker. Experience was significant for 21 workers but, as table 1a shows, there were six workers for whom it was not an important determinant of productivity. In four of the cases the co-efficients are either wrongly signed or insignificant, while in two further cases the co-efficients are trivially small, predicting productivity rises of just 3% a year. In all six cases, the R^2 is less than 0.1.

Table 1: The determinants of output - individual workers.

1a – Workers who do not learn (dependent variable – worker output, cents per hour)

Worker	Jennie Crounnie	Amelia Kagon	Josefa Psystas	Julia Sydlo	Josefa Szydlo	Julia Wilk
Experience	-0.0034	-0.0046	0.0017	0.0076	-0.0046	0.0073
	(-1.9)	(-1.8)	(0.6)	(2.4)	(-2.3)	(3.2)
Experience^2						
Intercept	13.79	10.76	10.92	11.99	13.44	11.48
	(126.3)	(73.8)	(70.8)	(64.8)	(112.2)	(86.3)
Adj R2	0.03	0.02	-0.01	0.04	0.04	0.09
SE	0.49	0.70	0.73	0.92	0.57	0.64
F	3.4	3.4	0.4	5.8	5.1	10.1
N	89	97	95	104	94	96
Omitted weeks	0	1	0	0	0	0
Initial earnings	13.79	10.76	10.92	11.99	13.44	11.48
after one year	13.62	10.53	11.01	12.37	13.21	11.85
% rise from initial	-1%	-2%	1%	3%	-2%	3%
after two years	13.44	10.31	11.09	12.75	12.97	12.22
% rise from initial	-2%	-4%	2%	6%	-3%	6%

1b – Workers who do learn (dependent variable – worker output, cents per hour)

Worker	Amelia Cyapik	Antonia Czahur	Agnes Gows	Josefa Gows	Kate Gows	Franciska Guzdek	Honata Hanasiak	Anna Kacur	Sophie Kalisz	Mary Klekot	Mary Kopoc
Experience	0.026	0.145	0.169	0.073	0.212	0.116	0.038	0.062	0.146	0.103	0.092
	(11.4)	(15.3)	(15.6)	(24.8)	(15.5)	(10.0)	(9.5)	(4.7)	(14.8)	(8.0)	(5.9)
Experience2		-0.00084	-0.0010		-0.0016	-0.00080		-0.00038	-0.00097	-0.00031	-0.00062
		(-9.2)	(-9.7)		(-11.8)	(-7.4)		(-3.0)	(-10.1)	(-2.5)	(-4.2)
Intercept	10.08	6.39	5.67	8.48	5.06	6.22	7.86	8.83	6.30	6.56	8.19
	(76.3)	(31.6)	(23.8)	(50.6)	(16.7)	(24.0)	(34.0)	(30.7)	(29.4)	(23.4)	(23.8)
Adj R2	0.57	0.88	0.89	0.86	0.81	0.68	0.47	0.41	0.83	0.83	0.44
SE	0.66	0.66	0.72	0.86	0.93	0.77	0.86	0.87	0.71	0.93	1.06
F	128.9	376	394.5	614.1	206.49	99.9	138.0	33.0	248.2	261.3	38.4
N	99	100	98	98	96	99	101	92	101	108	97
Omitted weeks	0	0	2	1	0	2	0	1	0	1	1
Initial earnings	10.08	6.39	5.67	8.48	5.06	6.22	7.86	8.83	6.30	6.56	8.19
After one year	11.39	11.52	11.55	12.14	11.78	9.95	9.76	11.01	11.15	10.94	11.25
% rise from initial	13%	80%	104%	43%	133%	60%	24%	25%	77%	67%	37%
After two years	12.70	12.43	12.62	15.79	10.70	9.83	11.66	11.29	11.14	13.76	11.20
% rise from initial	26%	94%	123%	86%	111%	58%	48%	28%	77%	110%	37%

Worker	Apolonia Krul	Agnes Lalack	Mari Lukais	Bronislaw Ostrasky	Ozolzy Papuzysky	Mary Rokovsky	Anida Sokolovsky	Franciska Sokolovsky	Flora Sroka	Helena Stabak
Experience	0.140	0.116	0.033	0.063	0.017	0.083	0.080	0.053	0.040	0.138
	(14.4)	(13.7)	(14.1)	(22.7)	(8.4)	(8.1)	(7.0)	(5.8)	(9.7)	(23.1)
Experience2	-0.00098	-0.00081				-0.00034	-0.0004	-0.00033		-0.00086
	(-10.5)	(-10.1)				(-3.5)	(-3.8)	(-3.7)		(-14.8)
Intercept	6.19	7.40	9.04	7.04	11.37	6.84	8.41	9.52	8.84	5.92
	(28.4)	(39.4)	(68.7)	(43.6)	(97.6)	(29.2)	(34.4)	(47.8)	(36.0)	(46.0)
Adj R2	0.78	0.79	0.68	0.85	0.42	0.79	0.67	0.50	0.50	0.93
SE	0.72	0.56	0.66	0.76	0.56	0.70	0.79	0.62	1.18	0.42
F	195.5	185.6	197.4	515.5	71.1	192.7	97.1	45.8	94.1	708.4
N	109	101	94	90	96	104	94	91	95	101
Omitted weeks	0	2	1	1	0	2	3	0	0	0
Initial earnings	6.19	7.40	9.04	7.04	11.37	6.84	8.41	9.52	8.84	5.92
after one year	10.74	11.13	10.65	10.19	12.21	10.10	11.34	11.35	10.86	10.64
% rise from initial	74%	50%	18%	45%	7%	48%	35%	19%	23%	80%
after two years	10.38	10.96	12.26	13.34	13.04	11.70	12.19	11.53	12.88	11.04
% rise from initial	68%	48%	36%	90%	15%	71%	45%	21%	46%	86%

For the remaining 21 workers we include experience squared where it is statistically significant. Table 1b shows that, for the 21 workers for whom experience mattered, it was both a significant and important determinant of productivity. Table 1b does, however, show sizeable variations in learning. While it could be that workers had different abilities as spinners or as learners, closer inspection of the data suggests otherwise: those with low rates of learning had high initial earnings. Thus the six 'non-learning' workers in table 1a have six of the seven highest initial rates of productivity. The remaining worker in the top seven by initial earnings, Ozolzy Papuzysky, had the lowest rate of learning of the 21 learners. This intuition can be tested more formally by regressing the rise in output over two years, measured in cents per hour, on initial earnings, also measured in cents per hour. Table two shows that low initial earnings were a very good predictor of high rates of earnings growth for the 21 workers listed in table 1b. It is worth noting that the estimated co-efficient of -0.83 is not statistically different from -1 at the 5% level of significance. It appears, therefore, that earnings were a target-seeking variable, so that any shortfall in initial earnings would be fully compensated for by additional learning, with all workers ending up with identical high productivity-pay equilibriums.

Table 2 Do initial earnings explain the extent of learning?

Dependent variable	2 Increase in earnings (cents per hour)
Initial earnings	-0.84****
	(-8.3)
Intercept	10.65****
	(11.8)
Adj R^2	0.72
SE	1.25
F	69.1
N	27

**** significant at 0.1% level

We can explain heterogeneous rates of learning by heterogeneous levels of initial earnings. How then do we explain heterogeneous levels of initial earnings? The most plausible explanation is that some of the workers had prior experience of ring spinning, and had already undergone a period of learning. This would explain the inverse relationship between high initial rates of productivity and low on-the-job learning. We cannot tell from our dataset what jobs, if any, the workers in our sample had held previously. We can, however, use the 1910 Census to find out more information about a handful of workers. Every entry in each of the two enumeration districts closest to the Lyman Mills were checked against a list of all ring spinners starting in the Lyman Mills from 1904 onwards.[25] This yielded twenty-two matches. In addition the names of all workers identified in the Census as cotton spinners in the remaining 30 enumeration districts in Holyoke were checked against the same list, although this did not yield any additional names.[26] Finally, every name on the list of workers was searched for using the Ancestry.com genealogy search engine, yielding one additional match. For the twenty-two workers identified in the Census we know their ages, whether they were native born, whether they were literate and whether they spoke English. In addition, we can calculate how long they had been in the United States when they began work in the mill. These variables were regressed on initial earnings. As equation 3a shows, neither being native born nor a new arrival, nor being able to read, write, or speak English affected initial earnings at any level of statistical significance. In contrast age was a statistically significant and important determinant of initial productivity. Equation 3b re-estimates equation 3a excluding the insignificant variables, and including the additional worker identified from the genealogy search engine.

[25] The 1910 Census is available online at Ancestry.com. Enumeration districts 561 and 562, Hampden County, Massachusetts.
[26] Enumeration districts 547-578

Table 3 Do worker characteristics explain initial earnings?

Dependent variable	3a Initial earnings (cents per hour)	3b Initial earnings (cents per hour)
Age	0.34****	0.31****
	(4.1)	(4.7)
Native born	-0.1	
	(0.1)	
New Immigrant	0.1	
	(0.1)	
Able to read	0.14	
	(0.1)	
Able to write	2.44	
	(1.1)	
English speaker	0.64	
	(0.4)	
Intercept	-1.1	1.67
	(0.4)	(1.1)
Adj R^2	0.52	0.49
SE	2.25	2.32
F	4.9	21.9
N	22	23

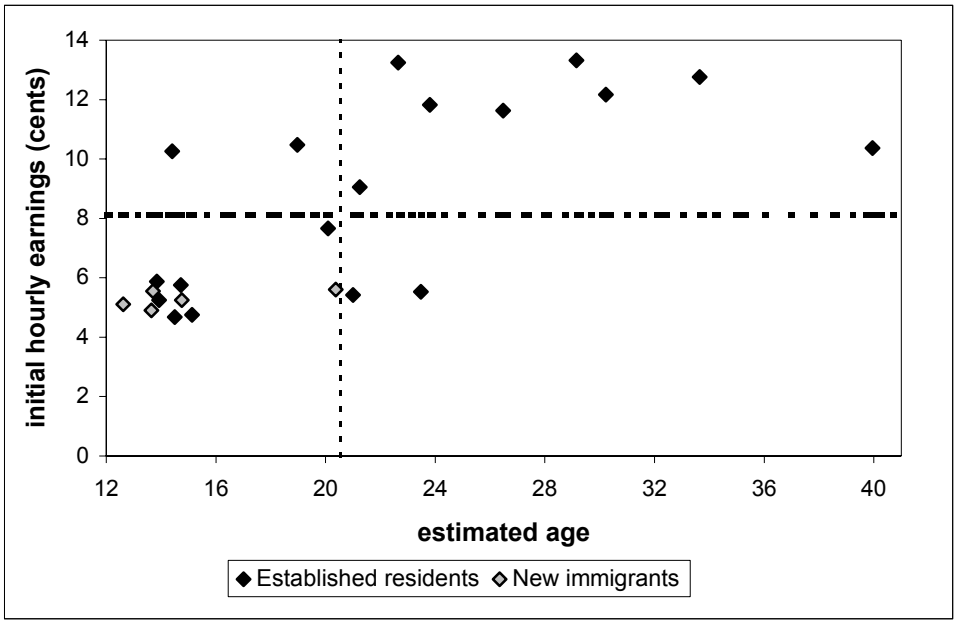
**** significant at 0.1% level

Notes: "New immigrant" is a dummy variable taking the value one if the worker had been in the US for one year or less on starting work.

Table 3 shows that older workers had higher levels of initial earnings. We argue that the most plausible explanation is that older workers had, on average, higher levels of previous experience as ring spinners than did younger workers. The alternative hypothesis is that the Lyman Mills paid workers according to a seniority system. A plot of initial earnings against age, given as figure three, rejects this hypothesis. Two of the thirteen workers younger than average had higher than average initial earnings, while two of the ten workers older than average had lower than average initial earnings. So, for example, whilst most workers starting work aged younger than 16 had initial earnings close to 5.3 cents per hour, one fourteen year old started at the Lyman Mills on 10.3 cents per hour. This is not consistent with age related pay rates, but is consistent with the productivity model put forward here, if a few younger workers had prior spinning experience. In addition, as figure 3 shows, all five of those starting work within

one year of immigration – who we can be fairly sure had no or limited experience spinning – earned low and similar wages, irrespective of age.

Figure 3: The distribution of workers' initial earnings by age.



Notes: The Census gives the age in whole years, rather than the actual date of birth. We therefore add six months to that age to give the estimated actual age on census day. We add to that the number of days elapsing between the Census and starting work to give the estimated age on starting work.

New immigrants are workers who lived in the US for up to one year prior to starting work, established residents are those who lived in the US for more than one year prior to starting work.

The finding that age is a good explanator for initial earnings implies that ring spinning skills are transferable from place to place. This in turn implies that these skills did not atrophy with time taken out of the labour market. We can use our data to test this hypothesis. If workers were able to retain prior levels of productivity after breaks in service, we should see that workers returned to the Lyman Mill at their previous levels of earnings after a period away from the mill. The Lyman data allow us to test this econometrically, by looking at whether

weekly earnings were lower after a break in service. As before, we regress earnings on experience and experience squared, again using data covering all workers who joined the mill from 1904 onwards, although this time we include data for all weeks worked, rather than restricting ourselves to just the first two years at the mill. We include dummy variables for breaks of different lengths. Since we previously found that workers often recorded high levels of output in their first week on the job, we test whether workers earnings were lower in their second week back following a break in service.[27] Although the co-efficients appear sensible, the results are generally insignificant. Only the break of more than one year is significant even at the 10% level, and that result is based on a sample size of just three workers. Since none of the results are significant at the customary 5% level, we conclude that there is no evidence that breaks in service reduced productivity: ring spinning appears to be a skill that once learned, was not forgotten.

[27] We also tested for the effect on productivity in the first and fifth weeks after returning. None of the co-efficients was significant at the 10% level.

Table 4 The effect of breaks in service on productivity

Dependent variable	4 worker output (cents per hour)
Experience	0.035****
	(47.7)
experience squared	0.0001****
	(28.7)
1 week (N=524)	0.06
	(0.8)
2 weeks (N=70)	-0.03
	(-0.1)
3 weeks (N=18)	-0.28
	(-0.7)
4 weeks (N=12)	-0.25
	(-0.5)
5-10 weeks (N=18)	-0.27
	(-0.7)
11-26 weeks (N=17)	-0.72
	(-1.77)
27-51 weeks (N=7)	-0.79
	(-1.24)
>52 weeks (N=3)	-1.63*
	(-1.67)
Constant	9.3****
	(276.9)
Adj R^2	0.34
SE	1.69
F	447.7
N	8600

* significant at the 10% level, **** significant at the 0.1% level.

There is no single definition of what constitutes a skilled job and what constitutes an unskilled job. We have found that ring spinning has three notable characteristics. First, workers improved on the job, and did so for some considerable time, and to a considerable extent. We can value this investment in human capital using the standard method which states that a worker's investment in human capital is equal to the discounted difference between training and post-

training wages.[28] There are five workers who satisfy the twin conditions necessary: they had no prior experience and were employed for the entire learning period: Antonia Czahur, Sophie Kalisz, Mary Klekot, Bronislaw Ostrasky and Helen Stabak. The age at which these workers began spinning varied between 12 and 15, and three were new immigrants to the US. We can be fairly certain, therefore, that they joined the mill without prior ring spinning experience. In addition all five remained with the mill for two years allowing us to assess their investment in human capital over the entire learning period. Using the methodology outlined above the value of these workers' investments in human capital varied from a low of $76 to a high of $187, with an average of $120.[29] This seems plausible: using the same methodology, Bessen, for example, finds that the female weavers' human capital was worth $110 per person in 1845.[30] $120 was not a trivial sum in this period, and represented the equivalent of 24 weeks post-training earnings. Clearly ring spinners did have genuine and non-trivial skill levels.

That said, we find no evidence that any workers were unable to learn. We found no evidence of a group of workers who did not learn, and left the mill, and, for those who stayed productivity proved to be a target seeking variable, with all workers ending up broadly equally skilled. In addition, we have found that once learnt, the ability to spin does not appear to have been forgotten: none of the measures designed to capture the intuition that workers forgot how to spin when away from the mill were statistically significant.

Given that workers improved substantially over time, doubling their hourly output in their first two years of ring spinning, it is not correct to view ring spinning as simply unskilled. On the contrary, the skill appears to have taken

[28] Gary S. Becker, Human Capital : A Theoretical and Empirical Analysis, with Special Reference to Education, 3rd ed. (London: University of Chicago Press, 1993), pp. 30-33

[29] We use a discount factor of 5%.

[30] Bessen, "Technology and Learning.", table 1, without separations, expressed in 1905 $s for comparability, converted using John J. McCusker, "Comparing the Purchasing Power of Money in the United States (or Colonies) from 1665 to Any Other Year Including the Present" Economic History Services, 2001, URL : http://www.eh.net/hmit/ppowerusd/

two years to master fully. Equally, however, it is not true to think of ring spinning as skilled insofar as that implies that untrained workers were unable to produce any yarn, or that only some workers are able to become effective spinners. Ring spinning is a skill, but it is one that every worker could learn, and, once learnt, it does not appear to be forgotten. In that sense it is perhaps comparable in nature to riding a bike, driving a car, or learning to read. Workers could be certain when they began work as ring spinners that they would be able to master the task effectively, that the initial period of low productivity and low wages would last for a predictable time and that they would be able to take breaks from the mill without seeing their skills decline. These were desirable job characteristics for female immigrants in this period.

The effect of worker learning and job turnover on the Lyman Mill

The use of piece rates means that high rates of labour turnover did not alter the Lyman Mill's unit labour costs, since inexperienced, less effective workers were paid proportionately lower wages. But labour turnover can raise unit capital costs, if inexperienced workers use capital less efficiently than those with greater experience. The effect on capital productivity is determined by the nature of learning. Learning may mean that workers learn how to use a given piece of equipment more effectively, so that capital productivity rises in line with labour productivity. Alternatively, learning may allow workers to manage more capital equipment. In this case capital productivity would not increase with labour productivity: instead the firm could hire fewer but more experienced workers to tend a given stock of machinery. The qualitative literature makes clear that the latter is a more appropriate description of mill work.[31] It was not the case that experienced ring spinners increased output per spindle substantially, rather they were able to tend more spindles successfully. This generates three hypotheses for the factory as a whole. The higher the average experience of workers present in the mill in any week should be (a) positively correlated with

[31] Ibid., pp. 6-9

output per worker, (b) uncorrelated with factory output, which would be constrained by the amount of capital available, and (c) negatively correlated with employment: the firm would substitute one experienced worker for more than one inexperienced worker.

The Lyman data set allows us to test these hypotheses directly. We regress worker productivity per hour, mill output per hour and total hours worked in the mill (a measure of employment) on the average experience of workers in that week.[32] If, as predicted, experienced workers are given more capital we will find a positive relationship between worker output and experience, no relationship between factory output and experience, and a negative relationship between total hours worked and experience. Further the R^2 on the factory output regression will be close to zero. As table 5 shows, these expectations are all confirmed. Greater experience did increase labour productivity, did not alter capital productivity, and did reduce labour inputs. The co-efficients on average experience are significant at the 0.1% level in equations 5a and 5c, and the R^2 on equation 5b is trivially small. Worker learning did not affect capital productivity: when workers were inexperienced the firm simply hired more of them to ensure that output and capital productivity was maintained.

[32] We exclude weeks in which the mill was not running at full capacity, as management may have reduced capital-labour ratios (if the factory was short of orders, and management wanted to share out work), or increased capital-labour ratios (if the factory was short of workers). In addition we exclude data prior to 1905 as we are unable to assess worker experience levels prior to that date.

Table 5. The effect of experience on worker output, firm output and firm employment.

Dependent variable	5a Worker output (cents per hour)	5b Factory output (cents per hour)	5c Hours worked in factory
Average experience	0.060****	-4.26	-7.03****
	(10.2)	(-1.4)	(-6.5)
Intercept	7.76****	716.5****	2141.3****
	(21.6)	(3.8)	(32.6)
Adj R^2	0.30	0.004	0.15
SE	0.80	418	145.9
F	104.4	1.9	42.9
N	244	244	244

* = significant at 10% level, ** = significant at 5% level
*** significant at 1% level, **** significant at 0.1% level

As we noted earlier, the use of piece rates means that, by definition, high rates of labour turnover and worker inexperience cannot alter unit labour costs. We have now shown that, by varying capital to labour ratios, the firm was successful in ensuring that labour turnover did not depress capital productivity or raise unit capital costs. The only additional burden placed on the firm from high rates of turnover was the cost of hiring large numbers of workers each year. But so long as there was a ready supply of would-be workers – as was usually the case in an immigrant centre such as Holyoke – that cost was also low. In short, the firm was essentially uninterested in the experience-composition of its workforce, and hired labour simply as a factor of production, with one worker interchangeable for another, albeit not always at a rate of one to one.

We have now found that labour turnover did not lower unit labour costs, but did lower labour productivity. Our data show that the Lyman Mill hired 134 ring spinners per 100 employed per year, similar to the 125 hires per 100 employed per year reported by Nelson for the Amoskeag, another major New England cotton textile mill.[33] These figures were much higher than the

[33] Nelson, Managers and Workers., p. 85.

corresponding figure for Britain, 22, and much lower than that for the US South, 190.[34]

We now go on to simulate the effect of these different worker turnover rates on labour productivity at the Lyman Mills. To do this we first use regression analysis to estimate output according to experience at the Lyman Mills, effectively formalising figure one. Second, we calculate the average number of workers at each level of experience at Lyman Mill itself, and estimate equivalent numbers for mills in the US South and for the British Quarry Bank Mill. For each scenario we then multiply the proportion of workers at that level of experience by the output that such a worker obtained at the Lyman Mill, averaging the results to find average productivity. By doing so we simulate the Lyman Mill's productivity levels with job turnover rates prevalent in the US South and in Britain.

We calculate the effect of experience on productivity by regressing deflated revenue product on experience, measured in weeks.[35] To increase precision, we use data on actual hours worked, converted into average week equivalents, so that we avoid counting part weeks as full weeks. In light of figure one, we restrict our attention to the first two years, and include both experience and experience squared as explanatory variables: we expect to find a positive co-efficient on experience and a negative co-efficient on experience squared, since output increases with experience but at a declining rate. The co-efficients given in table 6 are as predicted, with experience rising by 25% in the first year, and 35% over the first two years, in line with a casual reading of figure one.[36]

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[34] Mary Rose, "The Gregs of Styal, 1750-1914: The Emergence and Development of a Family Business" (PhD, Manchester, 1977)., p. 115, Nelson, Managers and Workers., p. 85.

[35] We use data for workers who joined the mill from 1904 onwards, for whom we can be sure that we know their initial earnings. We exclude data for each worker's first week at work: workers earned on average substantially more in their first week than in subsequent ones. This indicates either that they were assisted, or, more likely, that they took over machines with partially finished bobbins for which they were paid on completion.

[36] The equation has a low adjusted R^2 value. To check that was not caused by the experience and experience squared functional form being too restrictive, we reran the equation using a set of 96 dummy variables, one for each level of experience. This imposes no restrictions on the nature of the learning curve. The overall R^2 for that specification was also 0.21, suggesting that our

Table 6. The determinants of output – all workers

Dependent variable	6 worker output (cents per hour)
Experience	0.059 ****
	(18.8)
Experience^2	-0.00028 ****
	(-8.0)
Intercept	8.89 ****
	(165.5)
Adj R^2	0.21
SE	1.85
F	844
N	6266
Predicted rise in one year	24.9%
Predicted rise in two years	34.9%

* = significant at 10% level, ** = significant at 5% level,
*** significant at 1% level, **** significant at 0.1% level

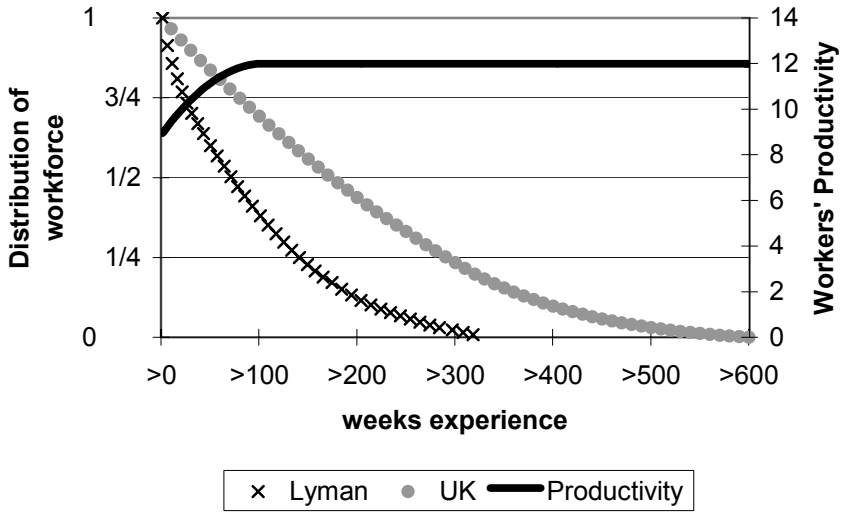
The Lyman payroll records give the mix of workers by experience. It is therefore a simple exercise to apply our estimate of earnings by experience to the known experience mix of Lyman workers, giving the average productivity of workers in that mill at a typical moment in time. For mills in the US South and at the British Quarry Bank Mill we know the proportion of workers who quit each year, but we do not know the distribution of workers by experience. For our simulations, we therefore increase the Lyman quit rate by 18% at all levels of service to give an annual turnover rate of 190 per 100 employed per year, the figure given by Nelson for the US South.[37] Similarly we reduce the Lyman quit rate by 76% at all levels of service to give an annual turnover of 22 per 100

specification is appropriate. Low R^2 for this sort of regression are not in fact unusual: even with 54 independent variables (and 1345 implicit variables) in their regression of output on experience and other items, Lazonick and Brush have an adjusted R^2 of 0.34. Lazonick, "'Horndal Effect'.", pp. 74-76.

[37] Nelson, Managers and Workers., p. 85.

employed per year, the British rate.[38] The longest service worker in our Lyman sample stayed for 351 weeks. We allow workers at Quarry Bank Mill to have job durations of up to 600 weeks, reflecting the lower rates of job turnover. Figure 4 gives the proportion of workers in the Lyman and Quarry Bank Mills who have at least a given amount of experience by the end of that week. (The figures for the US South were excluded for clarity, as they proved almost identical to the figures for the Lyman mills.) We can see from the graph that – inevitably – 100% of workers in both countries had at least 1 week's experience on the job. In contrast the proportion of British workers with 100 weeks' or more experience was approximately double the equivalent figure for the Lyman mills. Estimated average productivity, from equation six, is also given in figure four.

Figure 4: Distribution of workforce and worker productivity by experience



Combining the productivity and experience estimates in figure four gives the effects of different rates of job turnover on aggregate labour productivity at the Lyman Mill. Table 7 shows that the effect was very limited: had the Lyman Mills been able to reduce labour turnover to British levels, labour productivity would have increased by just five percent. Similarly, had labour turnover

[38] Rose, "Gregs"., p. 115.

worsened to levels prevalent in the US South, average labour productivity would have worsened by less than two percent.

Table 7. The effect of different labour turnover rates on labour productivity

Labour turnover rate as per:	Average productivity (cents per hour)
Lyman Mills	11.06
US South	10.91
UK (Quarry Bank Mill)	11.63

A number of factors explain this result. First, newly hired workers at the Lyman Mills, had, on average, almost three quarters of the productivity of workers with two years experience, reflecting the fact that many of the hires new to the Lyman Mills had previous experience of ring spinning.[39] This limits the effect of job turnover on productivity. Second, although US mills hired many workers each year, they also had many workers who stayed a long time. Thus although is it true that more than half of all workers employed in the Lyman Mills left within a month of being hired, it is also true that 60% of workers at the Lyman Mill at any given time had more than a year's experience on the job. Lyman Mill workers were divided into a core group of long stay workers, accounting for a high proportion of output and a low proportion of worker turnover, and a peripheral group of short stay workers who account for a high proportion of worker turnover and a low proportion of output. This is consistent with Hareven's finding for the Amoskeag mill.[40]

The mill as 'resource' – piece rates as an appropriate labour market institution.

Introductory economics teaches us that firms seek low unit costs and workers seek high wages. Although low unit costs may adequately characterise firms' aims in this labour market, the aims of ring spinners a century ago were, as we have shown, a little more complex. High wages were important, but two other

[39] Bessen, "Technology and Learning.", Figure 1.
[40] Hareven, Family Time and Industrial Time., pp. 240-244.

aspects of the job were also important: for immigrants, initial job availability and for female workers with domestic responsibilities, flexibility. A large number of potential workers in Holyoke, and other New England textile towns, were immigrants, or children of immigrants, often new to the city. One aspect of a 'good job' for them was one that was readily available, and for which no prior experience or qualifications were required. Mill work, including spinning, satisfied these criteria. Except in depressions would-be workers could expect to gain employment relatively quickly. No prior experience was needed, and firms routinely employed immigrants, and those who did not speak English. Further, we have shown that employers did not pay lower initial wages to immigrants, to the illiterate, or to those unable to speak English, and piece rates guaranteed them pay rises as and when they learned the job. Furthermore, prospective workers could expect to learn the skill successfully: we have found no evidence of a group of workers who did not learn, and instead found evidence that all prospective workers could expect to end up on wages of around twelve cents per hour.

We have already noted that ring spinners were, almost without exception, female, and, as Hareven notes, 'many married women shuttled back and forth between the workplace and home', juggling responsibilities at home and at work.[41] For these workers in particular, a job that one could leave and return to, if necessary time and time again, was highly desirable.[42] The ability to leave and return to work is usually a characteristic of unskilled work, where workers are interchangeable, one for another. Unskilled work, however, is poorly paid, creating a conflict for workers wanting both the wages that are only available to those with skills, and the flexibility that firms are reluctant to grant to those who embody expensive – and unrecoverable – training costs. The use of piece rates as the labour market relationship between ring spinners and the mill overcame this conflict, in two ways. First, firms did not pay for training: workers bore the costs

[41] Ibid., p. 198.
[42] One in seven of all workers had five or more breaks of service, Ibid., p. 242.

of learning through lower wages during the learning process. This meant that firms had no need or incentive to 'trap' workers seeking flexibility into long-term contracts. Second, by varying the capital to labour ratio, firms were able to make workers perfectly interchangeable, albeit not at a one-to-one ratio. As such, no worker became indispensable, and again, firms had no need or incentive to resist worker preferences for flexibility. It is worth noting that even in mills that did not use piece rates, ring spinners were paid according to the number of spindles tended. This had essentially the same feature as piece rates: inexperienced workers were given less capital and less pay, and as such management was indifferent to the experience composition of the workforce. So long as new workers were available, firms were indifferent to workers' job durations, and so had no reason to object to workers treating the mill as a resource, and shuttling back and forth between market and domestic work, as their needs changed.

This form of industrial organisation would have been unsuccessful in the "Waltham system" era in which the mills employed young Yankee women. These women, unlike later immigrants, needed to be persuaded to move to mill towns. That in turn required the promise of a reasonable standard of living as an incentive, which made a system based on low initial earnings inappropriate. Second, many of these women, unlike later immigrants, did not live close to the mill, and so they were unable to live at home while working in the mill.[43] The provision of company boarding houses was also needed to persuade parents that mill work was respectable for their daughters. If the mill charged the full cost of boarding houses to the workers, and paid the workers only their marginal revenue product, as under a piece rates system, there would be a serious chance that the cost of board would exceed the wages paid during their first weeks in the mill. Since the girls were credit constrained, this was not a possible equilibrium. Instead, mills in the Yankee era provided boarding houses, and paid day rates. In

[43] The homes of over 90% of female millhands employed by the Hamilton Manufacturing Company, Lowell, January-July 1836 were over 20 miles from Lowell. Thomas Dublin, Transforming Women's Work: New England Lives in the Industrial Revolution (Ithaca and London: Cornell University Press, 1994)., author's calculation from figure 3.3, p. 83.

effect the mill, rather than the worker, was paying the training costs. It then became important to the mill that the workers stayed a minimum length of time, so that the mill could re-coup its investment in worker training. To that end, the Lowell mills, for example, required workers to stay for twelve months as a condition of employment, and exhibited a positive preference for girls who came from far enough afield that it was hard for them to leave for home.[44]

This paternalistic system collapsed when young Yankee women were replaced by immigrants, because the incentives for firms and workers changed. Since they lived with their own families, immigrant workers did not need boarding house accommodation, or want the rules that went with it. Since 46% of them left within a year they did not want to be tied to twelve month contracts. Instead they were prepared to take the initial poverty that comes to the inexperienced under piece rates in exchange for the prospect of pay rises and the flexibility that the piece rate system offered them. Similarly Lyman Mills did not want to pay to train workers when those workers may well have left before the firm could recoup its investment. Both firm and worker preferred a system of pay equal to the marginal product, rather than a flat rate irrespective of experience and so the move in labour market institutions from paternalism to piece-rates was an appropriate institutional change.

Conclusion

We have shown that female ring spinners c. 1900 improved their productivity substantially through on the job learning in their first two years spinning. That in turn equipped them with a valuable skill that was both transferable to other employers, and which did not atrophy with time away from the mill. The use of piece rates meant that workers, not firms, paid for the skill formation. This in turn meant that firms were willing both to take on workers

[44] Elizabeth Faulkner Baker, Technology and Woman's Work (New York and London: Columbia University Press, 1964), p. 11, Ware, Early New England Cotton Manufacture., p. 215.

irrespective of their characteristics or previous experience, and to tolerate high levels of worker turnover. This was reinforced by the Lyman Mill's ability to vary the capital to labour ratio with the experience of the worker, so that unit costs were unaffected by labour turnover. The ready availability of work, payment according to output rather than literacy or nativity, and the ability to leave the mill and return later were important to female immigrant workers, who were both able to find work initially and to treat the mill as a resource, moving between home and mill according to their changing needs. As such, piece rates should be seen not only as an appropriate response to the needs of workers and employers in this era, but as an example of the way in which 'the competitive market ameliorates, not accentuates, the consequences of social prejudices.'[45]

[45] Claudia Goldin, *Understanding the Gender Gap: An Economic History of American Women*, ed. Robert W. Fogel and Clayne L. Pope, *NBER Series on Long-Term Factors in Economic Development* (New York and Oxford: Oxford University Press, 1990).

Bibliography

Abbott, Edith. *Women in Industry: A Study in American Economic History*. New York and London: D. Appleton and Company, 1910.

Arrow, Kenneth J. "The Economic Implications of Learning by Doing." *Review of Economic Studies* (1962): 155-73.

Baker, Elizabeth Faulkner. *Technology and Woman's Work*. New York and London: Columbia University Press, 1964.

Becker, Gary S. *Human Capital : A Theoretical and Empirical Analysis, with Special Reference to Education*. 3rd ed. London: University of Chicago Press, 1993.

Bessen, James. "Technology and Learning by Factory Workers: The Stretch-out at Lowell, 1842." *Journal of Economic History* 63, no. 1 (2003).

David, Paul A. "The "Horndal Effect" in Lowell, 1934-1856: A Short-Run Learning Curve for Integrated Textile Mills." *Explorations in Economic History* 10 (1973): 131-50.

Davis, Lance, and Stettler, Louis. "The New England Textile Industry, 1825-60: Trends and Fluctuations." In *Output, Employment and Productivity in the United States after 1800*, edited by NBER, 213-42. New York: Columbia University Press, 1966.

Dublin, Thomas. *Transforming Women's Work: New England Lives in the Industrial Revolution*. Ithaca and London: Cornell University Press, 1994.

———. *Women at Work: The Transformations of Work and Community in Lowell, Massachusetts, 1826-1860*. New York and Guildford: Columbia University Press, 1979.

Goldin, Claudia. *Understanding the Gender Gap: An Economic History of American Women*. Edited by Robert W. Fogel and Clayne L. Pope, *NBER Series on Long-Term Factors in Economic Development*. New York and Oxford: Oxford University Press, 1990.

Green, Constance McLaughlin. *Holyoke, Massachusetts : A Case History of the Industrial Revolution in America*, *Yale Historical Publications Miscellany*. New Haven: Yale University Press, 1939.

Hareven, Tamara K. *Family Time and Industrial Time: The Relationship between the Family and Work in a New England Industrial Community*. Cambridge, UK: Cambridge University Press, 1982.

Lazonick, William, and Brush, T. "The 'Horndal' Effect in Early Us Manufacturing." *Explorations in Economic History* 22 (1985): 53-96.

MacLean, Annie Marion. *Wage-Earning Women*. Edited by Richard T. Ely, *The Citizen's Library*. New York: The Macmillan Company, 1910.

Nelson, Daniel. *Managers and Workers: Origins of the Twentieth-Century Factory System in the United States, 1880-1920*. second ed. Madison, Wisconsin: The University of Wisconsin Press, 1995.

Nickless, Pamela J. "A New Look at Productivity in the New England Cotton Textile Industry, 1830-1860." *Journal of Economic History* 39, no. 4 (1979): 889-910.

Rose, Mary. "The Gregs of Styal, 1750-1914: The Emergence and Development of a Family Business." PhD, Manchester, 1977.

Saxonhouse, Gary R. "Productivity Change and Labor Absorption in Japanese Cotton Spinning 1891-1935." *Quarterly Journal of Economics* 91 (1977): 195-219.

Ware, Caroline F. *The Early New England Cotton Manufacture: A Study in Industrial Beginnings*. Cambridge, MA: The Riverside Press, 1931.

Wright, T. P. "Factors Affecting the Cost of Airplanes." *Journal of the Aeronautical Sciences* 3 (1936): 122-28.