WHITTLING AWAY AT PRODUCTIVITY DISPERSION

By

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Abstract

In any time period, in any industry, plant productivity levels differ widely and this dispersion is persistent. This paper explores the sources of this dispersion and their relative magnitudes in the textile industry. Plants that are measured as being more productive but pay higher wages are not necessarily more profitable; wage dispersion can account for approximately 15 percent of productivity dispersion. A plant that is highly productive today may not be as productive tomorrow. I develop a new method for measuring *ex-ante* dispersion and the percentage of dispersion "explained" by mean reversion. Mean reversion accounts for as much as one half the observed productivity dispersion. A portion of the dispersion, however, appears to reflect real quality differences between plants; plants that are measured as being more productive expand faster and are less likely to exit.

Keywords: textiles, productivity dispersion, mean reversion and plant productivity levels.

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I. Introduction

Economists have long been interested in the widespread cross-sectional dispersion in plant quality within an industry.[1] Different models of industry equilibria employ different *dispersion sources* to generate dispersion in plant quality. Models in which technical change or selection lead to creative destruction are based on real and persistent differences in plant quality (cf. Dwyer, 1994; Caballero and Hammour, 1994; and Jovanovic, 1982). In other models, plants are subject to idiosyncratic productivity shocks, which may or may not be persistent (cf. Ericson and Pakes, 1992; Hopenhayn, 1992; and Dixit, 1992).[2] Additionally, Chari and Hopenhayn (1992) generate dispersion through technical change and vintage human capital. Given the breadth and richness of this theoretical literature, it is important to determine empirically the relative importance of

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[1]Plant or firm quality has been proxied by size (cf. Lucas, 1978), growth rates (cf. Mansfield, 1962), and profit rates (cf. Pakes' review of Mueller, 1987; and Rumelt, 1991) and the measured value of an installed unit of capital, i.e., q (Hopenhayn, 1992b).

[2]In Ericson and Pakes (1994) the productivity shocks are influenced by the firm's level of investment.

the different dispersion sources.

When measuring plant productivity levels in the textile industry, I find that the most productive plants produce up to three times the output of the least productive plants with the same inputs. Previous empirical research has found that: (1) more productive plants pay higher wages; and (2) plant productivity levels have a large transitory component.[3] This paper measures the potential for these two dispersion sources to explain the observed dispersion in productivity levels. A third possibility is that the dispersion results from imperfect competition. In order to generate null hypotheses, however, I must assume perfect competition; this paper asks: what percentage of the dispersion in productivity levels is *expected*, given the magnitude of a dispersion source and the assumptions of a competitive market?

Most measures of productivity do not account for heterogeneity in worker and/or job quality. In a competitive equilibrium, more productive plants may pay higher wages because they employ higher quality workers (Doms, Dunne, and Troske; 1994) or they provide poorer working conditions. This will lead to dispersion in measured productivity that may be thought of as measurement error (a worker's skill level is an unobserved

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[3] See for example Bartelsman and Dhrymes, (1991); Baily, Hulten, and Campbell (1992); Olley and Pakes (1992); Bahk and Gort, (1993); and Gort and Bahk and Wall, (1993).

production input and job quality may be thought of as an unobserved production output.) My data clearly demonstrates, however, that wage dispersion is not the whole story; if one plant can produce three times the output per input as another plant with labor that is 30 percent more expensive, then it must be more profitable, *ceteris paribus.* Approximately 15 percent of the observed dispersion is expected in the context of a competitive market given the magnitude of wage dispersion.

The second source of productivity dispersion is transitory idiosyncratic shocks. Demand or supply shocks and/or measurement error will lead to dispersion in observed productivity. A stochastic competitive market (see Section IV) predicts that there will be no *ex-ante* dispersion in productivity levels. This paper develops a new method for measuring *ex-ante* dispersion and the percentage explained by mean reversion in the context of highly unbalanced panel data with serial correlation. Within three years, up to one half the dispersion can be explained by mean reversion.[4] Given its magnitude, determining the economic mechanism behind mean reversion should be a research priority.

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[4]Dwyer (1994b) develops a method for analysis of variance in a balanced panel with serial correlation. It then executes this methodology on a balanced version of the data sets used in this paper. In 4 out of 21 four-digit textile industries, there are enough plants present in every year to create a balanced panel. Balancing the panel, however, omits over 90 percent of the plants ever present in these industries. The results of this alternative methodology are then compared to the results in this paper; the results are remarkably similar.

Many papers have found evidence suggesting that manufacturing industries are not in a long run equilibrium.[5] If an industry is not in a long run equilibrium, one would expect the more productive plants to grow faster and to be less likely to exit (cf. Dwyer, 1994; and Jovanovic, 1982). Provided productivity is appropriately measured, this paper shows that this is indeed the case. This suggests that a portion of the observed dispersion does indeed reflect actual differences in plant quality.

This paper's contribution is to develop and execute a methodology for apportioning productivity dispersion into different sources. Some of the dispersion is the product of wage dispersion and some of it appears to reflect real quality differences between plants. The largest dispersion source, however, is transitory shocks. These results are suggestive as to the plausibility of different models of industry equilibria. For example, models in which plants differ because of their stocks of general human capital differ seem inconsistent with the evidence.

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[5]For example, productivity growth is largely an aggregation phenomenon (Bartelsman and Dhrymes, 1991; Olley and Pakes, 1992; and Baily, Hulten and Campbell, 1992), i.e., when computing the aggregate level of productivity the weights of the more productive plants become larger over time. Within an industry some plants expand while others contract (Dunne, Roberts and Samuelson, 1989; and Davis and Haltiwanger, 1992). Plants that are measured as being less productive are more likely to exit (Olley and Pakes, 1992; and Baily, Hulten and Campbell, 1992).

The next section develops the methodology for measuring plant productivity levels and dispersion in productivity in 21 different four-digit textile industries. Section III measures the extent to which dispersion in productivity levels can be explained by wage dispersion. Section IV develops and executes a procedure measuring the proportion of productivity dispersion that is the product of transitory shocks. Section V argues that a portion of the dispersion in productivity levels is real. Concluding remarks finish out the paper.

II. Measuring Productivity at the Plant Level

Productivity is defined as the ratio of outputs to inputs. Output is measured as real value added. Inputs are measured as a weighted geometric average of employment and capital stock. The weights for the geometric average are taken from estimates of a Cobb-Douglas production function.

My database, an extract of the Longitudinal Research Database (LRD), includes plants in 21 different four-digit textile industries from 1972 to 1987. The panel is highly unbalanced. This results from plants entering and exiting as well as the fact that small plants are sampled with a probability of less than 1 in non-census years. The appendix contains a description of the sampling methods as well as a discussion of the construction of each variable. Table 1 reports the number of plants and firms ever present in each industry.

The LRD contains substantial reporting error especially among small and young plants. How to handle outliers has always been a contentious issue when working with this data (c.f., Baily, Hulten, and Campbell, page 263, 1992). Rather than throwing out outliers according to some arbitrary rule, I develop techniques for measuring dispersion that are not outlier dominated.

My measure of total factor productivity, TFP, will weight capital inputs (measured as the book value of capital)[6] and labor inputs (total employment) according to the econometric estimates of a value added Cobb-Douglas production function.[7] I am therefore assuming that production technology can be characterized by a Cobb-Douglas production function, with unbiased technical change. For each four-digit industry, I estimate:

$$\log(RVA_{it}) = a + \sum_{t=72}^{87} \sum_{r=0}^{2} a_{tr} I_{itr} - a_{72\,0} I_{i72\,0} + \alpha \log(TE_{it}) + \beta \log(Book_{it}) + \epsilon_{it}.$$

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[6]Book value of capital is used to measure capital inputs for lack of a better measure. I have experimented with different methods for measuring assets as the sum of real investment less depreciation. Book value is marginally better at predicting value added.

[7]This form is the most convenient to work with from a theoretical standpoint. Dhrymes (1991) found that results are generally not sensitive to the choice of production function.

Here RVA, TE, and BOOK are real value added, total employment, and the book value of capital, respectively.[8] The subscripts, itr, denote the plant, time period, and region respectively. The indicator variable, I_{irt}, is defined as:

$$I_{irt} = \begin{cases} 1 & \text{if year} = t \text{ and region} = r, \\ 0 & \text{otherwise,} \end{cases}$$

where region 1 is the mid-atlantic states (NY NJ and PA), region 2 is the southern states (VA, WV, NC, SC, GA, FL, KY, TN, AL, MS) and region 0 is all other states. Time-region dummies are included to reduce simultaneity problems stemming from a possible correlation between labor inputs and productivity.[9] Table 2 summarizes the results of these regressions. Observe that the coefficient estimates are plausible, and that the production functions exhibit constant returns to scale or close to constant

[8]Ordinary least squares is used to estimate the production function. These estimates are not efficient, because the error term is not independent across time. The large number of observations, however, should ensure that the estimates are reasonably accurate. Furthermore, my results are robust to non-econometric measures of productivity. Therefore, generating efficient estimates of these parameters has not been a research priority.

[9]If a plant receives additional information regarding its productivity after it has hired its capital but before it hires its labor then a plant will hire more labor when it expects to be highly productive. This results in the error term being positively correlated with labor and the coefficient on labor will have an upward bias. Including time region dummies reduces this problem to the extent that labor inputs are hired on basis of information concerning aggregate rather than idiosyncratic productivity shocks. For further elaboration of this issue see Olley and Pakes (1992).

returns to scale. TFP is then computed as

$$TFP = \frac{RVA}{TE^{\alpha}K^{\beta}}.$$

Note that defining productivity as the ratio of output to inputs implicitly assumes constant returns to scale; a large plant and a small plant with the same output to input ratio are by definition equally productive. When estimating Cobb-Douglas production functions, I measure close to constant returns to scale, rather than imposing it (Table 2). I have experimented with other non-econometric measures of productivity that impose constant returns to scale (labor productivity and TFP measured as a Solow residual--the ratio of output to a geometric average of labor and capital inputs, where labor and capital are weighted by the average labor share and one minus the average labor share, respectively). My conclusions are in general robust to these alternative specifications.

Table 1: Number of Firms and Plants Ever Present in Each Industry

SIC	Number of Firms	Number of Plants

2211 (Broad woven fabric mills, cotton)	334	496
2221 (Broad woven fabrics mills, man made fiber and	531	776
silk)	233	249
2231 (Broad woven fabric mills, wool)	422	460
2241 (Narrow fabrics and other smallwares mills)	325	376
2251 (Women's hosiery above the knee)	541	609
2252 (Women's hosiery below the knee)	1583	1645
2253 (Knit outerwear mills)	139	167
2254 (Knit underwear mills)	922	1008
2257 (Circular knit fabric mills)	499	548
2258 (Lace goods and warp knit fabrics, an		
aggregation see appendix)	180	177
2259 (Knitting mills, NEC)	447	471
2261 (Finishers of broad woven cotton fabrics)	468	523
2262 (Finishers of broad woven man-made fiber and	321	337
silk)	678	733
2269 (Finishers of textiles NEC)	380	432
2273 (Carpets, an aggregation see appendix)	586	858
2282 (Yarn texturizing, throwing, twisting and	344	355
winding mills)	22	34
2283 (Yarn and thread mills, an aggregation see	217	249
appendix)	249	267
2295 (Coated fabrics, not rubberized)	885	931
2296 (Tire cord and fabric)		
2297 (Nonwoven fabrics)		
2298 (Cordage and twine)		
2299 (Textile goods NEC, an aggregation see appendix)		

In each four-digit industry, plants are grouped into ten ranks on basis of productivity, with each group having the same number of plants in it. That is, plants are ranked into deciles 1 through 10, with 1 being the least productive and 10 being the most. This paper measures the dispersion of productivity as the ratio of the ninth decile's average productivity to the second decile's average productivity (hereafter the TFPratio).[10] Figure 1 charts the time evolution of this ratio for 20 four-digit textile industries between 1972 and 1987.[11] The TFPratio

[10]This unit independent measure of dispersion is chosen because: (1) protecting confidentiality requires the grouping of observations; and (2) the first and tenth deciles are avoided due to outlier problems stemming from faulty measurement, i.e., human error.

typically ranges from between two and three; TFPratios as high as four are not uncommon. Note that this figure shows no trend towards convergence. Furthermore, when the TFPratio of each industry is plotted separately, dispersion consistently falls over time in only one industry.

III. Labor or Job Heterogeneity

In this section, I argue that a portion of the *observed* dispersion in productivity levels is the result of differing costs of labor inputs. In order to formulate a null hypothesis, I will consider an equilibrium in which there are no adjustment costs and no entry costs. Furthermore, I assume that there are many plants who produce a homogeneous product and are price takers. In order for an equilibrium to exist, plants must have CRS production functions.

Table 2: Estimates of Production Functions

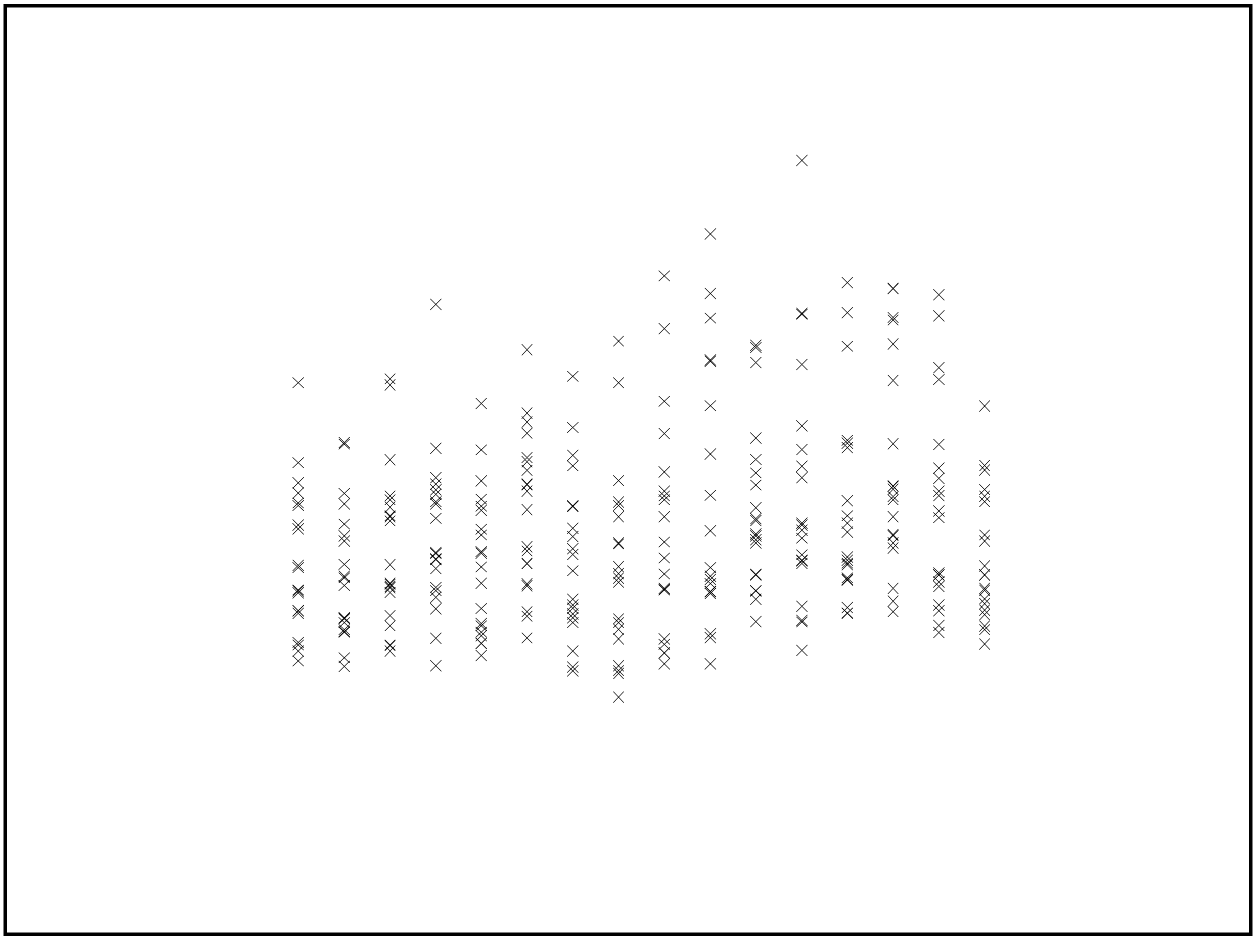
SIC	"	$	"+$	R^2

[11]TFP ratios can be computed from Figures A1-A6 and A13-A18 in Dhrymes (1991) for different industries and methodologies. Similar magnitudes are observed. For the Cobb-Douglas residual, industries 35, 36, and 38 exhibit TFP ratios of 2.0, 2.0, and 1.9 in 1972 and 3.1, 2.5, and 2.7, in 1987, respectively.

2211	0.8242 (.0164)	0.1739 (.0131)	0.9981 (.0090)	0.88
2221	0.8013 (.0117)	0.1720 (.0093)	0.9732* (.0071)	0.86
2231	0.6936 (.0274)	0.2773 (.0224)	0.9709 (.0151)	0.86
2241	0.7740 (.0185)	0.1845 (.0136)	0.9585* (.0123)	0.83
2251	0.8550 (.0226)	0.1665 (.0188)	1.0215 (.0145)	0.85
2252	0.8678 (.0177)	0.1849 (.0135)	1.0527* (.0103)	0.84
2253	0.6332 (.0114)	0.3303 (.0091)	0.9635* (.0076)	0.83
2254	0.8579 (.0358)	0.1369 (.0265)	0.9948 (.0195)	0.84
2257	0.7718 (.0144)	0.1859 (.0113)	0.9577* (.0089)	0.80
2258	0.7811 (.0210)	0.2374 (.0161)	1.0185 (.0124)	0.83
2259	0.5732 (.0393)	0.3632 (.0328)	0.9363* (.0225)	0.87
2261	0.8333 (.0265)	0.1929 (.0214)	1.0262 (.0143)	0.89
2262	0.8152 (.0192)	0.1776 (.0152)	0.9928 (.0104)	0.89
2269	0.8457 (.0282)	0.1784 (.0222)	1.0242 (.0169)	0.82
2273	0.7585 (.0198)	0.2467 (.0162)	1.0052 (.0100)	0.80
2282	0.7805 (.0220)	0.1992 (.0165)	0.9798 (.0135)	0.81
2283	0.8845 (.0132)	0.1319 (.0101)	1.0164* (.0081)	0.79
2295	0.8193 (.0258)	0.2048 (.0197)	1.0241 (.0143)	0.82
2296	0.9080 (.0743)	0.1934 (.0716)	1.1014* (.0507)	0.72
2297	0.7182 (.0303)	0.2739 (.0204)	0.9921 (.0190)	0.82
2298	0.8304 (.0271)	0.1753 (.0219)	1.0057 (.0153)	0.86
2299	0.7451 (.0167)	0.2559 (.0131)	1.0010 (.0102)	0.84

The standard errors are in parentheses, which should be interpreted with caution because the procedure does not take into account the serial correlation in the error term. The * in column four denotes that the hypothesis of constant returns to scale can be rejected with 95 percent certainty.

Figure 1: Productivity Dispersion in The Textile Industry



Reports the TFPratios for 20 four-digit textile industries over time. The TFPratio is the ratio of the mean productivity level of the 9th decile plant to the 2nd decile plant when ranked according to productivity.

In equilibrium all plants will maximize current profits and minimize current costs. CRS production functions imply that minimized costs are linear in output:

$$c^*(y) = c^* y,$$

where y is output. This implies that profit per unit output is a constant:

$$\Pi = (p - c^*)\,y,$$

where p is price and B is profits. Therefore, a finite positive level of equilibrium output requires the equilibrium price to equal the per unit cost of the plants with the lowest costs,

$$p = \underline{c}^*,$$

where $\underline{c}^*$ is the lowest per unit cost of all plants. Aggregate output and who will produce this output is then chosen by the Walrasian auctioneer to clear the output market. This is a rather unsatisfying concept of an equilibrium, because it has no prediction regarding the size distribution of plants. Nevertheless, this equilibrium predicts that all plants earn zero economic profits and have the same per unit costs.

In measuring productivity, I have assumed a value-added production function of the form:

$$Y = AL^{\alpha}K^{\beta},$$

where Y is real value added, K is book value of capital and L is total employment.

Suppose the actual production function is:

$$Y = A(S + \phi U)^{\alpha}K^{\beta},$$

where S and U are skilled and unskilled workers, respectively (S+U= L). That is, skilled and unskilled workers are perfect substitutes.[12] If this is the case, my measure of TFP is inaccurate because it treats all workers as being identical, when there may actually be skill differentials across plants. A plant with high skilled workers is being measured as a highly productive plant.

Consider two plants. Plant 1 hires more skilled workers than plant 2. Assume that both rent capital at a rate of r. Assume that each plant has CRS production functions and normalize output and price to 1. Cost minimization implies that they will both use the same capital stock per unit output ($K_1=K_2$). The zero profit condition implies that their wage bill is the same:

$$w_1L_1 = w_2L_2 \quad \textbf{or} \quad \frac{w_1}{w_2} = \frac{L_2}{L_1},$$

where w_i is plant i's average wage. The productivity of plant i is measured as:

$$TFP_i = \frac{1}{L_i^{\alpha}K_i^{\beta}},$$

Therefore, the TFPratio is given by:

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[12]This production function is chosen, because it is the most intuitive. Generalizing the math to allow for the possibility that skilled and unskilled workers are imperfect substitutes and that and the degree of substitutability differs across plants is straightforward. The prediction regarding the relative measured productivity levels remains the same. Defining the true measure of productivity, however, becomes more problematic.

$$\frac{TFP_1}{TFP_2} = \frac{L_2^{\alpha} K_2^{\beta}}{L_1^{\alpha} K_1^{\beta}} = \left(\frac{w_1}{w_2} \right)^{\alpha}.$$

That is, given the output elasticity of labor and the relative wages of two plants, the assumptions of a competitive market predict the relative *measured* productivity levels. For any industry in any year, I can compute the ratio of the average wages of plants in the 9th decile to those in the 2nd (Wratio), and I have an estimate of α. Therefore, I can predict a TFPratio for each industry in each year:

$$pTFPrat_{jt} = (Wratio_{jt})^{\alpha},$$

where jt denotes the industry and time period, respectively. The percentage explained by wage dispersion can be expressed by:

$$\%Wages_{jt} = 100\left(\frac{pTFPrat_{jt} - 1}{TFPratio_{jt} - 1} \right).$$

This definition uses the TFPratio minus one--the percentage difference in productivity levels of the 85th and 15th percentile plants--as the measure of dispersion. If the predicted dispersion equals the actual dispersion then the percentage explained is 100, If the predicted dispersion is 1, then the percentage explained is zero.

Table 3 presents the time mean of the TFPratio, the Wratio, the pTFPrat and the %Wages for each industry. The largest Wratio is in industry 2298, twine and cord; plants in the ninth decile plants pay 64 percent more wages than plants in the second decile. This predicts that the difference in productivity levels is 51 percent. The observed difference, however, is 216 percent. Therefore, wage differences explain about one fourth of productivity dispersion in industry 2298.[13] The percent explained by wages range from 2 to 23 percent with a median of 12.5%. Therefore, if the majority of the productivity dispersion is due to differences in human capital, then the human capital must be specific in nature, i.e., there is no spot market for it.

Table 3: Percent of Dispersion in Productivity Levels Explained by Wages.

SIC	TFPrat	Wratio	pTFPrat	%Wages

[13]Note that this exposition is only an approximation, because the numbers reported are time means of variables computed in each year.

2211	2.448	1.175	1.141	10.1
2221	2.328	1.207	1.163	12.1
2231	2.691	1.305	1.200	12.3
2241	2.483	1.389	1.288	19.8
2251	3.380	1.373	1.310	13.6
2252	2.344	1.317	1.269	19.5
2253	3.054	1.513	1.296	16.0
2254	2.885	1.199	1.167	10.4
2257	2.967	1.350	1.259	13.1
2258	2.992	1.438	1.326	17.1
2261	3.023	1.297	1.230	12.2
2262	2.704	1.441	1.344	21.1
2269	3.365	1.324	1.264	12.0
2273	3.796	1.340	1.246	8.9
2282	2.724	1.284	1.215	12.5
2283	2.334	1.180	1.158	11.8
2295	2.891	1.311	1.245	13.1
2296	4.693	1.085	1.075	2.2
2297	2.798	1.364	1.243	12.3
2298	3.163	1.644	1.508	23.4
2299	3.029	1.409	1.286	15.1

IV. Transitory Shocks

One will observe dispersion in productivity even if all plants earn zero expected profits, because of price dispersion, uncertainty in the production process, as well as measurement error. Dispersion in prices (within a four-digit industry) is measured as dispersion in productivity, because the real output of a plant is measured as revenue deflated by a four-digit price index. If price differences between plants are transitory, then the observed differences may be consistent with a long run competitive equilibrium. Furthermore, transitory shocks to the production process and/or measurement error can result in *ex post* dispersion in the absence of *ex ante* dispersion. To analyze this issue, it is useful to define a stochastic competitive equilibrium. Consider a discrete time model in which plants first commit to a vector of inputs. A transitory idiosyncratic productivity shock is then realized that determines output. Assume that there are a large number of plants which produce a homogeneous output and are price takers. Assume that the expected equilibrium price will equal the realized price.

A plant's problem is given by

$$Max_{[x]}\ E(\Pi) = E(pe^{\epsilon_i} f(x) - wx),$$

where x is a column vector of inputs, w is a row vector of input prices, $e^{\epsilon}f(x)$ is a homogenous of degree 1 production function, and ϵ_i is the transitory idiosyncratic shock.

Cost minimization and CRS implies that costs and expected profits are linear in expected output:

$$c^*(y^e)=c^*y^e \quad implies \quad (E(\Pi))^*=(p-c^*)y^e,$$

where $y^e = E(e^{\epsilon}f(x))$. In equilibrium: $p = c^*$ for the most efficient plants; and all plants in operation have the same cost per unit expected output and therefore the same expected productivity. The Walrasian auctioneer chooses the expected output of each plant such that the actualized aggregate output will clear the market at the equilibrium price. Even if there is dispersion in *ex-post* productivity levels, *ex-ante* there is none. Under this specification, the productivity shock is a supply shock. Building a stochastic equilibrium which allowed for demand shocks would require a more complicated demand structure. In the data, however, I do not distinguish between supply or demand shocks or, for that matter, measurement error.

Framework for the Empirical Application

The question is simple: what percentage of the variation is not "explained" by plant effects? Applying standard analysis of variances procedures, however, is problematic. First, one would have to find or develop an ANOVA procedure for an unbalanced panel with serial correlation in the error term (for a discussion of the difficulties involved see Dwyer, 1995). Even with such a procedure, however, the results would be outlier sensitive; experimentation with ANOVA procedures reveals that the importance of plant effects increases with the percentage of outliers that are dropped from the data set. Therefore, I develop the following procedure that is not outlier dominated.

In this section I will define measures of *ex-post* and *ex-ante* dispersion. I simultaneously work out an example, which assumes a specific distribution of the random variables that collectively form a plant's productivity level. The example is intended to help the reader build intuition regarding the interpretation of these measures in terms of familiar parameters. The measures of *ex-post* and *ex-ante* dispersion, however, are sensible unit independent measures of dispersion for any distribution. Let plant i's TFP in period t be given by:

$$TFP_{it} = V_t\, e^{\varepsilon_{it}} A_i \quad \text{and} \quad tfp_{it} = v_t + \varepsilon_{it} + a_i,$$

where lower case letters denote logarithms. The transitory component, ε_{it}, and the permanent plant component, a_i, have the following distributions:

$$\varepsilon_{it} \sim n(-\sigma_\varepsilon^2/2,\ \sigma_\varepsilon^2) \quad \text{and} \quad a_i \sim n(\mu_a, \sigma_a^2).$$

I assume that ε_{it} is iid across plants and time, and a_i is iid across plants. The assumption that ε_{it} is independent across time is for expository convenience only. The time shock, V_t, can be either deterministic or random and independent of a_i and ε_{it}. Because all measures of dispersion are ratios, the time shock always cancels out. Therefore, to simplify the exposition I assume that $V_t = 1$ and $v_t = 0$. I am now ready to state my null and alternative hypotheses:

H_0: $\sigma_a^2 = 0$; and

H_a: $\sigma_a^2 > 0$.

Under the null hypothesis, a stochastic competitive equilibrium, there is no dispersion in the permanent component of a plant's productivity level.

Clearly,

$$tfp \sim n(\mu_{a} - \frac{\sigma_{\varepsilon}^{2}}{2},\ \sigma_{\varepsilon}^{2}+\sigma_{a}^{2}),\ \textit{and}$$

$$\rho(tfp, a) = \frac{\sigma_{a}}{\sqrt{\sigma_{a}^{2}+\sigma_{\varepsilon}^{2}}},$$

where D is the correlation coefficient. That is, the log of observed TFP and the permanent component have a bivariate distribution and are positively correlated. If there are no transitory shocks to plant productivity levels, $F_{,}^{2} = 0$, then the correlation coefficient is one. As the magnitude of the transitory shocks goes to infinity, the correlation coefficient goes to zero.

It can be shown that

$$TFPratio = \frac{\exp(tfp_{.85})}{\exp(tfp_{.15})} \approx \exp(2.1\sqrt{\sigma_{\varepsilon}^{2}+\sigma_{a}^{2}}),$$

where tfp_{x} denotes the solution to $tfp = F^{-1}(x)$, where F^{-1} is the inverse of the cumulative density function of tfp. That is, if $x = .85$, $TFP_{x} = \exp(tfp_{x})$ is the productivity level of the 85th percentile plant.

Define

$$E_{t+x}\ TFPrat_{t} = \frac{E(TFP_{t+x\,i}\ |tfp_{it} = tfp_{.85})}{E(TFP_{t+x\,j}\ |tfp_{jt} = tfp_{.15})} = \frac{E(A|tfp_{.85})}{E(A|tfp_{.15})},$$

that is, the expected productivity level of a plant x years from now given that it was the 85th percentile plant today divided by the expected productivity level of a plant x years from now given that it was the 15th percentile plant today. The time independence assumptions imply that this is just the ratio of the expectation of A given the respective percentiles.

It can be shown that the expected TFPratio is given by:

$$ETFPratio = \frac{E(A|tfp_{.85})}{E(A|tfp_{.15})} \approx \exp\left(2.1\left(\frac{\sigma_a^2}{\sigma_a^2+\sigma_e^2}\sqrt{\sigma_a^2+\sigma_e^2}\right)\right).$$

(cf. Hogg and Craig, pages 117-120 (1978)).

Note that the expected TFPratio is less than or equal to the TFPratio and equal to it only if there are no transitory shocks to the production process. Under the null hypothesis--that there is no dispersion in the permanent component to plant productivity levels--the expected TFPratio equals 1.

The percentage explained can be defined as:

$$\%Shocks_{t+x} = 100\frac{(TFPratio_{t+x} - 1)-(E_{t+x}TFPratio_t - 1)}{(TFPratio_{t+x} - 1)}$$

which is approximately equal to:

$$\%Shocks \approx 100\left(\frac{\sigma_{\epsilon}^{2}}{\sigma_{a}^{2}+\sigma_{\epsilon}^{2}}\right).$$

Note that this expression is based on the approximation log(1+x)=x, which is problematic in this context, because x is typically large. Nevertheless, it illustrates that the percentage explained by shocks is the ratio of the variance of the transitory shocks to the total variance. If there are no transitory shocks, the percent explained is 0; if there is no variance in the permanent component of plant productivity levels the percent explained is 100.

The $E_{t+x}TFPratio_t$ can be estimated by:

$$Sample\ E_{t+x}TFPratio_t = \frac{Mean\ TFP_{t+x}\ of\ plants \in Decile\ 9\ in\ year\ t}{Mean\ TFP_{t+x}\ of\ plants \in Decile\ 2\ in\ year\ t}.$$

This is a consistent estimate of the empirical analogy to the theoretical definition of the expected tfpratio; the ratio of the mean productivity of plants that were in the ninth decile to the mean productivity of plants that were in the second. This estimate, however, has two problems: (1) it is biased in small samples; and (2) there may be sample selection bias under H_a.

The potential size of the small sample bias can be established as follows. Let X and Y be random variables from the distribution of TFP_{t+x} given that the plant was in the ninth and second decile, respectively.

$$E(\text{sample } E_{t+x}\ TFPratio_t) = E\left(\frac{\bar{X}}{\bar{Y}}\right) = E(\bar{X})\ E\left(\frac{1}{\bar{Y}}\right),$$
$$\text{provided } E\left(\frac{1}{\bar{Y}}\right) \text{ exists.}$$

Here the bars denote sample means. By Jensen's inequality,

$$E\left(\frac{1}{\bar{Y}}\right) > \frac{1}{E(\bar{Y})}.$$

By the central limit theorem, the distribution of a sample mean approaches a normal distribution as the sample size becomes large. It can be shown that if W - $n(1, F^2)$ and Z - $n(\mu,(\mu F)^2)$ then $E(1/W) = \mu E(1/Z)$. That is, the bias of the estimator is in proportion to the mean divided by the standard error. Furthermore, monte-carlo results suggest that the bias is less than 4.5% if $\mu/F > 5$. That is, if the standard deviation is less than one fifth the mean then the bias should be less than 5 percent.

To ensure this bias is small, the ETFPratio is only estimated if the samples from which the numerator and the denominator are calculated satisfy two criteria:

(1) the sample size exceeds 10, and

(2) the mean of the sample is greater than five times the standard error.

These conditions are placed on both the numerator and the denominator to ensure consistency. The first condition is to give some credibility to invoking the central limit theorem. The second requirement should ensure that the bias is less than five percent.

The *sample selection bias* results from the less productive plants being more likely to exit. This will bias the sample means upward and the bias will be larger in the denominator than in the numerator, because plants in the lower deciles are more likely to exit (Olley and Pakes, 1992; Baily, Hulten and Campbell, 1992, and Dwyer, 1994). Therefore, the ETFPratio is biased downward under the alternative hypothesis, which increases the probability of accepting a wrong null hypothesis.

Table 4 presents the time mean of the TFPratio and the sample $E_{t+x}TFPratio_t$ for x ranging from 1 to 12 for all industries. A cell was set to missing if an ETFPratio could not be computed (given the above restrictions) in at least four different years. Table 5 reports the percentage explained by transitory shocks.

The percentage explained within one year can be computed for seven industries, and runs between 34 and 50 percent; as much as 50 percent of the dispersion in productivity levels disappears within one year. At three years, as much as 70 percent of the dispersion disappears. The largest percentage explained computed in any industry for any X is 81 percent, even though the percentage explained can be computed for up to ten years in two industries. It appears that there is a permanent component to a plant's productivity level and the null hypothesis can be rejected.

In order to compute the ETFPratio and %Shocks for more industries, I compare the plants in deciles eight and nine (70 - 90 percentiles) to those in the second and third deciles (10-30) in Tables 6 and 7. The results are similar; 36.3 percent and 56.3 percent of the dispersion is explained within one and three years respectively, for the median industry. Once again the percentage explained is always less than 100 percent; the maximum ever explained is 85.5 percent.

Note that the EXTFPratio falls montonically in the first three years for all industries. Between three and four years, however, the Etfpratio increases for three out of six industries (Table 6). Therefore, there appears to be serial correlation in a plant's productivity level that "exhausts" itself within three or four years. First order auto-regressions on the balanced panel show that this is indeed the case (Dwyer, 1995).

Section III suggests that the plants that pay higher wages are actually using more labor measured in efficiency units. If one believes that labor is paid the value of its marginal product, then the efficiency units of a plant's labor is in proportion to its payroll. Therefore, total payroll can be used as a measure of labor inputs rather than total employment. One can re-estimate a Cobb-Douglas production function with the payroll rather than total employment as a measure of labor inputs to get an estimate of ", and compute total factor productivity as:

$$WATFP = \frac{RVA}{Book^{\beta}(Payroll)^{\alpha}},$$

This method, however, is problematic. It is not clear whether a firm pays high wages because it is highly productive or appears to be highly productive because it employs high quality labor; the average wage of a plant is an endogenous variable that is likely to be correlated with the error term, i.e., productivity.[14] Nevertheless, I computed Table 4-7 for the wage adjusted

[14]Baily, Hulten, and Campbell make this point (page 203, 1992).

Table 4: Expected TFPratios: Compares 80-90 and 10-20 Percentiles

SIC	TFPrat	E1TFPr	E2TFPr	E3TFPr	E4TFPr	E5TFPr
2211	2.44	1.76	1.57	1.38	1.49	.
2221	2.32	1.84	1.74	1.52	1.44	1.56
2231	2.69	.	.	.	.	.
2241	2.48	.	.	.	.	.
2251	3.38	.	.	.	.	.
2252	2.34	1.65	.	.	.	.
2253	3.05	2.26	1.84	.	.	.
2254	2.88	.	.	.	.	.
2257	2.96	2.23	1.87	.	.	.
2258	2.99	.	.	.	.	.
2261	3.02	.	.	.	.	.
2262	2.70	.	.	.	.	.
2269	3.36	.	.	.	.	.
2273	3.79	2.43	2.03	1.73	.	.
2282	2.72	.	.	.	.	.
2283	2.33	1.69	1.52	1.42	1.53	1.38
2295	2.89	.	.	.	.	.
2296	4.69	.	.	.	.	.
2297	2.79	.	.	.	.	.
2298	3.16	.	.	.	.	.
2299	3.02	.	.	.	.	.

SIC	E6TFPr	E7TFPr	E8TFPr	E9TFPr	E10TFPr	E11TFP	E12TFP
2221	1.57	1.52	1.37	1.38	1.45	1.32	.
2283	1.25	1.38	1.27	1.35	1.74	.	.

Table 5: Percent Explained By Shocks: Compares 80-90 and 10-20 Percentiles

SIC	%Shocks1	%Shocks2	%Shocks3	%Shocks4	%Shocks5	%Shock6
2211	37.5	56.8	71.2	62.1	.	.
2221	37.0	41.1	59.2	65.6	54.4	54.2
2252	49.6	.	.	.	.	.
2253	34.4	56.3	.	.	.	.
2257	35.7	54.1	.	.	.	.
2273	42.4	59.5	69.3	.	.	.
2283	47.0	59.5	67.4	60.1	72.2	81.1

Table 5 (Cont): Percent Explained By Shocks: Compares 80-90 and 10-20 Percentiles

SIC	%Shocks 7	%Shocks 8	%Shocks 9	%Shock10	%Shock11	%Shock12
2221	60.1	70.8	70.4	63.7	75.2	.
2283	70.9	79.1	72.7	42.2	.	.

Table 6: Expected TFPratios: Compares 70-90 and 10-30 Percentiles

SIC	TFPratio	E1TFPr	E2TFPr	E3TFPr	E4TFPr	E5TFPr
2211	2.06	1.63	1.55	1.31	1.31	1.18
2221	1.97	1.64	1.50	1.41	1.38	1.34
2231	2.22	.	.	.	.	.
2241	2.09	1.77	1.63	.	.	.
2251	2.71	2.13	.	.	.	.
2252	1.98	1.65	1.65	1.48	.	.
2253	2.43	1.83	1.77	1.75	.	.
2254	2.32	.	.	.	.	.
2257	2.37	1.95	1.79	1.55	1.45	.
2258	2.44	1.85	1.64	1.63	.	.
2261	2.41	.	.	.	.	.
2262	2.20	1.78	1.60	1.59	.	.
2269	2.57	2.17	.	.	.	.
2273	2.95	2.19	1.84	1.78	1.80	.
2282	2.23	1.60	1.41	1.31	1.47	.
2283	1.98	1.55	1.41	1.35	1.42	1.29
2295	2.33	1.75	1.68	.	.	.
2296	3.25	.	.	.	.	.
2297	2.24	.	.	.	.	.
2298	2.56	.	.	.	.	.
2299	2.45	1.75	1.69	.	.	.

SIC	E6TFPR	E7TFPr	E8TFPr	E9TFPr	E10TFPr	E11TFPr	E12TFP
2211	1.35	1.39	1.48	1.22	.	.	1.15
2221	1.22	1.27	1.25	1.13	1.41	1.23	1.20
2273	1.39	.	.	.	.	.	.
2283	1.20	1.47	1.24	1.29	1.42	1.19	1.20

Table 7: Percent Explained By Shocks: Compares 70-90 and 10-30 Percentiles

SIC	%Shocks 1	%Shocks 2	%Shocks 3	%Shocks4	%Shocks5	%Shocks6
2211	39.4	47.3	68.8	65.6	81.1	62.5
2221	32.6	48.1	55.8	59.7	63.9	75.7
2241	30.6	40.5	.	.	.	.
2251	23.4	.	.	.	.	.
2252	33.2	31.6	50.0	.	.	.
2253	38.5	45.0	49.4	.	.	.
2257	30.9	42.9	60.4	66.5	.	.
2258	36.6	48.1	52.3	.	.	.
2262	34.3	47.8	36.2	.	.	.
2269	33.1	.	.	.	.	.
2273	36.3	54.3	56.9	55.6	.	79.3
2282	50.6	65.4	74.4	63.6	.	.
2283	42.9	57.2	63.5	56.3	70.0	78.9
2295	40.7	49.6	.	.	.	.
2299	47.7	47.3	.	.	.	.

SIC	%Shocks 7	%Shocks 8	%Shocks 9	%Shock10	%Shock11	%Shock12
2211	61.6	53.3	75.3	.	.	85.5
2221	71.0	72.9	85.5	56.2	75.4	79.0
2283	51.6	75.3	70.9	56.6	80.3	78.7

measure of productivity. I only summarize the results because they are rather similar. The magnitude of the dispersion is somewhat smaller, but the percentage explained by shocks in the median industries are nearly identical (38.1% and 57.8% within one and three years, respectively, when comparing 70-90 percentiles to 10-30 percentiles). Therefore, it appears as though the transitory shocks are operating independently of wage differentials.

V. Are These Measurements of Productivity Meaningful?

Section IV demonstrated that there is a permanent component to a plant's measured productivity level. A portion of this component is certainly the result of persistent measurement error. If plants that are measured as more productive are truly more competitive, however, then they should be more likely to expand and less likely to exit.[15] In answering this question, it is important to avoid sample selection bias. Therefore, I compute the average growth rates of real value added, total employment and real book value of capital as well as the exit rate between census years (72&77, 77&82, 82&87) for each productivity decile. In census years plants are sampled with probability 1 (in theory). Table 8 reports the average growth rates as well as the exit rates for each productivity decile for the first measure of productivity. Results were similar for the wage adjusted measure of productivity and are not reported. The growth rates are increasing in productivity while the exit rates are falling, as predicted.

It is worth noting that the growth rates are computed on basis of the average productivity over the two census years for a reason. If one computed the same table, but ranking on basis of the initial productivity level, then regression to the mean

[15]Dwyer (1994) presents a model that yields these implications, within the context of a distortion free competitive equilibrium.

dominates the results. In computing productivity, real value added is the numerator and book value of capital and total employment are in the denominator. Therefore, if plants that are measured as highly productive contain substantial measurement error, one would expect the measurement error to be positive in the numerator and negative in the denominator. When computed on basis of productivity at the beginning of the time period growth of real value added was decreasing in productivity, while book value and total employment were increasing in productivity, exactly as regression to the mean predicts.

There clearly is a large transitory component to a plant's measured productivity level. Nevertheless, the productivity level of a plant is inversely related to its probability of exiting. Furthermore, the average productivity level over two census years is positively associated with both the growth of inputs and outputs. Therefore, it appears that the permanent component to a plant's measured productivity level is indicative of its underlying competitive position.

Table 8: Growth Rates and Exit Rates by Productivity Ranking

Decile	GRVA	GTE	GBOOK	EXIT

1	-0.204	-0.109	-0.070	0.395
2	-0.011	-0.080	-0.074	0.343
3	0.025	-0.067	-0.079	0.314
4	0.033	-0.049	-0.003	0.300
5	0.079	-0.045	-0.056	0.262
6	0.147	0.051	0.001	0.255
7	0.132	0.008	-0.012	0.203
8	0.201	0.031	0.066	0.217
9	0.172	0.050	0.037	0.206
10	0.228	0.106	0.062	0.250

Columns 2-4 report the weighted average of the growth rates of real value added, total employment and book value of capital between census years (between 1972&1977, 1977&1982, and 1982&1987). The growth rate is computed as the difference divided by the average. The deciles are computed on basis of the average of TFP at the beginning and end of the time interval. Each plant is assigned a ranking on basis of its relative standing within its four-digit industry. In computing the exit rates, the plants were assigned into productivity deciles according to their TFP in the beginning of the time interval. A plant was counted as having exited if it was not observed in any industry in the following census year.

VI. Conclusion

If an economist were to look at an industry with widespread dispersion in productivity levels, he might conclude that there were large distortions in the industry that allowed the inefficient to remain in operation. This research demonstrates that the

majority of observed dispersion can be rationalized within the context of a competitive industry equilibrium; an equilibrium that is distortion free and efficient by construction. Widespread dispersion in productivity levels, therefore, is not necessarily evidence of inefficiency. Furthermore, the results are suggestive as to which models of productivity dispersion fit the textile industry.

Approximately one half of the dispersion is due to transitory demand or supply shocks and/or measurement error. A stochastic competitive equilibrium predicts that all productivity dispersion will disappear over time when fixing plants into their original deciles. Within three years, approximately one half the observed dispersion disappears. These results are consistant with models in which a plant is subject to idiosyncratic productivity shocks (cf. Hopenhayn, 1992; and Dixit, 1992). Further research on the economic origins of these shocks, however, is required (vs. the hypothesis that the mean reversion is entirely the product of reporting error).

The fact that some plants pay their workers higher wages implies that they must get more out of their workers in order to be competitive. Within the context of a competitive equilibrium, approximately 13 percent of the dispersion in productivity can be accounted for by wage dispersion. Therefore, it is unlikely that models in which differences in general human capital lead to differences in plant qualities will account for a "large" portion of the observed dispersion in productivity.

Nevertheless, a portion of the dispersion persists over long time periods. This may be the result of mis-measurement of capital inputs or persistent differences in market power. The fact that more productive plants are less likely to exit and grow faster, however, suggests that a portion of this dispersion is real; there appears to be a case for creative destructive based explanations of industry evolution. Some plants are consistently more productive than others and they are expanding and driving the less productive out of business. But if the more productive plants grow faster and are less likely to exit, then why do we not observe convergence in productivity levels over time? Dwyer (1994) focuses on this puzzle.

Appendix: Data

My data set consists of the textile plants (SIC 2200-2299) in the Longitudinal Research Database (LRD), which is based on the Annual Survey of Manufactures (ASM) and the Census of Manufactures (CM).[16] The sample runs from 1972 until 1987. Regression analysis can be performed separately on 22 different industries. The TFPratio, however, can only be computed for 21 industries due to the small number of observations in industry 2259. Statistics taken from industries 2259 and 2296 are sometimes suppressed due to confidentiality requirements.

The CM is carried out every five years (1967, 1972, 1977, 1982, and 1987) and each plant is, in principle, sampled with probability one. The ASM draws a sample of plants two years after the census, and then follows this sample for five years (these samples begin in 74, 79, and 84). The sample probability is increasing in plant size.

My sample is a subset of a sample that includes all information available on every plant ever in the SIC codes 2200-2299 from 1967 to 1989. The sample is truncated to drop administrative record cases, which are small plants for which only a limited amount of information is collected, and drops pre-1972 and post-1987 observations. The pre-1972 observations were dropped in order to construct a complete time series and the

[16]For a detailed description of this database see McGuckin and Pascoe (1988).

post-1987 observations were dropped because book-value of assets were not collected in 1988 or 1989. The regressions are ran separately for each four-digit SIC code, and therefore a plant was only included in the regression if it was in that textile industry. My unbalanced sample contains four years in which all firms are sampled with probability one (in theory), and three different samples in which large firms are sampled with a higher probability. Because of the way the sample is drawn, the probability of a new plant entering my database is only positive in the years 1972, 1974, 1977, 1979, 1982, 1984, and 1987.

To resolve an apparent inconsistency in the classification of plants in census and non-census years the following aggregations are made: SIC 2258 includes DIND 2258 and 2292; SIC 2273 includes DIND 2271, 2272 and 2279; SIC 2283 includes DIND 2281, 2283 and 2284; SIC 2299 includes DIND 2291, 2293, 2294 and 2299 (DIND is the derived industry code). The relevant prices indices were computed as a Laspeyres price index with 1987 as a base year via Gray's productivity database with total value of shipments as the relevant weights (Gray, 1989).

Variable Construction:

RVA (Real Value Added)

Value added is computed as the total value of shipments plus changes in the value of inventories less the cost of materials (including materials, supplies, fuel, electric energy, cost of resales, and cost of contract work). Value added is deflated through Gray's shipments price index to generate RVA.

TE (Total Employment)

Total employment is the sum of the average number of production workers and nonproduction workers.

BOOK (Book value of Capital)

The only measure of assets that can be calculated consistently across small plants (which are intermittently sample) and large plants is book value. That is the book value of buildings and machinery at the end of the period plus the capitalized value of rental payments deflated by Gray's investment price index.

$$Assets_t = (BAE_t + MAE_t)/PINV_t + (BR_t+MR_t)/(r_tPINV_t).$$

Here BAE and MAE are the book value of assets and machinery at the end of the period; BR and MR are rents paid for buildings and machinery; and r is the user cost of capital.

Payroll and Average Wages

Payroll is the sum of total salaries and wages (SW) plus legally required supplemental labor costs (LE) and voluntary supplemental labor costs (VLC). Average wages are payroll divided by total employment (TE).

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