The "Horndal Effect" in Early U.S. Manufacturing*

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I. THE PRODUCTION-RELATIONS HYPOTHESIS

In a Swedish-language book on productivity and profitability, Erik Lundberg (1961, pp. 130, 131) introduced the economics profession to the "Horndal effect":

> During a period of fifteen years beginning in the mid-1930s, one of the steel works (Horndal) of the Fagersta concern was neglected. No new investments were made

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except for a minimum of repairs and broken equipment replacement (without modernization). In spite of this, there was an annual increase in man–hour production of two percent during this period. This compares to a production growth per man–hour of four percent for the whole concern. In other plants of the company significant new investments were made during this time.[1]

Lundberg referred to the "Horndal effect" as "pure productivity," making no attempt to discover the underlying causes. Instead he called for more analysis "to show the importance of all the undefined factors which are covered under [these] all-encompassing and diffuse labels" (Lundberg, 1961, p. 133).

Some U.S. economists, however, have not been at all reticent to cite the Horndal experience (as reported by Lundberg) as evidence to support very specific explanations of productivity growth. In a seminal article on "learning by doing," Kenneth Arrow (1962) argued that the sustained productivity growth at Horndal could "only be imputed to learning from experience". More recently, Paul David (1973, 1975, Chap. 2) has analyzed the "Horndal effect" in Lawrence Mill No. 2, a cotton textile mill that began operations in Lowell, Massachusetts in 1834. According to David, labor productivity at Lawrence Mill No. 2 increased at an average compounded rate of just under 2% per annum from 1835 to 1856 despite the absence of investment in new machinery. He goes on to argue that the case of Lawrence Mill No. 2 "probably represents the earliest well-documented instance of short-run learning effects [making] its story the true precursor to the Swedish steel mill built at Horndal a century later."[2]

Like Arrow, David merely assumes that the productivity growth at Lawrence Mill No. 2 was the result of "learning by doing." Neither considers the possibility that the "Horndal effect" might have been caused by other (to use Lundberg's words) "undefined factors." Little or no evidence is presented in either case—the Swedish steel mill or the American textile mill—to establish that the temporal configuration of the "sustained" productivity growth even took the form of a "learning curve." For the steel mill, the only evidence cited is that productivity grew at an average of 2% per annum for 15 years. For the textile mill, David uses four data points, representing his estimates for peak labor productivity levels over the period 1835–1856, and finds that the "least-squares fit of the 'learning curve' proves most satisfactory indeed." He concludes

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[1] Translation by S. Herzenberg.

[2] The Horndal mill was not built in the mid-1930s as David claims, but was already a going concern in the early 19th century. Major investments in plant and equipment were made in the 1880s (Söderlund, 1957–1958). These facts in themselves raise serious doubts about the applicability of the learning-by-doing argument to Horndal in the 1930s and 1940s (see Helper and Lazonick, 1984).

> Surely the evidence presented here provides sufficient cause . . . to insist that
> Horndal share with Lowell the honor . . . in giving its name to the productivity
> effect of learning-by-doing in the context of a fixed production facility. (David,
> 1975, p. 184)

A prime purpose of this paper is to test the learning-by-doing hypothesis as an explanation of the productivity growth at Lawrence Mill No. 2 during its first 2 decades of operation. As illustrated in Fig. 1, there certainly was sustained productivity growth at Lawrence Mill No. 2 from 1834 to 1855. Over this period, output (in yards of "type C" cloth per weaver–hour) rose steadily (with greater cyclical fluctuations before 1842) at an average compounded rate of 3.1% per annum.[3]

But can this growth be attributed to learning by doing? The learning-by-doing hypothesis implicitly assumes that the relation between inputs and output is simply technical in nature, and that the productive capabilities of an enterprise will *of necessity* improve with production experience. If this were the case, one might posit a universal explanation—a "technically determined" learning curve—for cases of productivity growth on the basis of fixed production facilities such as occurred a century apart at the U.S. textile mill and the Swedish steel mill.

But if the relation between inputs and output is partially *social* in nature, then historically specific factors that motivate and condition the objectives and work efforts of different participants in the production process must be considered in explaining changes in productivity. The contention that social factors, and in particular the impact of management–worker relations on work intensity, were determinants of the observed productivity growth at Lawrence Mill No. 2, we call the *production-relations* hypothesis (see Lazonick, 1984).

To posit the production-relations hypothesis is not to reject learning by doing as one *possible* explanation of productivity change. The learning-by-doing hypothesis has intuitive appeal. It is reasonable to expect that the performance capability of participants in production will improve with experience. It is also reasonable to expect that such improved capability is "irreversible" (disappearing only with the disappearance of the learning entity) and that productive capability will improve at a

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[3] It should be noted that David's growth rate differs from ours. He computed output per worker–hour for the whole mill using an indirect method for estimating the number of actual worker–hours. The weaving process, from which our productivity growth rate is derived, was the most important single component of cloth production in terms of direct labor inputs. David also assumed that each of the four peaks in output per worker–hour that he derived represented the same phase (the peak) of the business cycle at each point in time. In fact, in the main weaveroom, highest levels of output per weaver–hour usually occurred in troughs, presumably because inferior weavers were laid off while the slack labor markets meant that the remaining (technically superior) weavers could be compelled to work harder than at other times.
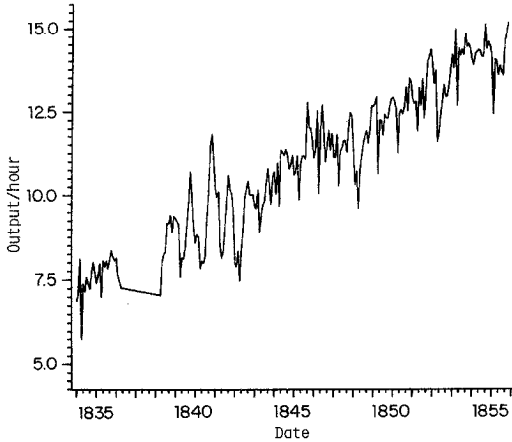
FIG. 1.   Output per weaver–hour, January 1834–November 1855. (Yards of "C" cloth.) No data available for May 1836 through March 1838. For variable definition, see Appendix.

diminishing rate. These assumptions are embodied in the cumulative measures of experience that are used in empirical studies of learning by doing (see David, 1975, Chaps. 2, 3; Fellner, 1969; Rapping, 1965; She-shinski, 1967; Zevin, 1975).

These assumptions are consistent, moreover, with the basic neoclassical proposition that the production function is technically determined. An implicit assumption of the hypothesis is that improved performance *capability* will automatically result in improved *performance*. But if we recognize that production is a *social process*—that social relations, mo-tivation, and effort influence production outcomes—then we cannot posit such an automatic translation of changes in input capability into changes in input performance.

It is worth noting in this regard that Harvey Leibenstein (1966) cited the Horndal case (again as reported by Lundberg, 1961) as evidence to support his original formulation of the "X-efficiency" hypothesis—a hy-pothesis that cannot possibly be equated with learning by doing unless the latter is turned into a mere tautology. Unfortunately, despite numerous subsequent books and articles on the subject of "X efficiency," Leibenstein has never tested or developed the hypothesis by means of empirical analysis. Hence "X efficiency" has remained a rather vague, and un-substantiated, concept. In our formulation of the production-relations hypothesis and its application to the experience of Lawrence Mill No. 2, we hope to reveal something about both the ways in which motivation and work effort change over time and the extent to which such social factors affect productivity outcomes.

Our empirical task is to distinguish between the technical determinants (of which learning by doing is but one) and the social determinants of

productivity growth. The existence of detailed production and payroll records for Lawrence Mill No. 2 has made it possible to construct a relevant microlevel data set. With the exception of 2 years from 1836 to 1838 for which payroll records are missing, we have gathered comprehensive *month-by-month* data on labor productivity, piece rates, earnings, and looms per weaver *for every operative* who worked in the main weaveroom of Mill No. 2 from 1834 to 1855—12,762 observations, of which 12,140 are used in regression analysis. Individual operatives have also been classified by ethnicity and literacy. We have also compiled monthly time series on cotton quality, absenteeism, labor turnover, permanent separations, overseers per operative, and the number of auxiliary workers ("sparehands"). In addition, we have researched a substantial amount of qualitative material including written communications between managers within the Lawrence Company and across Lowell cotton textile firms.[4]

In the next section of the paper, we formulate a production function that distinguishes between the technical and social determinants of productivity change. We also provide some general background on changes in the nature of the labor supply to the Lowell cotton textile mills that is pertinent to the construction of relevant independent variables. In the following section, we present our model for analyzing productivity change at Lawrence Mill No. 2, a model based on our qualitative understanding of the nature of capitalist production, the specific socioeconomic environment in which the textile mill operated, and the types of cross-section and time-series data that we have available. In the next section, we record the statistical results of pooled times-series, cross-section regression analysis of the Lawrence Mill No. 2 data for the period 1834 to 1855. In the concluding section, we discuss the implications of these results for understanding the nature of the production process and the determinants of productivity change in Lawrence Mill No. 2 as well as in capitalist production in general.

II. TECHNICAL AND SOCIAL DETERMINANTS OF PRODUCTIVITY CHANGE

Given the labor-intensive character of cotton textile production in the 19th century, our primary problem is to distinguish between increases in productivity caused by, on the one hand, the application to the production process of *improved* productive capabilities of workers, and, on the other hand, the *more complete* utilization of the *existing* productive capabilities of workers. In other words, we have to account for changes in the quality

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[4] The Lawrence Manufacturing Company records are to be found in the Baker Library Manuscripts Division at the Harvard Graduate School of Business Administration. A more extensive report on the historical sources is in Brush (1981).

of labor power—the capacity to work—as well as changes in the extent to which this labor power is actually realized in the form of labor services— work effort actually expended in the production process.

In addition, the analysis of productivity change must distinguish between the impacts of changes in the application of labor power to the production process and changes in the capital inputs that enter into production. It is true that over our period there was no *major* investment in the capital equipment at Lawrence Mill No. 2. Nevertheless, there were potentially important modifications and alterations in the quality of the existing capital inputs as well as changes in the quantity of capital inputs per worker that must be taken into account.

Let us therefore formulate the production function as $q = f(t, h, e)$, where q is output *per worker, t* is a measure of the productive capability of the physical capital inputs available to each worker, h is the productive capability of each worker, and e is the work effort actually applied by each worker. For simplicity, h can be viewed as the *quality* of labor services inherent in the worker while e can be viewed as the *quantity* of those services actually expended (although in actuality work effort itself will obviously have a qualitative dimension). If the productivity of physical capital depends on the expenditure of effort by the worker, zero work effort will result in zero output per worker no matter what the quality of t and h that enter the production process.[5] It can be assumed that there will be diminishing returns to increases in work effort per unit of time and that at some point the marginal product of work effort will fall to zero. In this formulation of the production function, increases in t and h are *effort decreasing* in the sense that they permit the worker to produce more *at the same level of work effort.*

If formulated correctly, the learning-by-doing hypothesis as applied to the analysis of the "Horndal effect" posits that increases in q are caused by changes in h which accrue through experience at relevant productive tasks (be they managerial or operative). The production-relations hypothesis posits that increases in q are caused by changes in the level of e, holding t and h constant. Our formulation of the production function, focusing as it does on the quantitative impacts of qualitative phenomena, brings to the fore a host of measurement problems not normally confronted in productivity studies. Our measures of t and h are attempts to capture the quantitative impacts of qualitative changes in productive capability. Moreover, we do not have a direct measure of e, our purely quantitative dimension. Rather we must rely upon our theoretical analysis of the

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[5] The characteristics of this production function are elaborated in Lazonick (1984). If work effort is viewed as purely quantitative, zero work effort *over a sufficiently long work period* will always result in zero output; if zero work effort resulted in positive output, then the worker would not be necessary to the production process. If work effort is viewed as qualitative, then zero work effort *may* just result in a lower quality product.

social and technical nature of the production process to construct variables that capture changes in work effort.

The analysis of the determinants of work effort (or, as Marx called it, the intensity of labor) is central to understanding the social relations of the capitalist workplace (see Lazonick, 1983a). How hard particular workers work will be manifestations of their individual or collective responses to incentives, both positive and negative, that the enterprise manager holds out. Profit-maximizing managers will attempt to structure incentives to minimize unit costs (over an appropriate time horizon). If we assume (as most economists implicitly do) that workers view work as a disutility—a mere means to an end—then it follows that workers will attempt to get the most remuneration for the least possible expenditure of work effort. Insofar as workers are successful they will undermine managerial attempts to minimize costs. The relation between work effort and rewards will be, therefore, an inherently conflictual issue, with the constraints on cost minimization by capitalists and "on-the-job" utility maximization by workers being determined in part by the relative power of the two sides.

The task of historical analysis is to discover the sources of relative power. One source will be exit. The existence of alternative opportunities permits individuals to protect not only their earnings but also their work conditions. Another source will be collective action—what Hirschman (1970) has called "voice"—either through formal management–union bargaining or informal setting of work norms by the workers themselves. If the response of workers to incentives is individualistic, management can, the labor market permitting, fire workers whose performance is "subpar." If the response of workers to incentives is collective, however, to give all, or even some, of the workers the sack for inadequate performance may be a prohibitively expensive managerial remedy.

In the 1830s and well into the 1840s, workers in the Lowell mills had no formal bargaining power. Strikes staged in 1834 and 1836 over wage cuts were clearly unsuccessful (Brush, 1981; Dublin, 1979, Chap. 6). But these workers did possess considerable power of individual exit. As is well known, the labor force in the Lowell mills of the 1830s was made up primarily of "Yankee farmgirls." To attract the daughters of America's yeomanry into the mills required not just relatively high wages but, more importantly, good working conditions along with the closely supervised structure of life in the Lowell boarding houses. Only then could mill work represent a respectable prelude to womanhood. Attempts by Lowell managers to cut wages or intensify work could, and at times did, lead to an exodus back to the farms and a drying up of new recruits (at least from the regions from which the previous workers had been drawn) (Dublin, 1979, Chap. 3; Ware, 1966, Chap. 8).

By all accounts, from the late 1830s it became increasingly difficult to

recruit an adequate supply of farmgirls. On the demand side, in Lowell alone between 1835 and 1847, the number of mills increased by 114%, the number of spindles by 158%, the number of looms by 122%, and the number of female employees by 71% (Eno, 1976, p. 255). On the supply side, the reserves of New England farmgirls were probably declining absolutely by the late 1830s as the economic viability of New England farming was deteriorating (Bidwell and Falconer, 1925, pp. 237ff; Wilson, 1936, Chaps.1–4; Field, 1978).[6] At the same time, the generally well-educated Yankee farmgirls found themselves with an expanding wage-employment alternative to working in the mills. Up until the 1830s, school teaching during the winter months had been a male-dominated occupation, with females—many mill operatives among them—confined largely to summer teaching. From the 1830s, however, women were increasingly employed as winter teachers. As proportions of the winter and summer teaching forces in Massachusetts, females were 33 and 93%, respectively, in 1839–1840, but 50 and 90%, respectively, in 1849–1850. Over this period the number of female winter teachers employed in Massachusetts increased from 1079 to 2142 (Preston, 1982).

As the Yankee farmgirl labor supply dwindled, however, the population of Lowell grew—from 18,010 in 1837 to 33,383 in 1850, an increase of 85%. Increasingly the labor force for the Lowell mills could be drawn

[6] Data from the U.S. Census from 1820, 1840, 1850, 1860, and 1870 show the following trends in agricultural employment in the New England states:

	1820	1840	1850	1860
Massachusetts				
(1)	63,460	87,837	55,699	62,634
(2)	0.58	0.41	0.15	0.14
Maine				
(1)	55,031	101,630	77,016	80,708
(2)	0.82	0.73	0.41	0.39
New Hampshire				
(1)	52,384	77,949	47,408	45,544
(2)	0.84	0.78	0.40	0.39
Vermont				
(1)	50,951	73,150	48,312	52,989
(2)	0.85	0.82	0.43	0.53

(1) = agricultural employment
(2) = proportion of labor force engaged in agriculture

Note. The 1850 Census included only males over 15 in the "total labor force." To adjust the reported labor force figure to include females, the total labor force for each state was estimated by using the ratio of total employment to male employment as stated in the 1870 Census. The 1860 Census includes farmers and farm laborers.

from a pool of local urban residents (Eno, 1976, p. 255).[7] The boarding-house system declined and was replaced by less paternalistic contractual relations between management and labor (Dublin, 1979, p. 166). But, like the Yankee farmgirls, the native-born female residents of Lowell were not in general dependent on factory work for their sustenance. Most of them came from families in which the male head of household was able to earn a family wage, and it was exceptional for an American woman to remain at mill work once she was married (Dublin, 1979, pp. 31, 32, 50–54). Since the minority of workers who *were* dependent on mill work to earn a basic living in the early 1840s were relatively indistinguishable parts of a labor force that was not dependent, even they were endowed with substantial power to control their work conditions and earnings.

All this changed with the large-scale influx of Irish into the mills in the late 1840s. As the data from the Mill No. 2 main weaveroom show, output per weaver–hour continued its steady climb from the early 1840s until the end of our period whereas from the late 1840s the previously horizontal trend in real earnings per hour turned sharply downward (see Figs. 1 and 2). Unlike those Yankee workers for whom mill work was not essential to the securing of sustenance, the Irish were in general dependent on mill earnings for their basic livelihoods. As Thernstrom (1964, Chap. 4) has shown, the common laboring jobs available to Irish *men* around 1850 did not provide anywhere near a minimal family wage. Hence the earnings of older children and, in many cases, wives were crucial components of day-to-day subsistence. Lacking the range of alternative opportunities open to most American workers and being more dependent on mill earnings to meet their basic needs, the Irish had much less power to resist intensification of labor implemented by means of stretch-outs, speed-ups, and the use of inferior cotton. Moreover, the availability of the Irish posed a serious threat to the ability of the remaining American workers to resist unremunerated intensification of labor. The very presence of the Irish as a reserve army of labor threatened the jobs of the Yankees. Furthermore, the social distance between the two groups on the shop floor probably made it more difficult to enforce the collective setting of output norms in order to protect the relation between work effort and pay.

From the 1830s to the 1850s, therefore, two-stage transformation of the nature of the labor supply took place; first, from one in which Yankee

[7] Data in the Hamilton Manufacturing Company Register Books show that the net change in the number of Hamilton workers who were full-time residents of Lowell as a percentage of the net change in Hamilton workers averaged 5.9% in 1834–1838; 9.8% in 1839–1843; and 9.9% in 1844–1848. Hamilton Manufacturing Company Register Books, Volumes 482–483, 485–490, Manuscripts and Archives Division, Baker Library, Harvard Graduate School of Business Administration.
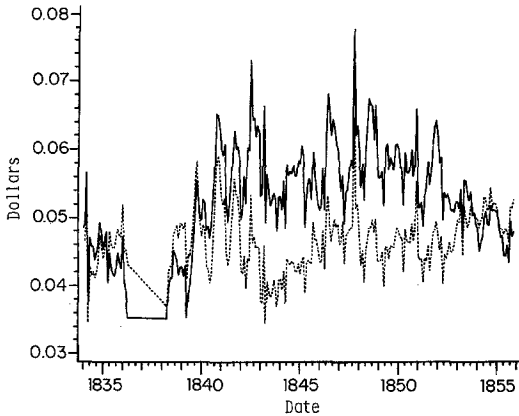
FIG. 2. Average hourly real and nominal wages, January 1834–November 1855. Solid lines represent real wages; dotted lines represent nominal wages. No data available for May 1836 through March 1838. The nominal wage series is the average hourly earnings of weavers in the Lawrence Mill No. 2 main weaveroom. The real wage series is derived by dividing the nominal wages series by the Warren–Pearson Index, Base: 1824–1842, in Arthur H. Cole, *Wholesale Commodity Prices in the United States, 1700–1861* (Harvard UP: Cambridge, 1938), Table 45 (All Commodity Index of Wholesale Prices with Variable Group Weights at New York. Monthly 1797–1861).

farmgirls predominated to one in which permanent Yankee operatives were increasingly prevalent, and then to one characterized by an increasing proportion of Irish workers. Given this transformation, there is reason to believe that the levels of experience on the part of workers and the relative power of management and labor were anything but stable from the mid-1830s to the mid-1850s. In particular, we would expect the importance of learning by doing as a determinant of productivity growth to have been greatest in the 1840s when a presumably more experienced, permanent Yankee labor force was being employed than in either the 1830s or 1850s. In contrast, we would expect the strength of management to effect unremunerated intensification of labor to have been greatest in the last third of our period with the coming of the Irish. It is these specific hypotheses that we wish to test with the data drawn from the main weaveroom of Lawrence Mill No. 2.

III. THE PRODUCTION FUNCTION IN EARLY U.S. TEXTILE MANUFACTURING

Our dependent variable, graphed in Fig. 1, is output per worker–hour (YWH), the observations being average hourly output of each regular weaver ("piecehand") in the main weaveroom of Mill No. 2 for each month from January 1834 through November of 1855 with the exception of the period from May 1836 through March 1838 for which payroll records are missing. (For 9 of these 23 months, however, Mill No. 2 was entirely closed down because of depressed economic conditions.)

Mill No. 2 produced one standard type of cloth throughout the period of analysis, so our productivity measure can be in physical quantities. We shall assume that each unit of this cloth was of constant quality at each point in time as well as over time.

Our independent variables are grouped under three headings: (1) technical variables (t) that reflect changes in technical conditions that are *not* inherently part of a managerial strategy to intensify labor; (2) human capabilities (or physico-cognitive) variables (h) that reflect changes in the performance capability of operatives or management; and (3) work effort variables (e) that reflect changes in the power of management or labor to control the intensity of labor, *given t and h*. Since some factors may reflect changes in both t and e (for example, cotton quality) or h and e (for example, overseers per worker), the attribution of factors to particular categories depends crucially upon our identification of the phenomena that the variables are capturing, and hence upon our prior knowledge of the nature of the production process. What follows is a general description of the variables that enter into a production function that relates output per weaver–hour in Lawrence Mill No. 2 to technical conditions, the physico-cognitive abilities of human resources, and the relative power of management and workers to control the levels of work effort. (For the variables listed below, a more complete technical description and discussion is provided in the Appendix.)

Technical Capabilities (t) Variables

(1) D1, D2, . . . D11 are monthly dummy variables (January through November, respectively) that adjust for variations in the technical capability of the Lawrence Mill No. 2 weaveroom because of seasonal factors. Four such factors stand out: increased yarn breakages during the dry winter months; "freshets" or backwaters that typically occurred in April, rendering the power source, and hence production, irregular despite the locks and canal system; shortages of water power in the summer and fall months; and the heat of the summer months (July and August) which may have had a negative impact on the productive capabilities of workers at any given level of work effort. The third factor, however, was not an annual occurrence, and so is treated separately below as WPOW.

(2) DTECH1 is a dummy variable to control for the introduction of a relatively inexpensive, but potentially important, technical change in the main weaveroom in May 1835. What was described in the company records as an "alteration of looms" was probably a device that made the shifting of the pace weight self-acting. The resultant improvement in the let-off motion permitted the production of more consistent and standardized cloth.

(3) DTECH2 is a dummy variable to control for the introduction of a new type of cotton picker into the mills of the Lawrence Manufacturing

Company in August 1844. By permitting the transformation of a given grade and staple of cotton into a higher quality cotton input, the cotton picker would have permitted more output for the same amount of labor effort, holding grade and staple of cotton constant.

(4) DCOTL2 is the cotton quality variable, RCOTL (described below), interacted with DTECH2. This interactive variable allows us to test the hypothesis that the preparation of cotton and its consequent impact on output per worker varies significantly with the quality of raw cotton used.

(5) WPOW is a dummy variable that controls for periods of deficiencies in power supply because of water shortages in the Lowell locks and canals system. During such periods the output of the mill was constrained by lack of power, and hence management had an interest in maximizing output per unit of available water power. To do so management lowered the speed of the looms, reducing both power consumption and yarn breakages. It appears that they then reduced the size of the labor force temporarily, giving the remaining workers more of the slower looms to tend for the duration of the power shortage, but at the piece rate that had previously prevailed. This temporary increase in loom complements is not captured by our looms per weaver variable (LPW below) since it is derived from piece-rate *changes* (see Appendix).

Human Capabilities (*h*) Variables

(6) LNTIME, the logarithm of cumulative months since Lawrence Mill No. 2 opened for operation, is a conventional measure of learning by doing. In fact, Paul David uses this measure in his study of productivity growth in Lawrence Mill No. 2. In early U.S. cotton firms, labor turnover was certainly much higher than managerial turnover, and the very existence of the company records, now at our disposal, demonstrates that the retiring managers did pass on a substantial amount of information and know-how to their successors. We can assume, therefore, that *cumulated learning* in Mill No. 2 resided in management. Hence LNTIME represents the managerial contribution to the productive efficiency of the Mill No. 2 weaveroom.[8]

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[8] In his study of "learning by doing" in New England textiles, Zevin (1975, p. 5) argues that "the manager alone could be the repository of knowledge acquired from production experience and that this knowledge could be used to make old and new workers and machines more productive." We would argue, however, that the productivity results of many management decisions are determined not so much by accumulated managerial knowledge, but more by changes in the structure of production relations. As one of the authors has shown in another context (Lazonick, 1983b), much managerial knowledge may become irrelevant or even an obstacle to productivity growth as production relations change. Zevin (1975, p. 5) also argues that over time management learns "the most efficient intensity of production." But given the inherent conflict over the intensity of labor, managers and workers may by no means have been in agreement over just what the proper measure

(7) LNEXPADJ, the logarithm of the number of cumulative days worked by each weaver whose name appears on the payroll in any given month, is an attempt to capture the impact of weaving operatives' on-the-job experience as distinct from the experience of the "mill" as a whole. We have incomplete information on the actual relevant experience of individual workers. We have virtually complete information on days spent in the main weaveroom of Mill No. 2, but we do not know how much experience was acquired in other rooms at the Lawrence Manufacturing Company or at other textile mills. The longer the average careers of Lowell mill workers and the shorter the average stay in the Mill No. 2 main weaveroom, the less problematic these truncated job profiles become since in the extreme there would be no reason to assume that, in any given month, those with more experience acquired in the Mill No. 2 weaveroom had any more or less externally acquired experience than those with less internally acquired experience. As explained below, however, we can correct for the bias inherent in truncated job profiles by performing regression analysis on deviations of monthly observations for individuals from the historical (Mill No. 2 main weaveroom) means for those individuals.

(8) CAPUTIL is a measure of capacity utilization in the Mill No. 2 main weaveroom (see Fig. 3). It permits us to take into account variations in output per worker–hour caused by variations in demand. As noted above (note 3), the highest levels of output per worker–hour usually occurred in troughs of the business cycle. During booms, management could sell as much cloth as the fixed machinery capacity could produce, an inducement to maximize output per *loom*. But in slumps, with inventories piling up and productive capacity outstripping demand, management would be more inclined toward maximizing output per *worker*. This objective could be achieved by laying off inferior workers, increasing the number of looms per weaver, and slowing somewhat the speed of each loom. Up until the early 1840s and then less systematically in the early 1850s,

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of "efficiency" should be. It should also be noted that David specifies a log–log relationship between cumulated time and output per worker–hour, hence positing that each successive increase in elapsed time leads to equivalent percentage increases in output per worker. Given what we know about productivity growth without technical change in capital inputs, however, we have doubts about the appropriateness of this functional relationship. In effect, David is assuming that it is just as easy to obtain equivalent percentage increases in output per worker–hour at higher levels of output as at lower levels of output. We would argue that it becomes more difficult. In order to model this assumption, we specify a linear–log relationship between cumulated time and output per worker–hour, in effect positing that each successive 1% increase in elapsed time results in equivalent absolute increments (and hence declining percent increments) in output per worker–hour. The same arguments apply to our modeling of the relation between individual workers' experience and output per worker–hour, below.
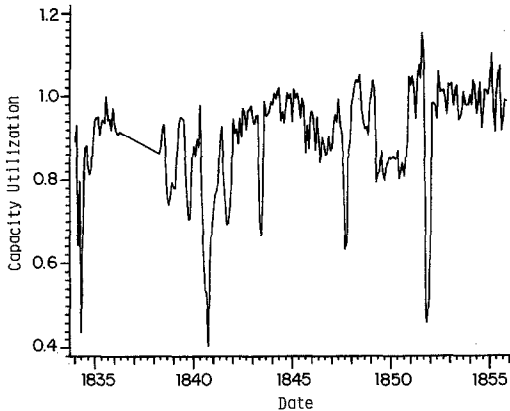
FIG. 3. Capacity utilization, January 1834–November 1855. (Ratio of looms tended to looms available.) No data available for May 1836 through March 1838. For the reason that capacity utilization is sometimes greater than 1.0, see Appendix.

Mill No. 2 management explicitly made note of high productivity workers in the payroll books, and apparently used this information as a basis for deciding who to retain in slack periods. Also, when water shortages compelled the mill to operate at less than full capacity, weavers tended an extra loom at lower speeds causing labor productivity to rise. It could be argued that the impact of CAPUTIL on labor productivity reflects changes in work effort as well as changes in the quality of physical capital. In slumps, management often temporarily altered the looms per weaver ratio from two to three and less often from three to four, typically slowing the speed of the looms somewhat as the number of looms per weaver increased. In addition, the power of management to intensify the labor of employed workers was undoubtedly greater in a downturn than in an upturn. We believe, however, that we have captured any impacts on work effort directly by means of our "work effort" variables listed below so that changes in CAPUTIL will reflect changes in human capabilities rather than changes in the intensity of labor.

(9) SPARPAUX is the number of "sparehands" doing auxiliary work for each piecehand (regular weaver) in the Mill No. 2 main weaveroom. "Sparehands" (also called "dayhands" since they were on day rates) were employed to learn to weave. Typically, one or two "sparehands" were actually relatively high-paid weavers whose job it was to teach fresh recruits. How was the work of sparehands related to the work of piecehands? We have evidence that sparehands were doing weaving independently of regular weavers. We have found no evidence, however, that sparehands were doing auxiliary tasks such as weft carrying and cleaning that would have had a direct effect on the productivity of weavers. Nevertheless, it is possible that at certain points in our time period

management redivided labor in the weaveroom, utilizing sparehands to perform tasks previously done by regular weavers. For periods following such redivisions of labor (if in fact they did occur), our measure of output per weaver–hour, including as it does only the output and hours of piecehands, would be inflated. SPARPAUX is meant to control (albeit in a rather crude way) for this possibility.

Work Effort (e) Variables

These variables are the most complex in our model. We can divide them into two types: (a) "managerial strategy" variables, reflecting the power of management to get more work effort out of their workers; and (b) "workers' control" variables, reflecting the power of workers to control the relation between the levels of work effort they expend and the rewards they receive.

(a) Managerial Strategy

(10) LPW is the average number of looms tended by each weaver in Mill No. 2 during any given month (see Fig. 4). Management can attempt to intensify work by "stretching-out" (more looms per weaver) and/or by "speeding-up" (more picks per minute per loom). A stretch-out from say two to three looms per weaver does not *necessarily* increase either work effort or output per worker–hour. The looms are always slowed somewhat when stretch-out occurs, but not necessarily to the point where work effort expended per unit of labor–time is at the pre-stretch-out level. Since the slowing of looms per se is effort saving (less yarn breaks per unit of time) while the increase in looms per worker per se is effort increasing (attention must be paid to more looms), the change in the level of work effort required to achieve the same level of output both
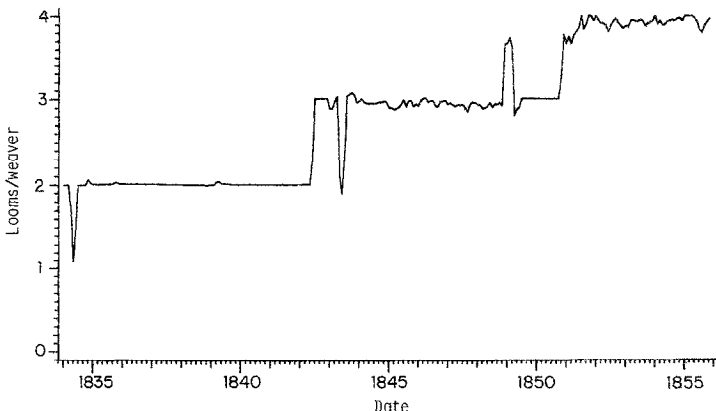

Fig. 4.   Average number of looms per weaver, January 1834–November 1855. No data available for May 1836 through March 1838. For variable definition, see Appendix.

before and after the shift to more looms will depend on how these two effects counterbalance one another. If we assume that for any given change in loom complements, the same level of output would require the same level of work effort before and after the change, then a positive relation between LPW and YWH would indicate intensification of labor.

(11) RCOTL is an index of the quality of cotton used by Mill No. 2 (see Fig. 5). An increase in cotton quality (either in terms of longer staple length or cleaner grade) is a form of effort-decreasing technical change: more output per worker–hour can be produced with the same amount of work effort because, *other things equal,* there will be fewer yarn breaks per hour and hence less downtime. A significant *positive* relation between RCOTL and YWH would be consistent with the hypothesis that over time management makes trade-offs based on the relative prices of inputs and outputs between higher unit cotton costs and higher levels of physical productivity. But precisely because higher quality cotton is more expensive, management may very well choose to use lower quality cotton to cut raw material costs even though such a choice of technique will, *other things equal,* result in lower levels of productivity because of more downtime (caused by more yarn breaks per unit of time). Management will find it particularly attractive to use low quality cotton when it can ensure that "other things" will *not* remain equal: when it has the power to compel workers to work harder to repair more yarn breaks per unit of time even though the harder work may not result in either higher levels of output or earnings per hour.[9] A significant *negative* relation between RCOTL and YWH, therefore, would strongly support the hypothesis that management introduced lower quality cotton in periods when it had enhanced power to intensify labor, enabling it to achieve simultaneously lower cotton costs and higher levels of labor productivity. On a priori grounds, the observed deterioration of cotton quality over our period (see Fig. 5) leads us to classify RCOTL as a work effort variable rather than a physical capital variable.

(12) OPW is the number of overseers per worker in any given month. Throughout our period there were one to five overseers in the main weaveroom, although the usual number was two or three. OPW tended to increase over the period as a whole because supervisory personnel were not eliminated in proportion to the decline in the number of weavers employed as the complement of looms per weaver rose from two to three and then to four. Since the amount of machinery to be overseen remained constant throughout this period, we interpret increases in OPW as reflecting closer supervision. A rise in OPW, however, will not automatically result

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[9] For a more extensive analysis of the interaction of changes in cotton quality with production relations and the resultant impact on productivity and costs, see Lazonick (1981), Lazonick and Mass (1984), and Mass (1984).
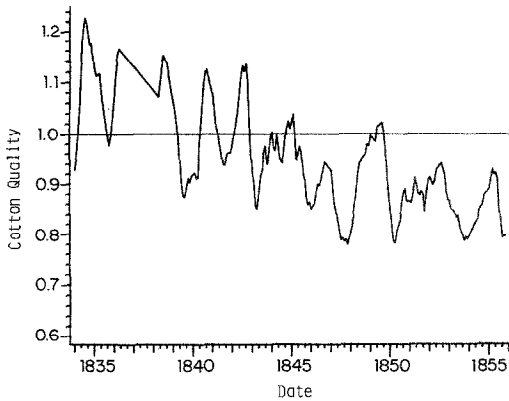
FIG. 5.   Cotton quality index by month of use, January 1834–November 1855. (Ratio of mill price to New York price of Uplands cotton.) No data available for May 1836 through March 1838. For variable definition, see Appendix.

in higher levels of labor productivity. Closer supervision will yield productivity results when the collective or individual power of workers to resist intensification of labor is weak.

(b) Workers' Control

(13) ABSENT is a measure of absenteeism for individual weavers; that is, the amount of *voluntary and temporary* labor mobility that Mill No. 2 weavers enjoyed during their employment in the main weaveroom. A human capital theorist might predict a negative relation between ABSENT and YWH on the assumption that individual workers lose job-relevant skills when they experience frequent separations. It is not known, however, what workers did during their temporary absences from the main weaveroom. They may very well have gone to work at other Lowell mills that offered superior work conditions. Our interpretation of ABSENT is that it reflects the power of workers to exit temporarily from unsatisfactory work environments. When ABSENT is high, management efforts to intensify labor are more constrained by the fear of aggravating the problem of high levels of absenteeism. Like the human capital theorist, we would predict a negative relation between ABSENT and YWH, but we would interpret the impact of ABSENT to be on the level of work effort rather than on the level of human capabilities in the production function.

(14) FALLPRES measures the extent to which individual workers were present in Mill No. 2 in the summer and fall months, that is, July–November (see Fig. 6 for annual average FALLPRES). This variable represents an attempt to capture the supposed transition from an impermanent (Yankee farmgirl) to a permanent (urban resident) labor force
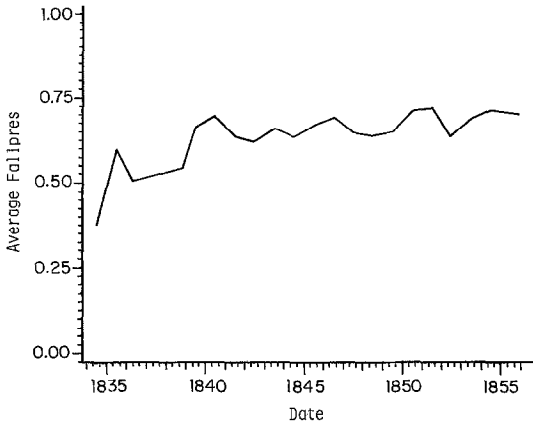
FIG. 6. Annual average FALLPRES (permanent workforce), January 1834–November 1855. No data available for May 1836 through March 1838. Calculations for 1836 based on average of first 4 months; for 1838, average of last 9 months; and for 1855, average for first 11 months. For variable definition, see Appendix.

in Lowell. We have no direct measure of "farmgirl" status, or lack thereof, among the Lowell operatives. But it has been generally argued that those with agrarian attachments would typically return to the farms during the hot summer months and would help with the harvest and putting up food in the early fall. If we could identify who these people were in the Mill No. 2 sample, we could test the hypothesis that, because of this alternative opportunity, operatives with continuing ties to the agrarian sector were better able to avoid unremunerated intensification of labor during their stints as weavers than those who lacked such ties.

(15) LPQUITD measures the ability of weavers to quit the Mill No. 2 main weaveroom *permanently* (in contrast to ABSENT and FALLPRES which measure temporary separations). We have lagged our measure of permanent quits 1 month to test the hypothesis that the ability of workers to depart definitively from the weaveroom constrained managerial attempts to intensify labor.

(16) TEACH is an index of the availability and relative attractiveness of teaching jobs for "literate" Mill No. 2 weavers. Hence, it is a measure of a very specific alternative opportunity. A significant negative relation between TEACH and YWH would support the hypothesis that the *existence* of an important alternative opportunity undermined the ability of management to intensify labor.

(17) LNPIECER, the logarithm of the average real piece rate times the average loom complement, is a measure of the earnings incentive to which a weaver could respond in any given month. Given current earnings incentives, workers may have *chosen* to work harder in order to achieve higher earnings, although as indicated above we would expect that different

workers had different trade-offs between "on-the-job leisure" and earnings. In contrast to the coercive managerial strategy inherent in OPW, this variable represents an attempt to capture the extent to which workers voluntarily responded in the form of work effort to real piece-rate incentives offered by management. (We do not directly consider here the managerial strategy of *manipulating* the piece-rate incentive in order to minimize costs.)

(18) BEGEND, the total elapsed time since a weaver first entered the Mill No. 2 main weaveroom, is a measure of seniority as distinct from actual shopfloor experience. More days actually worked probably endowed a weaver with more physico-cognitive capacities, whereas those who were around longer (but not necessarily with more accumulated days worked) were less likely to acquiesce in intensified work than those who were relatively new to the weaveroom. Given the development of the Lowell labor supply described above, those with more seniority are likely to have been Yankees who placed a relatively high value on the enjoyment of respectable work conditions, thus limiting the acceptable level of self-imposed work intensity. In addition, a weaver with more seniority probably learned that to drive herself too hard could be self-defeating since it might provide a basis for management to adopt the higher levels of output as new output *norms*, paying lower piece rates to yield the same basic wage. The Irish apparently had little power to resist intensification. More-over, since being a mill worker undoubtedly represented an *improvement* over previous socioeconomic experiences for the Irish, they probably had less aversion to intense work than did the Yankees. With the coming of the Irish, the traditional Yankee opposition to rate busting must have been severely tested. It is likely that those with long attachments to mill work who remained in the mills despite the advent of "Irish" conditions offered more resistance to intensification of labor than did the newcomers. Hence, controlling for experience, we would expect BEGEND to have a negative impact on YWH throughout our period.

(19) ETHNIC is a variable that specifies the probability that a person is non-Irish or Irish. This variable permits us to test the hypothesis that, holding technology and human resource characteristics constant, the Irish were more susceptible to intensification of labor than were Yankees. A significant positive relation between ETHNIC and YWH would be con-sistent with our hypothesis that Irish workers, being more dependent on mill work and possessing less social power than Yankee workers, had less power to resist undesired intensification of labor.

(20) ETHNICITY, the proportion of weavers in any given month who are non-Irish (see Fig. 7), measures the extent to which "Irish conditions" pervaded the weaveroom, thus, according to our theoretical framework, subjecting non-Irish as well as Irish to much more oppressive social relations of production than those that prevailed in the "Yankee" era.
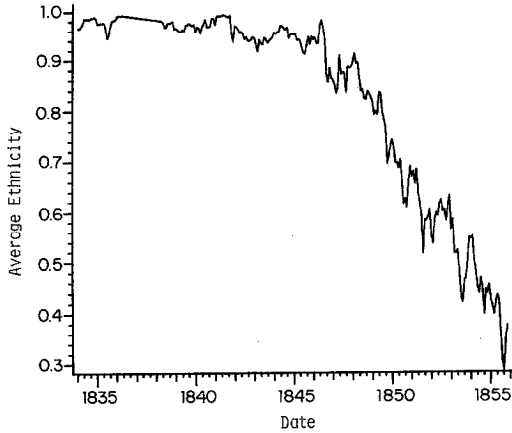
FIG. 7. Average ethnicity, January 1834–November 1855. (All Yankee = 1, all Irish = 0.) No data available for May 1836 through March 1838. For variable definition, see Appendix.

IV. EMPIRICAL RESULTS

To test alternative hypotheses concerning the determinants of productivity growth in the Mill No. 2 main weaveroom, we ran pooled time-series cross-section regressions with output per weaver–hour as the dependent variable. In the estimation of two variants of the production function model that are presented below, the data were transformed (as mentioned previously) into deviations of individual observations from the historical means for each individual in the Mill No. 2 main weaveroom.[10] In this way, we avoid the implicit, and unwarranted, assumption that all individuals who worked in the weaveroom started on an equal footing in terms of experience and other related characteristics that might influence individual productivity. In other words, we do not constrain all individuals to have the same intercepts in the functional relationships between their input and output. In the presentation of the empirical results below, the *M* at the end of each variable name indicates that the variable is measured in terms of deviations from the individual's mean for each observation. It should be noted that the use of this method precludes the *direct*

[10]For a mathematical justification of this procedure, see Brush (1983). The difference-from-means OLS estimation used in this paper is similar to that described in Hausman (1978, p. 1261). The deviations from means approach is equivalent to the introduction of separate dummy variables for each individual who appears in the data set. Our model has an unbalanced design because individuals are present in the sample for different lengths of time, and is therefore somewhat different from the standard fixed effects approach. A proof of the equivalence of the covariance transformation estimator with fixed effects and the least-squares dummy estimator (see Hsiao, 1985, Chap. 3; also Wallace and Hussain, 1969, pp. 60, 61), however, is unaffected by the presence or absence of an unbalanced design.

inclusion in our model of variables such as individual ethnicity and literacy directly since the measures of these variables remain constant over time for any given worker, and hence there are no deviations from individual means. "Literacy" (whether or not a weaver signed her name in the payroll book) does, however, enter indirectly in the construction of our TEACH variable (see Appendix) and, as outlined immediately below, ETHNIC is utilized as an interactive variable.

Below we present the regression results of our model with ETHNIC as well as FALLPRES interacted with the human capabilities and work-effort variables listed above. The use of FALLPRES and ETHNIC as interactive variables enables us to discern whether the transformations in the nature of the labor force from impermanent to permanent workers and from Yankee to Irish workers resulted in significant differences in the impacts of the other independent variables on output per weaver–hour, as well as to test the hypothesis that one or both of these trans-formations can be considered as altering the balance of power between management and workers as we have posited.

From the mid-1840s the change in the ethnic composition of the Mill No. 2 main weaveroom is marked (see Fig. 7), whereas from about 1840 there is only a slight upward trend in the relative numbers of "permanent" and "impermanent" workers (see Fig. 6). On the basis of the qualitative evidence presented in Section II, we would have expected a more pro-nounced upward trend in average FALLPRES after the early 1840s. It should be noted, however, that changes in average FALLPRES might give a misleading impression of changes in the underlying cross-sectional data that we actually use for regression analysis. In Fig. 6, for example, increasing permanence among one portion of the labor force could be masked by increasing impermanence among another portion. An ex-amination of the underlying data, however, failed to reveal any persistent movements over time in the distribution of individuals by values of FALLPRES to support such an argument.

Even in the form of cross-sectional data, FALLPRES is, or course, not a direct measure of loss of "farmgirl" status. In our model the existence of agrarian ties serves as an alternative opportunity that permits workers to exert control over work conditions in the mills. But farmgirls who chose to remain in the mills during the summer and fall months would not necessarily relinquish the power that the *threat* of exit afforded them. Yet they would be counted as "permanent" workers. On the other hand, non-farmgirl operatives who taught summer school would be correctly identified as "impermanent" by FALLPRES. Other non-farmgirl operatives may have left Mill No. 2 during the summer and fall months to visit friends (which would have been more difficult during the winter months) or to work in other mills. Moreover, a study by Dubnoff (1976) of Irish mill workers in Lowell has shown higher rates of absence from work by

Irish women than Irish men, and it may be that, for any number of reasons, Irish weavers in Mill No. 2 (all of whom were women) were taking prolonged absences from Mill No. 2 that are captured by FALLPRES. In any case, we do not have clear-cut transitions from "impermanent Yankees" to "permanent Yankees" to "permanent Irish," and must even consider the experiences of "impermanent Irish." In the discussion that follows, the abbreviations MI, MY, PI, and PY refer to impermanent Irish, impermanent Yankee, permanent Irish, and permanent Yankee workers, respectively.

It should also be noted that in Regression 1 below we have not interacted the t variables with ETHNIC and FALLPRES. Our theoretical framework set out in Section III as well as our explicit inclusion of h and e variables in the production function lead us to posit a priori that the impact of these inputs per se on productivity will not differ across groups of workers. Regressions that were run with interactive t variables (excluding the monthly adjustment variables) in conjunction with interactive h and e variables yielded results that were not significantly different from those of Regression 1. Moreover, none of the coefficients of the interactive t variables were statistically significant, supporting our decision not to interact the t variables with ETHNIC and FALLPRES. But in both regressions—with and without interactive t variables—FALLPRES interacted with RCOTL is significant at the 5% level, lending confirmation to our view that cotton quality should be classified as a work-effort variable, not as a technical capabilities variable.

In Regression 1 the unadjusted coefficient of determination is 0.4133 and the adjusted coefficient of determination is 0.3368. Normally in a sample with over 12,000 observations, the degrees of freedom are large enough so that no adjustment to R^2 is required. But because we have

REGRESSION 1
Production Function with ETHNIC and FALLPRES Interacted
Dependent variable: YWHM, SD = 1.6677
$N = 12140$, $R^2 = 0.4133$, $\overline{R}^2 = 0.3368$, SSE = 19809.16

Independent variable	Parameter estimate	SD	T ratio
D1M	−0.409*	0.265	−6.440
D2M	−0.686*	0.269	−10.671
D3M	−0.292*	0.271	−4.394
D4M	−1.524*	0.265	−22.189
D5M	−0.597*	0.268	−8.633
D6M	−0.533*	0.265	−7.519
D7M	−0.152**	0.272	−2.193
D8M	−0.093	0.270	−1.269

REGRESSION 1—*Continued*

D9M	0.047	0.268	0.666
D10M	− 0.014	0.268	− 0.198
D11M	− 0.018	0.263	− 0.273
DTECH1M	− 0.086	0.136	− 0.628
DTECH2M	− 0.983	0.163	1.711
DTCOT2M	− 0.683	0.157	− 1.173
WPOWM	0.067	0.301	1.229
LNTIMEM	− 0.956	0.210	− 0.289
FLNTIMEM	− 0.151	1.020	− 1.476
ELNTIMEM	0.652	0.208	0.197
LNEXPADJM	0.137	0.703	1.064
FLNEXPADJM	0.602*	1.214	7.793
ELNEXPADJM	0.172	0.618	1.362
CAPUTILM	− 1.185	0.086	− 1.578
FCAPUTILM	− 0.266	0.204	− 0.520
ECAPUTILM	− 1.550**	0.078	− 2.290
SPARPAUXM	0.171	0.049	0.170
FSPARPAUXM	0.425	0.051	0.525
ESPARPAUXM	0.080	0.042	0.092
LPWM	2.379*	0.310	12.673
FLPWM	− 0.302**	0.670	− 2.157
ELPWM	− 0.266	0.280	− 1.458
RCOTLM	1.211	0.057	0.927
FRCOTLM	− 2.305*	0.203	− 3.584
ERCOTLM	− 0.156	0.053	− 0.135
OPWM	− 14.663**	0.008	− 2.033
FOPWM	15.781*	0.016	3.461
EOPWM	14.852**	0.008	2.144
ABSENTM	0.921	0.077	1.304
FABSENTM	− 1.330*	0.040	− 2.647
EABSENTM	− 1.045	0.066	− 1.394
LPQUITDM	− 0.660	0.088	− 1.063
FLPQUITDM	0.183	0.074	0.384
ELPQUITD	0.790	0.080	1.465
TEACHM	0.035	0.680	0.942
FTEACHM	0.007	1.824	0.407
ETEACHM	0.046	0.543	0.798
LNPIECERM	− 3.125*	0.098	− 5.114
FLNPIECERM	− 0.289	0.185	− 0.743
ELNPIECERM	1.054	0.089	1.822
BEGENDM	− 0.011	15.342	− 0.594
FBEGENDM	− 0.006	13.568	− 1.460
EBEGENDM	0.031	14.670	1.675
ETHNICITYM	− 6.768*	0.050	− 5.201
FETHNICITYM	− 0.253	0.183	− 0.404
EETHNICITYM	8.505*	0.042	6.479

* Significant at the 1% level.
** Significant at the 5% level.

used a fixed effects model in which all observations are deviations from the historical means of individuals, each individual in the sample has a separate intercept for the regression, adding 1345 implicit variables to those for which we explicitly derive coefficients. Hence the need to calculate an adjusted R^2.

Table 1 shows the impact on YWHM of a standard deviation change in the interacted (h and e) variables for each of the four groups of workers, classified by permanence and ethnicity.[11] If we (rather arbitrarily) describe as high an impact on productivity of over 20%, then the most striking results in Table 1 are that LPWM has a high positive impact on productivity change for *all* four worker classifications, ETHNICITYM has a high negative impact for Irish only, while LNEXPADJM has a high positive impact and RCOTLM a high negative impact for permanent workers only. In addition, LNPIECERM has a medium (10–20%) negative impact for all groups of workers, while BEGENDM had a medium negative impact for Irish and a medium positive impact for Yankees. Note that the impact of LNTIMEM is *negative* for all classifications of workers, not what one would expect if this variable indeed captured the contribution of management to productivity growth.

In Regression 1, the only technical capabilities variables that exhibit significant impacts on productivity are the January through July monthly adjustments. The interpretation of the negative coefficients for all of these variables, D1M through D7M, is that productivity in these months is significantly less than productivity in the excluded month, December. For lack of better information, we might assume that the monthly differences were due to the factors—humidity, backwaters, and July heat— mentioned above.

Of the human capabilities variables in Regression 1, only two, both interactive, are statistically significant. The t ratio for LNEXPADJM indicates that variations in experience among *impermanent Irish* (MI) workers has no significant impact on *their* productivity. The statistical results on the interacted variables reveal, however, that the Mill No. 2 permanent workers (both Irish and Yankee), although not Yankees taken as a group, are significantly different from the MI group in the positive direction in terms of the impact of their experience on productivity. Of all the variable classifications in Table 1, the two largest impacts on

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[11] To derive the standardized impact, we calculated a standardized coefficient for each h and e variable by multiplying the parameter estimate of each h and e variable in Regression 1 by its standard deviation, and then dividing the standardized coefficient by the standard deviation of the dependent variable, YWHM. If we designate the standardized coefficient of a noninteracted variable as c_1, an associated F-interacted variable as c_2, and an associated E-interacted variable as c_3, the standardized impact for MI workers is c_1, for PI workers is $c_1 + c_2$, for MY workers is $c_1 + c_3$, and for PY workers is $c_1 + c_2 + c_3$.

TABLE 1
Percentage of Standard Deviation Change in YWHM Caused by Standard Deviation
Change in Independent Variable by Permanence and Ethnicity of Worker

	Impermanent Irish	Permanent Irish	Impermanent Yankee	Permanent Yankee
LNTIMEM	− 12.05	− 21.29	− 3.90	− 13.13
LNEXPADJM	5.76	49.59	12.11	55.95
CAPUTILM	− 6.12	− 9.35	− 13.37	− 16.61
SPARPAUXM	0.48	1.80	0.66	1.98
LPWM	44.19	32.08	39.76	27.64
RCOTLM	4.14	− 23.93	3.66	− 24.41
OPWM	− 7.02	8.10	0.12	15.23
ABSENTM	4.26	1.08	0.12	− 3.06
LPQUITDM	− 3.48	− 2.64	0.30	1.14
TEACHM	1.44	2.22	2.94	3.72
LNPIECERM	− 18.35	− 21.53	− 12.71	− 15.89
BEGENDM	− 10.13	− 14.99	17.15	12.29
ETHNICITYM	− 20.27	− 23.03	1.14	− 1.62

productivity change are those of LNEXPADJM for PI and PY workers—
50 and 56%, respectively.

Capacity utilization has a negative sign, indicating that the productivity
of MI workers is higher in cyclical troughs, but the coefficient is not
statistically significant. The impact of declines in capacity utilization on
the productivity of Yankee workers is, however, significantly different
at the 5% level than that for the impermanent Irish, consistent with the
evidence from the payroll books (referred to above) that individual per-
formance was systematically monitored up to the early 1840s when Yankee
workers predominated in the weaveroom. Table 1 shows medium negative
impacts for both classifications of Yankee workers, but low negative
impacts for the Irish.

A number of the work effort coefficients are statistically significant.
LPWM is significant with a positive sign, indicating (under the assumptions
set out in Section III) that the work effort of the MI workers is being
intensified by means of stretch-out. At the 5% level, permanent workers
are significantly different from MI workers, the negative sign of the
coefficient indicating that the labor of permanent workers is more difficult
to intensify than that of MI workers, perhaps because of better shop-
floor cohesion and resistance to intensification by those with more consis-
tent attachments to the workplace. Next to the standardized impact of
LNEXPADJM for PI and PY workers, the impacts of all four classi-
fications of LPWM are the highest in Table 1, all with a positive sign.

RCOTLM, the quality of cotton variable, is not significant for MI
workers. The impact of cotton quality on permanent workers is, however,
significantly different than its impact on MI workers in the direction of

added intensification, suggesting that the fact of being permanent, and the lessened ability to exit from worsening work conditions inherent therein, reduces the ability of permanent workers to avoid the intensification impact of inferior cotton relative to MI workers. Note that, in the presence of permanent workers, the *relatively* successful resistance to increases in looms per weaver may well have led management to resort to the use of inferior cotton in order to cut costs. Permanent workers may well have reacted more adversely to discrete and easily recognizable increases in looms per weaver than to gradual deterioration in the quality of cotton. As can be seen in Table 1, the standardized impacts of RCOTLM for PI and PY workers are of about the same relatively high negative magnitude. Those for MI and MY workers are also of about the same magnitude, but relatively low and positive.

The overseers per worker variable for MI workers is significant at the 5% level with a *negative* sign, indicating that increases in overseers per worker may have been a specific managerial response to particular difficulties in getting high levels of productivity (relative to the prevailing norm) out of MI workers. In Table 1, MI workers are the only group for whom the impact of OPWM on productivity change is negative. An increased ratio of overseers to MI workers may have been needed because impermanent Irish lacked the necessary physico-cognitive capacities to perform factory work—a human capabilities factor. Alternatively, the problem may have been the integration of impermanent Irish into already existing conditions of very high levels of work intensity. In either case, the statistical results clearly indicate a different role of overseers for MI workers than for the other groups: at the 1% level for permanent workers and at the 5% level for Yankee workers the impact of OPWM on YWHM differs significantly from its impact for MI workers, and the coefficients of both interacted variables have positive signs. By the same token, it is possible (although by no means statistically proven) that the main function of overseers for PI, MY, and PY workers was to ensure high levels of work effort, holding human capabilities constant.

The coefficient of the absenteeism variable, ABSENTM, is not significant for MI workers. But the impact of this variable on permanent workers is significantly different than its impact on MI workers with a negative sign, suggesting to us that, for any given level of temporary separations as measured by ABSENTM, permanent workers had less power to control the pace of work than impermanent workers, presumably because of their higher dependence on mill work for earning a living. All of the standardized impacts of ABSENTM in Table 1, however, are relatively low.

The purpose of LNPIECERM is to discern whether workers increased their levels of work effort in response to positive incentives—in this case increases in real income for a given level of output—rather than in

response to negative incentives, particularly the threat of job loss. The existence of such noncoerced increases in work effort, leading to higher levels of productivity, would be supported by a positive coefficient on LNPIECERM. The highly significant, but *negative,* coefficient for MI workers rules out this positive incentive as an explanation of their productivity performance. Indeed the negative sign lends support to the contrary hypothesis of unremunerated intensification of labor: as indicated for the period from 1848 through 1855 in Figs. 1 and 2, as productivity went up, real piece rates were cut even to the point where real hourly wages declined. Moreover, permanent workers are not statistically different than MI workers in this regard. Unlike the other two coefficients in the group, however, the coefficient on ELNPIECERM is positive and just shy of being significant at the 5% level, suggesting that Yankee workers responded more positively to income incentives than did MI workers. Nevertheless, in Table 1 all the standardized impacts for this variable have negative signs.

Finally, and of utmost significance given all the other factors that have been held constant, the movement of the ethnic composition of the weaveroom toward more Irish (the inverse of ETHNICITYM) has a highly significant positive impact on the productivity of MI workers. Permanent workers as a group cannot be distinguished from MI workers, but Yankee workers as a group can be. In Table 1, there is a marked difference in the standardized impacts of ETHNICITYM for Irish and Yankee workers, respectively, indicating the ability of Yankees to resist being subjected to "Irish conditions" of stretch-out and speed-up in the early 1850s when the ethnic composition of the weaveroom was shifting heavily to Irish. Similarly, the highly significant positive coefficient of EETHNICITYM can be interpreted to mean that, with movements of ethnic composition toward more Irish, Yankee workers were better able to resist intensification of labor.

F tests on all the ETHNIC interactive variables taken together and all the FALLPRES interactive variables taken together in the regression above show both sets of variables to be significant at the 1% level. For purposes of comparison, however, we think that it is useful to estimate the production function with only ETHNIC as an interactive variable, particularly since we are much more confident that our measure of ETHNIC actually distinguishes between Yankee and Irish workers than that our measure of FALLPRES actually distinguishes between workers with and without *agrarian* ties (or other alternative opportunities such as summer school teaching), the structural distinction that the variable was originally designed to capture.

In Regression 2, the most notable impacts on the *t* variables caused by dropping the FALLPRES interactive variables from Regression 1 are that D7M (July) and D8M (August) are now significant at the 1% level.

REGRESSION 2
Production Function with ETHNIC Interacted
Dependent Variable: YWHM, SD = 1.6677
N = 12140,　R^2 = 0.4049,　$\overline{R}^2$ = 0.3270,　SSE = 20093.66

Independent variable	Parameter estimate	SD	T ratio
D1M	−0.387*	0.265	−6.073
D2M	−0.662*	0.269	−10.297
D3M	−0.267*	0.271	−4.031
D4M	−1.502*	0.265	−22.066
D5M	−0.561*	0.268	−8.259
D6M	−0.517*	0.265	−7.539
D7M	−0.265*	0.272	−3.860
D8M	−0.194*	0.270	−2.638
D9M	−0.019	0.268	−0.266
D10M	−0.080	0.268	−1.152
D11M	−0.069	0.263	−1.052
DTECH1M	−0.101	0.136	−0.743
DTECH2M	0.549	0.163	0.957
DTCOT2M	−0.289	0.157	−0.498
WPOWM	0.064	0.301	1.189
LNTIMEM	1.145	0.210	0.347
ELNTIMEM	−1.558	0.208	−0.469
LNEXPADJM	0.485*	0.703	4.171
ELNEXPADJM	0.124	0.618	0.995
CAPUTILM	−1.546**	0.086	−2.516
ECAPUTILM	−1.569**	0.078	−2.320
SPARPAUXM	0.503	0.049	0.651
ESPARPAUXM	−0.079	0.042	−0.091
LPWM	2.205*	0.310	13.656
ELPWM	−0.244	0.280	−1.335
RCOTLM	−1.401	0.057	−1.186
ERCOTLM	0.599	0.053	0.518
OPWM	−1.978	0.008	−0.311
EOPWM	12.740	0.008	1.833
ABSENTM	1.959*	0.077	2.882
EABSENTM	−1.550**	0.066	−2.073
LPQUITDM	−0.494	0.088	−0.988
ELPQUITDM	0.749	0.080	1.382
TEACHM	0.017	0.680	0.467
ETEACHM	0.058	0.543	1.009
LNPIECERM	−3.393*	0.098	−6.528
ELNPIECERM	1.053	0.089	1.820
BEGENDM	−0.018	15.342	−0.974
EBEGENDM	0.037**	14.670	1.967
ETHNICITYM	−7.192*	0.050	−6.189
EETHNICITYM	8.483*	0.042	6.455

* Significant at the 1% level.
** Significant at the 5% level.

The coefficients on D9M, D10M, and D11M (September, October, November) also appear to have been altered more than the coefficients on D1M through D6M (January through June). Since FALLPRES measures differences among workers in regularity of employment during the July–November periods, some of the impact of these differences on productivity may well be captured by the monthly adjustment variables with the exclusion of the FALLPRES interactives.

Table 2 summarizes the standardized impacts of the h and e variables. For both Irish and Yankees, LNEXPADJM and LPWM have high positive impacts on productivity change. ETHNICITYM has a high negative impact for Irish, while LNPIECERM has a medium negative impact for both groups. BEGENDM has a medium negative impact on both groups, but in opposite directions.

The impact of individual experience is clear-cut in Regression 2. The coefficient of LNEXPADJM refers to Irish workers in general, and is significant at the 1% level with a positive sign. Moreover, Yankee workers are not significantly different than Irish workers, and the sign of ELNEXPADJM is also positive. The positive standardized impacts of LNEXPADJM are both over 20%.

The coefficient of CAPUTILM is now significant at the 5% level with a negative sign, indicating that on average the productivity of Irish workers rose in cyclical troughs. Yankee workers are significantly different from Irish workers at the 5% level, and the negative sign indicates that for these workers the productivity increases in cyclical downturns were even stronger than for Irish workers.

The coefficient of LPWM is significant at the 1% level and positive. As in Regression 1, this finding is consistent with the hypothesis that

TABLE 2

Percentage of Standard Deviation Change in YWHM Caused by Standard Deviation Change in Independent Variable by Ethnicity of Worker

	Irish	Yankee
LNTIMEM	14.39	−5.04
LNEXPADJM	20.45	25.06
CAPUTILM	−7.98	−15.29
SPARPAUXM	1.50	1.32
LPWM	41.02	36.94
RCOTLM	−4.80	−2.88
OPWM	−0.96	5.16
ABSENTM	9.05	2.94
LPQUITDM	−2.58	1.02
TEACHM	0.72	2.58
LNPIECERM	−19.97	−14.33
BEGENDM	−16.55	16.01
ETHNICITYM	−21.59	−0.24

productivity gains by Irish were the result of the intensification of their labor by means of stretch-out. The coefficient of ELPWM indicates that Yankees as a group were not significantly different from the Irish in terms of the impact of stretch-out on productivity. For both Irish and Yankees, the highest standardized impact is associated with changes in LPWM.

Neither of the coefficients of RCOTLM or ERCOTLM is statistically significant. Comparing these results with the cotton quality findings in Regression 1 suggests that if inferior cotton was used by management in contexts where it had more power to intensify labor, then it was foisted on permanent workers as a group rather than on the Irish as a group or the Yankees as a group. In Regression 1, the overseers per worker variable is significant for impermanent Irish whereas in Regression 2 it is not significant for the Irish as a group, reinforcing the previous interpretation that it was the *impermanence* of the Irish rather than being Irish itself which posed particular productivity problems in the weaveroom.

The impact of the exclusion of the FALLPRES interactives on ABSENTM are particularly interesting. In Regression 1, the coefficient of ABSENTM, referring to the productivity impact of temporary quits for MI workers, is not significant, but in Regression 2 the coefficient referring to the same relationship for Irish workers in general is highly significant. In both cases, the sign of the coefficient is positive, indicating that temporary separations by Irish gave them no power to control the pace of work. But the coefficient of EABSENTM shows that at the 5% level Yankee workers are significantly different than Irish workers, in the *negative* direction: high levels of temporary mobility in and out of the Mill No. 2 main weaveroom apparently gave the Yankee workers relatively more power to control the pace of work than Irish workers. The standardized impacts shown in Table 2 are, however, relatively small for both groups of workers.

As for positive incentives, the coefficient of LNPIECERM in Regression 2 indicates that all Irish were in the same unfortunate position as impermanent Irish as revealed by Regression 1: a highly significant negative relation between real income incentives and productivity. Analogous to Regression 1, Yankee workers cannot be distinguished from Irish workers at the 5% level. For both Irish and Yankees, the standardized impacts of LNPIECERM are negative at a relatively medium (but for Irish bordering on high) level.

Consistent with the findings in Table 1, the impact of BEGENDM is negative for Irish and positive for Yankees, both at a medium level. In Regression 2, BEGENDM is not statistically significant but the ETHNIC interactive is significant at the 5% level. These results suggest that "seniority" led the Yankees to work harder but the Irish to restrict their output, perhaps reflecting the greater ability of employers to inflict *unremunerated* intensification on the foreign-born workers.

Finally, the highly significant negative coefficient of ETHNICITYM shows that, for Irish workers at least, an upward trend of productivity in the Mill No. 2 main weaveroom is highly correlated with the transition from "Yankee" to "Irish" production relations. For Irish workers, the standardized impact of ETHNICITYM is negative, more than offsetting the impact of the individual experience variable, LNEXPADJM. The significant positive coefficient of EETHNICITYM indicates that in this transition, the performance of Yankee workers can be distinguished from that of Irish, the general implication being that the social conditions inherent in "average ethnicity" in a given historical period can have a significant impact on observed productivity performance.

In our view, the regression results lend support to both the "learning-by-doing" and the "production-relations" hypotheses. What can we then say about the relative impacts of technical, human capabilities, and work-effort factors in the determination of productivity change? The inevitable problem of multicollinearity among the independent variables precludes us from giving a definitive answer to this question. We cannot say precisely how much of the variance a particular variable or group of variables explains. But one way to assess the relative impacts of the different variable classifications that takes multicollinearity into account is to calculate the additions to $\bar{R}^2$ when the results of regressions containing different combinations of classifications are compared. For example, if $\bar{R}^2_{q \cdot h}$, $\bar{R}^2_{q \cdot e}$, $\bar{R}^2_{q \cdot th}$, $\bar{R}^2_{q \cdot te}$, and $\bar{R}^2_{q \cdot the}$ are compared, $(\bar{R}^2_{q \cdot the} - \bar{R}^2_{q \cdot th})$ gives us a lower-bound estimate and $\bar{R}^2_{q \cdot e}$ an upper-bound estimate of the independent impact of e variables, while $(\bar{R}^2_{q \cdot the} - \bar{R}^2_{q \cdot te})$ gives us a lower-bound estimate and $\bar{R}^2_{q \cdot h}$ an upper-bound estimate of the independent impact of h variables. Table 3 shows the lower- and upper-bound estimates of percentages of $\bar{R}^2$ explained by variable classifications.

These results suggest that the production-relations hypothesis should be given at least as much attention as the learning-by-doing hypothesis in research into the "Horndal effect." There is more to the process of labor productivity growth than the technical development of inputs. Social influences on productivity growth must be considered as well.

TABLE 3
Lower-Bound and Upper-Bound Estimates of Variance Explained by Variable Classifications (Percent)

Variable classification	Regression 1		Regression 2	
	Lower bound	Upper bound	Lower bound	Upper bound
t	5.19	5.37	5.13	5.89
h	4.69	13.65	4.07	11.18
e	11.04	23.27	10.94	21.76

Despite the extreme microeconomic nature of our data set, we recognize that there is ample room for debate over the measurement and interpretation of all three classifications of variables in our study. Our microeconomic approach, however, at least brings the issue of the socio-technical nature of production into clear view rather than burying the sources of productivity growth within aggregated data, to be barely noticed, nevermind understood. We have constructed variables in particular ways to quantify many technical and social phenomena that are not easily measured and that might be measured in other ways. We have placed specific interpretations on these variables that are suggested by our theory of the production process. Other theories and interpretations are possible. *Given* our general theoretical framework and *given* the ways we have chosen to construct, interpret, and classify our variables, we are satisfied that we have generated meaningful statistical results. The results are meaningful not because of the degree of statistical significance per se, but rather because they support our contention that further research and debate over the theory, measurement, and interpretation of the social and technical determinants of productivity growth are in order.

In particular, it should be recognized that we still do not have a direct measure of the intensity of labor, and probably never will. But measurement problems should not damn the attempt to incorporate the notion of work effort into the production function. On the contrary, by confronting these problems, we can, at a minimum, develop an enlightened skepticism of conclusions drawn from more aggregated analyses, particularly when no attempt has been made to identify or distinguish between the impacts of social and technical factors on productivity.

V. SOME BROADER IMPLICATIONS

The development of theory and the development of empirical work must go hand in hand. For the empirical issues that have been addressed in this paper, neoclassical theory is not much help. A perspective that assumes that the firm simply responds to the dictates of the market while taking technology as given cannot possibly provide us with much insight into the role of social relationships and the exercise of power in an economic system. Over a century ago, Marx argued that the *interaction* of the relations and forces of production was the key to understanding capitalist development. One need not accept Marx's conclusions (Lazonick, 1983a) to agree that this is a proposition worth exploring rather than ignoring. In our view, the present study lends empirical support to the hypothesis that productivity outcomes are significantly affected by *who* has power over whom in the production process and *how* those who possess power choose to utilize it.

In particular, this study supports the proposition that "labor scarcity" puts power in the hands (or more accurately the feet) of workers. As a

consequence, labor scarcity will have an impact on the choice of technique, be it the choice of the quality of raw material (e.g., cotton), the choice of number of machines (e.g., looms) per worker, or the introduction of a new technology (i.e., *better* rather than simply more machinery). We would agree that, generally speaking, managers of capitalist firms make rational choices among alternative available techniques. But we would argue that they do not make these choices solely according to relative factor prices.[12] Conditions of labor scarcity endow the relevant workers with the power not only to demand higher wages but also to exercise more control over the pace of work in the production process. We would argue that it is the impact of labor scarcity on productivity, not just its impact on wages, that leads capitalists to look for skill-displacing techniques that will make them less dependent on "scarce" labor.

Alternatively, in conditions of "labor abundance"—as with the coming of the Irish to the vicinity of Lowell—capitalists will not only reap the benefits of lower wages, but will also take advantage of the situation to introduce more effort-intensive production techniques; that is techniques which require *more* work effort (either in the form of more extensive or intensive use of labor power) to achieve the same amount of output. One example is the propensity of capitalists to foist inferior cotton on more dependent workers. Another example is the introduction of more looms per worker without sufficient slowing of the looms to maintain work effort constant.

Lacking a theory of the role of work effort in the production function, economists and economic historians have been led to argue that an increase in the number of looms per worker makes workers more productive because they now have more capital with which to work (see for example, McGouldrick, 1968, pp. 38–40). But such an argument ignores the complementarity of capital and labor inputs in production, and confuses *more* capital with *better* capital. If a certain number of workers are given more looms of the *same* quality, more output can only result from the intensification of their labor, an outcome that is more likely to be achieved in conditions of labor abundance. It is only if these workers are given "better" looms—that is, looms that permit them to produce more output with the same input of work effort—that their labor will be aided by the "choice of technique." And, in contrast to increased capital–labor ratios resulting from stretch-outs, effort-decreasing technical change resulting from the introduction of better machinery is more likely to occur not in periods of labor abundance, but rather in periods of labor scarcity. One implication of our analysis is that economists had best begin to recognize the differences between qualitative and quantitative changes in capital–

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[12] For debate over choice of technique in early U.S. manufacturing solely in terms of relative factor prices, see, for example, Temin (1966) and Fogel (1967).

labor ratios if they want to understand productivity growth and technological change.

Wages are neither entirely independent nor uniquely related to the intensity of labor. "External" wages function to attract workers into the workplace, but "internal" wages are intended to entice work out of workers once they are there. If, under conditions of labor abundance, an employer seeks to eliminate some or all internal earnings premiums so as to pay workers an amount closer to the external wage, an attempt by the workers to restrict output is the likely result. Alternatively, conditions of labor scarcity will inhibit managerial attempts to eliminate earnings premiums, and hence may lead workers to respond more positively to wage incentives that are tied to output. The intensity of work effort, and with it productivity, will then be determined by the "on-the-job" utility-maximizing preferences of workers, and not by the power of employers to deny any given worker a job. In other words, any observed relation between work effort and pay will depend in part on the structure of social power that characterizes the prevailing social relations of production.

Moreover, given fixed capital, unit capital costs, and hence the return on invested capital, depend to some extent on work effort applied in combination with that capital (Lazonick, 1984). Factor prices are an outcome of the social relations of production as well as a precondition for the choice of technique. To explain not only productivity but also profitability, the interactions of factor prices, technology, and social organization must be analyzed in terms of a dynamic historical process.

The basic argument of this study is that alternative opportunities for attaining a "living" are important determinants of both the productivity of individual workers and the wages they receive. If different groups of workers such as Yankees or Irish—or men or women—face distinctly different alternative opportunities at a point in time or over time, we can expect that the unit labor cost outcomes across these groups of workers will be markedly different. It may be ill-advised, therefore, to impute productivity differences to wage differences of different segments of the labor force, as is done for example by both sides of a recent debate on productivity in the early New England textile industry (David, 1975, Chap. 2; Nickless, 1979). In our study, as the Irish entered the Mill No. 2 main weaveroom, real wages fell while labor productivity rose—if one's measure of "labor quality" is real wages, the Irish were "lower quality" workers than Yankees, but if one's measure of "labor quality" is labor productivity the Irish were "higher quality" workers. The higher levels of productivity achieved with the coming of the Irish were not, moreover, because the Irish had more "human capital" than the Yankees; in all probability they had less. If, on the basis of the productivity criterion, the Irish were "higher quality" workers than the Yankees, it was because employers found it easier to intensify their labor.

Economists have to rethink the whole concept of exploitation. They might start by going back to the distinction, put forth by Marx over a century ago, between the capacity to work and work actually performed, *given* the wage. The neoclassical notion of exploitation as consisting of wages below the value of the marginal product of labor has little to commend it. In the Marxian model, the ability of employers to exploit workers depends upon the existence of a reserve army of labor; that is, a situation where the labor demand curve intersects a perfectly elastic segment of the labor supply curve (Lazonick, 1983a). Given technology and human capabilities, productivity will depend upon the intensity of labor achieved in production. Given the supply price of labor, exploitation will depend on the degree of intensification. Higher degrees of intensification will shift the marginal product of labor curve upwards. *Given* the demand for labor curve (determined in part by the degree of intensification), the fact that profit-maximizing capitalists employ additional units of labor to the point where the market wage just equals the value of the marginal product of labor is incidental to the analysis of exploitation.

Finally, with the intrusion of conflict, power relations, and variations in work effort into the theory of production, the notion of "efficiency" that is so central to neoclassical orthodoxy ceases to be an objective measure of performance capability or welfare. The possibility that productivity may be raised by unremunerated intensification of labor should lead us to ask: efficient for whom? In the production process, the notion of "Pareto-optimal" moves, where nobody is made worse off than before, is only tenable if the structure of relative power is taken as given and remains unchanged. As often as not, references to "efficient" or "Pareto-optimal" outcomes mean only that the economist either views the production function as technically determined or considers a particular structure of production relations as ideal.

APPENDIX: DEFINITION OF VARIABLES

All variables refer to *monthly* observations for individual weavers in the Lawrence Mill No. 2 main weaveroom unless otherwise indicated.

Dependent variable: YWH = Output per weaver–hour of type C cloth.

Independent variables:

(1) $D1, \ldots, D11$ = monthly adjustments for variations in technical capability, where $D1 = 1$ if January, 0 otherwise; $D2 = 1$ if February, 0 otherwise; $\ldots$; $D11 = 1$ if November, 0 otherwise.

Dryer weather exacerbated problems of yarn breakages, holding other factors constant. Mean monthly measures of relative humidity for the Boston area averaged over the years 1886 through 1890 (for which the data are first available) were January, 73.1; February, 72.4; March, 70.8; April, 67.1; May, 74.9; June, 77.1; July, 78.8; August, 79.4; September, 82.9; October, 78.1; November, 74.9; December, 72.7. *Blue Hill Mete-*

orological *Observatory,* Mudge: Boston, 1886 and Wilson: Cambridge, 1887–1890.

(2) DTECH1 = a dummy variable to control for the introduction of a let-off motion on the looms in May 1835; 0 for every month prior to May 1835, 1 for May 1835 and every month thereafter.

Evidence on the introduction of the let-off motion and details of its mode of operation and function can be found in Lawrence Manufacturing Company records, Baker Library, Manuscripts Division, MAB-1, Letters from William Austin to Henry Hall, March 5, 1835 and May 1, 1835; James Montgomery, *A Practical Detail of the Cotton Manufacture of the U.S.A. Compared with that of Great Britain,* Niven: Glasgow, 1840, 103; Richard Marsden, *Cotton Weaving,* Bell: London, 1895, 72; Amasa Stone versus William and Amasa Sprague, Depositions from the trial, Rhode Island District Court, June Term 1840 at Newport, Rhode Island, located at Archives Branch, Federal Archives and Records Center, National Archives, Waltham, Massachusetts.

(3) DTECH2 = a dummy variable to control for the introduction of a new type of cotton picker into the mills of the Lawrence Manufacturing Company in August 1844; 0 for every month prior to August 1844, 1 for August 1844 and every month thereafter.

Evidence on the introduction of these cotton pickers into the Lawrence mills can be found in Lawrence Mfg. Co., MA-1, Letter from Henry Hall to William Aiken, September 26, 1845; BB-2, Ledgers, August 1844 and August 1845.

(4) DCOT2 = the cotton quality variable, RCOTL (defined below), interacted with DTECH2.

(5) WPOW = a dummy variable to control for known water power shortages for the Lowell mills; 1 for months during which power shortages occurred, 0 for all other months.

The identification of these power shortages is based upon an exhaustive search of the 79-volume collection of bound letters, most of them written to or by James B. Francis, the hydraulic engineer at the Lowell Locks and Canals. Proprietors of Locks and Canals records, Manuscripts Division, A-1 through A-79. The evidence is summarized in Linda Gray, *Water Power at Lowell,* photocopy, Harvard University, August 1983. There is evidence for water power shortages in 1838, 1839, 1840, 1849, and 1852. In addition, we included a known power shortage that occurred in 1846 due to a combination of seasonal shortage and increased demand for power as new mills were opened. Subsequently the supply of water power was expanded to meet this increased demand by the building of the Northern Canal. Where the precise duration of the power shortage was not cited in the Francis letters, a graph of capacity utilization was used to determine how many months on either side of the month cited were likely to have had water shortages. In addition the late summer

and fall months of 1841 were so similar to periods of known shortage that occurred in the previous 3 years that we decided to include them as well. September and October of 1845 were also included as power shortage months because capacity utilization during these months exhibited similar characteristics to capacity utilization during the power shortage months of 1846. Power shortage months are 1838(08,09,10), 1839(07,08,09,10,11), 1840(07,08,09,10), 1841(08,09,10,11), 1845(09,10), 1846(08,09,10,11,12), 1847(01), 1849(07,08,09,10), 1852(08,09,10,11).

(6) LNTIME = a measure of learning by doing by Mill No. 2 = logarithm of the cumulative months since Lawrence Mill No. 2 opened for operation in January 1834.

(7) LNEXPADJ = a measure of learning by doing by individual weavers = logarithm of number of cumulative days worked by each weaver whose name appears on the payroll in any given month.

There is a 2-year gap in the payroll records between April 1836 and April 1838. The experience variable is therefore adjusted to add days of experience for those workers who were in the weaveroom during both April 1836 and April 1838. Since the entire mill was shut down for 9 months during the intervening period, we need not adjust for that portion of the gap. We assume also that the average worker under consideration was away from the mill for an additional month before and after the shutdown, leaving 13 months of potential experience that might be ascribed to each worker. Thirteen months (at an average of 27 days per month) are then multiplied by the individual worker's absent rate in April 1838 to yield the days of experience imputed to the payroll-gap period.

(8) CAPUTIL = a measure of capacity utilization during any given month = the proportion of total loom capacity utilized each month = $[(A*B)+(C*B*D)]/(144*E)$, where

A = total days worked by piecehands in a given month,
B = average loom complement of piecehands in that month,
C = total days worked by sparehands in that month,
D = ratio of sparehand productivity to piecehand productivity in that month,
E = Mill No. 2 working days in that month,
and 144 is the number of looms in the Mill No. 2 main weaveroom.

Average daily output per sparehand during any given month is defined as total Mill No. 2 output minus the output of *all* Mill No. 2 weaving piecehands (in both main and auxiliary rooms), divided by the total number of sparehand days worked during the month. Our measure of capacity utilization is rendered inexact by the facts that we know neither the precise number of sparehands nor the precise number of looms tended by sparehands working in the *main* weaveroom. We estimate these values and use them to construct our measure of capacity utilization. The fact that CAPUTIL exceeds 1.0 from time to time (see Fig. 3) despite fixed

loom capacity reflects measurement errors in our estimation of these factors. Nevertheless, we believe that CAPUTIL provides a very good index of actual capacity utilization in the Mill No. 2 weaveroom from 1834 through 1855.

(9) SPARPAUX = the number of *auxiliary* sparehands per piecehand in any given month = $[A(1-B)]/C$, where
  A = total days worked by sparehands in a given month,
  B = ratio of sparehand productivity to piecehand productivity in that month,
  C = total days worked by piecehands in that month.
This measure of sparehands per piecehand nets out sparehands who might have been themselves tending looms, and therefore could not have been providing auxiliary services to piecehands.

(10) LPW = average number of looms tended by each weaver in a given month.

We do not in fact have direct evidence on looms per weaver. LPW was derived from information on the piece rates paid at any point in time as well as the trend in *average* number of looms per weaver for the weaveroom. Combining this trend with changes in piece rates over time allows us to distinguish between piece-rate cuts that were wage reductions per se and piece-rate cuts that were due to workers tending more looms. Benchmarks from sources internal to Lowell mills, newspaper accounts, and outside observers at Lowell corroborated our decisions of which piece rates to link to which loom complements. Figure 4 shows the average number of looms per weaver in any given month.

(11) RCOTL = an index of the quality of cotton actually used in main weaveroom production in any given month = the ratio of the price paid per pound of cotton, net of the cost of freight, insurance, and drayage, to the monthly price per pound of *standard quality* Upland cotton in New York.

Upland cotton prices are from Arthur H. Cole, *Wholesale Commodity Prices in the U.S., 1700–1861,* Harvard UP: Cambridge, 1938. The price paid by the mill for cotton, the weight of cotton shipped, as well as freight, insurance, and drayage charges are reported semiannually in Lawrence Mfg. Co. records, HA-2. Hence, the net price that the mill paid for cotton that is derived from these records is an average of the current month and the previous 5 months. The data from the semiannual accounts are interpolated to yield monthly data. The resulting series is lagged 3 months to represent the middle of the biannual reporting period. In order to match this derivation of the price that the mill paid for cotton in any given month as closely as possible to the New York price of standard quality ("middling") Upland cotton that was in effect when this cotton was purchased (and in the process adjust as well for delivery time from New York, New Orleans, and Charleston to Lowell), we calculated

the correlation coefficients of the mill's net price of cotton at time of purchase with the current New York Uplands cotton price, as well as with the New York price lagged 1 month through 5 months.

Monthly lag in the New York price of cotton

	0	1	2	3	4	5
Correlation coefficient	0.87747	0.88916	0.89436	0.89434	0.88777	0.87822

These coefficients suggest that a 2- to 3-month lag on the New York cotton price matches the mill's current net cotton price derived from the biannual records. In order to allow for this lag while at the same time making the form of the New York price series similar to the interpolated mill price series, we constructed a New York price series based upon a 6-month running average of the current month and 5 lagged months.

(12) OPW = overseers per worker (piecehands plus sparehands) in any given month.

(13) ABSENT = a measure of temporary separations while employed in the Mill No. 2 main weaveroom for individual weavers present in any given month = the ratio of the total number of workdays absent to the total number of workdays possible for every month in which a weaver worked at least 1 day.

(14) FALLPRES = a measure of the extent to which weavers depart temporarily for the summer and fall months = the number of days present in all prior mid-June through mid-November periods (calendar payroll months July through November) as a proportion of the total workdays possible over all prior mid-June through mid-November periods since that weaver first entered the Mill No. 2 main weaveroom.

Either the same values are entered from December through June of the current stint in the weaveroom, or zero is entered until a weaver has been present for at least 1 day during a July to November period. During July through November the value of FALLPRES is recalculated from month to month if the worker is present in any one of the months.

(15) LPQUITD = the proportion of weavers who quit the Mill No. 2 main weaveroom permanently in any given month = $A - B$, if $B > 0$, and $LPW_{t-1} > LPW_{t-2}$, or $CAPUTIL_{t-1} < CAPUTIL_{t-2}$; otherwise A; where

$$A = \frac{\text{permanent separations in } t - 1}{\text{number of weavers who worked in } t - 1},$$

$$B = \frac{(\text{weaver positions in } t - 2) - (\text{weaver positions in } t - 1)}{\text{weaver positions in } t - 2},$$

t = current month.

The proportion of permanent separations (A) has been adjusted by deducting any decrease in the stock of permanent positions available

from the previous month that are clearly the result of underutilization of capacity or increases in loom complements (B), so that $A - B$ reflects only voluntary quits and does not include layoffs. Some of the decreases in the stock of permanent positions may have been due to absolute labor shortages (which, judging from managerial correspondence, did occur at times), and hence should not be counted as permanent layoffs. We have not, therefore, deducted decreases in the stock of permanent positions if *both* capacity utilization was rising and the number of looms per weaver was not increasing. We have been unable to make an adjustment for workers who transferred to other rooms or mills of the Lawrence Manufacturing Company.

(16) TEACH $=$ an index of the remuneration and relative availability of teaching jobs for "literate" weavers $= [\text{LIT}*(A \div B)]/C$

$A =$ number of positions for female teachers in Massachusetts in a given month,

$B =$ wages of female teachers in Massachusetts in that month,

$C =$ number of positions for female operatives in Lowell in that month, and

$\text{LIT} =$ a measure of literacy $= 1$ if a weaver manifests the ability to sign her name, 0 if otherwise.

Data on numbers of female teachers from 1833–1834 to 1836–1837 and from 1838–1839 through the end of our period, and data on wages of female teachers for 1836–1837 and from 1838–1839 to the end of our period can be found in the *Annual Reports of the Massachusetts Board of Education*. Wage data for 1833–1834 through 1835–1836 were gathered from the manuscript material at the Massachusetts State House Archives. But data for 1837–1838 do not appear to be available in either published or manuscript form, and may never have been collected. Since 1837–1838 was a year for which Lawrence payroll records were also missing, only months from April through August 1838 had missing information. An average of the values for wages and teaching positions in 1836–1837 and 1838–1839 were used for these months. For all other months, annual data were converted to monthly data by assigning the same value for the entire school year starting in September and ending in August.

Data on the number of female workers in Lowell come from the *Annual Statistics of Manufacturing in Lowell*, Vox Populi: Lowell ("Statistics of Lowell Manufacturers"). The yearly figures were assumed to apply to January of that year, and were then converted to monthly data by interpolation.

"Literacy" is determined by whether or not a worker manifested the ability to sign her name in the payroll books. If a worker made a mark in the shape of a cursive L—*ℒ*—it generally meant that she was present at the mill on payday but could not sign her name. If she was not present, the Mill Agent would write an X or a friend might sign for her. A cursive

L is therefore the most distinctive indication that we possess of "illiteracy" while repeated signatures are the most distinctive indication of "literacy."

(17) LNPIECER = a measure of earnings incentives for weavers in any given month = the logarithm of the average real piece rate times the average loom complement = $\log\{[(A*B) \div C]/D\}$, where

A = average loom complement in a given month,

B = total piece earnings in that month,

C = total yards produced by piecehands in that month, and

D = 0.01 (price index), where the price index used is Arthur Cole's "All Commodity Index of Wholesale Prices," in Cole, *Wholesale Commodity Prices*.

(18) BEGEND = a measure of seniority = in a given month, the total elapsed time since a weaver first entered the Mill No. 2 main weaveroom.

(19) ETHNIC = ethnicity = the probability that a person is non-Irish.

(20) ETHNICITY = a measure of the ethnic composition (that is, "Yankeeness") of the main weaveroom = the proportion of weavers in any given month who are non-Irish.

The ethnicity of workers at Lawrence Manufacturing Company is unknown because register books that may have contained such information (as, for example, Dublin used for the Hamilton mills in *Women at Work*) have not survived. We therefore had to estimate the probability that a given name in our data base is Irish or non-Irish. Virtually all non-Irish workers in our data base were either English, Scottish, or American-born of British ancestry. For the sake of brevity (although not complete descriptive accuracy) we have labeled all these non-Irish as "Yankees."

To estimate these probabilities, we have drawn upon four relevant data sets in which the ethnicity of particular individuals is known.

Data sets used to determine ethnicity

	Set 1[a]	Set 2[b]	Set 3[c]	Set 4[d]	Total
Last names					
Irish	27,746	345	292	405	28,788
Non-Irish	9,525	830	263	10,375	20,993
Unknown				2,895	
Total					49,781
Women's first names					
Irish		291	226		517
Non-Irish		664	199		863
Total					1,380

[a] This data set was supplied by the Philadelphia Social History Project, University of Pennsylvania (funded by the National Institute of Mental Health, National Science Foundation, National Endowment for the Humanities, and the National Institute of Child Health and Human Development). It contains names and ethnicities of Philadelphia region males, 18 years of age and older, from the 1850 census manuscripts. Henry

Williams, Assistant Director of the Project, provided supplementary advice, including the warning that the list of 9525 "non-Irish" names contains a "not insignificant number of second generation Irish." Since the census was made in 1850, any second generation 18+ males would have had to have been born in the United States before 1832, a time at which there were relatively few Irish in the country. Hence we decided to leave the file as is rather than risk even greater distortion of the results by seeking to identify the second-generation Irish.

[b] The Murray Center at Harvard University stores the data files that Thomas Dublin prepared for *Women at Work* (Columbia UP, 1979). The file that was used here includes all workers at the Hamilton Mfg. Co. who were present in August 1850, from which we selected only those individuals with known ethnicity.

[c] This data set was prepared by Steven J. Dubnoff for his dissertation, "The Family and Absence from Work: Irish Workers in a Lowell, Mass. Cotton Mill, 1860," Brandeis University, April 1976. The data file contains the names and ethnicity of workers in Mill A of the Hamilton Mfg. Co. in June 1860.

[d] The Register books of the Hamilton Mfg. Col, Volumes 482, 483, 485, 486, 487, 488, 489, and 490, Manuscripts and Archives Division of Baker Library, were used to supply this list of names and ethnicities. Only the names of individuals who were leaving were used so that names drawn from the register books through March 19, 1849 (Vol. 490) would not overlap with the names in Dublin's file, which includes individuals present in the Hamilton Co. in August 1850.

The first stage of assigning the probability of Irish or non-Irish ethnicity to particular names involved ascertaining the frequency that a given unique last name was Irish or non-Irish from the "population" of last names comprised of the 49,781 surnames of known ethnicity. Since two names could have been the same name phonetically but have been spelled differently by an agent or an illiterate worker, a more liberal phonetic assignment was used on 1730, or 3.5% of the total names (all of which were in the Dublin and Dubnoff samples). Once the frequencies of Irish or non-Irish last names were established, frequencies of women workers' first names were calculated using the Dublin and Dubnoff samples (using the same phonetic rules as for last names). The next step involved pulling out all individuals who, on the basis of surnames, had a 100% probability of being either Irish or non-Irish. The average ethnicity per month of these individuals established a trend rate of ethnicity over the period. The probable ethnicity of individuals who do not have a 100% probability of being Irish or non-Irish depends upon when the individual first arrived in the mill. For example, one might say that a "Catherine Hagar" had a greater probability of being Irish if she arrived in 1855 than if she arrived in 1834. The final step was to use the first and last name probabilities

calculated from the four samples to assign an ethnicity probability to each individual in the Lawrence Mill No. 2 sample. The following rules were used: (1) If an individual's surname frequency was 75–100% Irish or non-Irish, then the individual was assigned that probability of being Irish or non-Irish, respectively. (2) If the surname frequency of an individual was between 25 and 75% Irish or non-Irish then the frequency of that individual's first name was also used in the calculation of an equal footing with the surname. (3) If no probability was available for a given surname, then probable ethnicity was assigned by the frequency of first name ethnicity. (4) If no surname or first name frequency was available for an individual, then that individual was assigned the value of the trend in ethnicity for the first month that the individual arrived in Mill No. 2.

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