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The plant life-cycle of the average wage of employees in U.S. manufacturing

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Abstract

This paper explores the evolution of the average wage of employees over the life-cycle of a manufacturing plant. The average wage starts out low for a new plant and increases along with labor productivity as the plant ages. As a plant approaches exit, its average wage falls, but more slowly than it rises in the case of growing plants. Moreover, the average wage does not fall as fast as productivity does. A dynamic model of labor quality and quantity choice by plants is estimated to assess the costs of altering labor quality and quantity over the plant life-cycle.

JEL codes: J31, J21, J24, L60, L23, L11, D24

Keywords: The average wage of employees; The evolution of the average wage; Plant productivity; Plant life-cycle; Employment dynamics; Adjustment costs; Manufacturing

1 Introduction

How does the average wage (the total wage bill per employee) a manufacturing plant pays to its employees change over the plant's life-cycle?[1] Are there substantial differences in the time-paths of the average wage between growing versus failing plants? How are the changes in the average wage related to changes in productivity over the plant's life-cycle? The answers to these questions matter for the theories of wage contracts, human capital accumulation on the job, adjustment costs in factors of production such as labor quantity and quality, the productivity-wage relationship, and the evolution of organizational complexity and employee hierarchy. This paper provides comprehensive evidence on the evolution of the average wage along the life-cycle of a manufacturing plant using data from the U.S. Census Bureau's Census of Manufactures over the period 1963-1997. Some facts are presented on how the average wage changes as a plant enters an industry, grows, and ages, and as it approaches exit. The patterns exhibited by the average wage are tied to the evolution of labor productivity. A dynamic model of plant-level labor quality and quantity adjustment is also built and estimated to explore the asymmetric patterns observed in the evolution of the average wage for growing versus declining plants.

Empirical evidence on the connection between a plant's age and its average wage is scant. Brown and Medoff (2003) find that older firms tend to pay higher wages on average. Their analysis is based on a relatively small number of workers, and highly established, older firms. Kölling et al. (2013) largely confirm Brown and Medoff's (2003) findings using a larger dataset that links establishments to workers in Germany, while Heyman (2007) finds some evidence in favor of a positive relationship using Swedish data. These studies do not track firms or plants over time, and do not consider the joint dynamics of the average wage and productivity along the firm life-cycle. In addition, while age measures a firm's distance from entry, it does not contain information on its distance to exit, and thus cannot fully account for where a firm stands in its life-cycle. The samples used in these previous studies also do not adequately represent the firm age distribution, especially its left tail.

This paper uses data for the entire set of manufacturing plants available in the U.S. Census Bureau's Census of Manufactures (CM) over a span of three decades. It characterizes the evolution of the average wage and labor productivity as plants move away from their entry point, and as they approach exit. The findings indicate that new plants start out with lower average wage and productivity compared with the established ones, but surviving plants achieve higher productivity and pay higher average wage as they age. Failing plants, on the other hand, experience a decline in both the average wage and productivity. For such plants, the average wage does not fall as fast as it rises in the case of surviving new plants. Furthermore, the average wage neither rises nor falls as fast as labor productivity does. Compared with the mature plants, failing plants are burdened by an increasingly larger wage bill as a fraction of their revenues, whereas new entrants and young firms incur a smaller wage bill relative to their revenues. The asymmetric evolutions of labor productivity and the average wage over the life-cycle of a plant are the focus of the paper.

The model in this paper connects a plant's productivity to its average wage. A plant's life-cycle dynamics are driven by two random processes: one that drives productivity, and the other the wage rate per unit of labor quality the plant faces. A plant chooses the quality and quantity of its labor force in the presence of these two random elements. The motivation behind labor quality, in addition to quantity, stems from the prior empirical evidence which suggests that worker quality accounts for a considerable portion of the wage differential across plants of different ages.[2] A further motivation is the evidence on a strong positive relationship between a firm's labor quality and productivity.[3] Worker quality can have alternative interpretations, such as human capital, a worker's skill, effort, and hours, or the degree of essentiality of a worker in the production process. A higher quality labor force comes at a higher average wage. This relationship is supported by the earlier work of Gort et al. (1990) and Gort et al. (1993), which suggest that variations in the average wage across plants are mainly due to the differences in human capital rather than the differences in the prices of a given labor type. The average wage in the model thus has an exogenous component that the plant takes as given, and an endogenous component that depends on the average labor quality, which is chosen by the plant. As a plant's productivity increases, its employment or the average quality of its labor force can also increase depending on the relative costs of these two inputs. Similarly, a decline in productivity can put a downward pressure on labor quality or employment. However, there are many frictions in the process of labor quantity and quality adjustment, giving rise to adjustment costs. These costs can dampen the movements in the average wage in either direction.

Adjustment costs in labor quantity and quality represent the effects of a variety of considerations, including the frictions in reorganizing production (e.g. plant expansion and contraction) and the frictions in the labor market (e.g. search costs), the effects of institutions (e.g. labor unions), and regulations.[4] Exogenous shocks to the wage rate per unit quality of labor can force a plant to alter its average wage at a cost. For instance, some workers can exercise their outside options if their wages are not adjusted when the demand for their services rises in the economy. Plants experiencing fast productivity growth may need to reorganize their workforce. Such reorganization may involve creating new jobs and hierarchies, as well as training, and moving labor across ranks and tasks. Similarly, as a plant experiences persistent episodes of low productivity, it may shed some of its employees who are non-essential for the main activity of the plant. It may also reduce worker compensation in real terms. Some workers may also quit in anticipation of the plant's exit. The plant may then have to reorganize its remaining labor force to maintain production. All of such events imply costly adjustments to the average wage.

To assess the magnitude of the adjustment costs associated with the average wage, the model's parameters are estimated. The estimates reveal that labor quality, inferred indirectly from the data on employment, wage bill, and revenue, is an important input of production. Furthermore, there are statistically and economically significant asymmetric adjustment costs. When only the continuing plants are considered, the mean annual cost of average-wage adjustment in any direction constitutes up to 1.6% of a plant's revenue at the median of the adjustment cost distribution. For plants adjusting their average wage downwards, the annual adjustment cost claims, on average, up to 3.6% of revenue. For plants adjusting their average wage upwards, the annual adjustment cost makes up as much as 0.8% of revenue on average. These shares are much higher when only the exiting plants are considered. A version of the model with both the average-wage and employment adjustment costs is also estimated. A plant may not be able to adjust its average wage holding employment constant. Similarly, changes in employment can induce changes in the average wage due to changes in the composition of a plant's labor force. Allowing for both channels of adjustment addresses potential biases due to using only one.

This paper contributes in a number of dimensions to the literature on the plant-life cycle of wages. First, it reveals a set of facts pertaining to the evolution of the average wage over a plant's life-cycle. Many prior studies do not analyze how the average wage changes along the entire plant life-cycle. Second, it explores the role of various frictions, represented by adjustment costs, in understanding how the average wage changes over a plant's life. Third, it considers the dynamic interaction between labor quality and quantity at the plant level. This interaction has implications for the time-paths of the average wage and employment, and for the adjustment costs associated with both. Finally, the data used here is much richer and more complete than those in most of the previous studies.[5]

The rest of the paper is organized as follows. Section 2 describes the data and presents the empirical findings. Section 3 introduces the model. The estimation methodology is presented in Section 4. The estimation results are discussed in Section 5. Section 6 concludes.

2 The evolution of the average wage

2.1 Data

The primary data source is the U.S. Census Bureau's Longitudinal Research Database (LRD). The LRD describes several aspects of manufacturing plants' production, including the total value of shipments and value added, as well as employment and total wage bill. The LRD also contains information on the classification and identification of plants, such as plants' ownership, location, and industry, as well as various status codes that identify birth, death, and ownership changes. These identifying codes are used in developing the longitudinal plant linkages.[6]

The analysis focuses on a subset of the LRD that includes eight waves of the Census of Manufactures (CM): 1963, and 1967-1997 quinquennially. The focus on these years are driven by the fact that plants are classified consistently into SIC industry codes, for which there was a substantial revision and transition into NAICS industry codes in 2002. The number of plants in the CM range from 305,691 in 1967 to 400,036 in 1997. Using permanent plant numbers, plants were linked from these CM's to form an unbalanced panel for the period 1963-1997. Plant entry, exit, and continuation were identified. A plant is observed at most eight times, when it appears in all waves of the CM.

The variables for the analysis are constructed as follows. A plant's revenue is its value of shipments deflated to 1987 dollars using 4-digit SIC level industry price deflators from the NBER-CES Manufacturing Industry Database based on the 1987 SIC code definitions.[7] The deflated value added is also calculated as an alternative measure of revenue, which is used in the model's estimation. Employment is a plant's total number of workers engaged in production and non-production activities. The main wage variable, the total wage bill, is deflated to 1987 dollars using CPI from Bureau of Labor Statistics. Using a plant's deflated revenue, its deflated wage bill, and its employment, three ratios were constructed for each plant-CM wave observation: (a) the average wage – the ratio of the total wage bill to employment, (b) labor productivity – the ratio of revenue to employment, and (c) the ratio of the total wage bill to revenue, equivalent to the ratio of (a) to (b). The empirical analysis describes the life-cycle evolutions of these three ratios.

2.2 Main findings

The life-cycle effects on key plant-level variables are estimated using alternative specifications of the following OLS regression

$$Y_{it} = \alpha + \sum_{\tau} \beta_X^{\tau} X_{it}^{\tau} + \sum_{\tau} \beta_E^{\tau} E_{it}^{\tau} + \beta_Z' \mathbf{Z}_{it} + \iota_{it} + \varepsilon_{it}, \tag{1}$$

where i indexes plants, t indexes census years, Y_{it} is either the average wage, labor productivity, or the wage-bill-to-revenue ratio, X_{it}^{τ} is an indicator of whether a plant is $\tau \in \{0, 5, 10, 15, 20\}$ years *to* its exit point (the last census it is observed), E_{it}^{τ} is an indicator of whether a plant is $\tau \in \{0, 5, 10, 15, 20\}$ years away *from* its entry point (the first census it is observed), and $\mathbf{Z}_{it}$ is a vector of plant-level controls.[8] A full set of industry-year fixed effects, ι_{it}, were also added to control for time and industry specific effects, such as the effects of industry life-cycles and aggregate shocks.[9] The omitted category, referred to as the 'mature plants', contains the plants that are more than twenty years away from their entry or exit, and the plants whose entry or exit do not fall into the sample period. The error term ε_{it} is assumed to be clustered by plant.

Of particular interest are the coefficients β_X^{τ} and β_E^{τ} of the life-cycle indicators X_{it}^{τ} and E_{it}^{τ}, which track the evolution of the dependent variable Y_{it} as a plant moves away from entry into maturity and as it approaches exit. The coefficients β_X^{τ} and β_E^{τ} quantify the magnitudes of these life-cycle effects. β_X^{τ} measures how much being τ years away from exit matters for Y_{it}, controlling for the time from entry as identified by the indicators E_{it}^{τ}, in addition to other controls. Similarly, β_E^{τ} measures how much being τ years from entry matters for Y_{it}, controlling for the time to exit identified by X_{it}^{τ}, in addition to other controls.

Specification I in Table 1 generates Figure 1. Consider, first, the evolution of the average wage in Figure 1a. New plants begin with an average wage that is roughly $2,700 lower than that of the mature plants. It takes at least twenty years for this gap to drop below $300. On the other hand, the average wage starts to fall as a plant approaches exit. The plants that are twenty years away from exit have about $200 lower average wage than the mature plants. This gap grows to $2,000 by the time of exit. The average wage tends to rise faster for surviving entrants than they fall for plants approaching exit. This is indicated by the different slopes of the average wage profiles for the two parts of the life-cycle on either side of the y -axis.

Next, turn to the evolution of labor productivity in Figure 1b. Compared with the mature plants, new plants start off with approximately $5,700 productivity disadvantage that diminishes over time. Failing plants exhibit a much larger productivity disadvantage. Exiting plants have about $10,000 lower productivity. Even as early as ten years prior to exit, the plants that eventually exit have around $4,000 lower productivity. Labor productivity tends to fall faster for plants nearing exit than it rises for aging entrants.

Table 1 OLS estimates for the evolution of average wage, labor productivity, and wages to revenue ratio

Dependent variable:	Average wage ($1,000)		Revenue/Employment ($1,000)		Wage bill/Revenue (%)	
Independent variables	**I**	**II**	**I**	**II**	**I**	**II**
Exit	-2.031***	-1.846***	-9.852***	-8.962***	0.675***	0.598***
	[0.018]	[0.018]	[0.160]	[0.157]	[0.038]	[0.038]
5 years to exit	-1.010***	-0.897***	-5.220***	-4.939***	0.634***	0.635***
	[0.019]	[0.019]	[0.174]	[0.171]	[0.042]	[0.041]
10 years to exit	-0.695***	-0.613***	-3.920***	-3.914***	0.461***	0.497***
	[0.024]	[0.024]	[0.219]	[0.215]	[0.053]	[0.052]
15 years to exit	-0.447***	-0.412***	-2.566***	-3.010***	0.273***	0.369***
	[0.031]	[0.030]	[0.275]	[0.269]	[0.066]	[0.065]
20 years to exit	-0.159***	-0.179***	-1.240***	-2.281***	0.031	0.211**
	[0.038]	[0.038]	[0.347]	[0.339]	[0.083]	[0.082]
Entry	-2.714***	-2.356***	-5.668***	-1.998***	-1.733***	-2.236***
	[0.017]	[0.017]	[0.156]	[0.155]	[0.037]	[0.038]
5 years from entry	-1.782***	-1.514***	-2.228***	0.282*	-1.247***	-1.580***
	[0.019]	[0.019]	[0.170]	[0.168]	[0.041]	[0.041]
10 years from entry	-1.180***	-0.964***	-1.141***	0.571**	-0.653***	-0.865***
	[0.023]	[0.023]	[0.207]	[0.204]	[0.050]	[0.049]
15 years from entry	-0.628***	-0.469***	-0.151	0.759***	-0.219***	-0.312***
	[0.026]	[0.026]	[0.239]	[0.234]	[0.057]	[0.057]
20 years from entry	-0.229***	-0.120**	1.537***	1.634***	-0.181**	-0.152
	[0.044]	[0.044]	[0.397]	[0.389]	[0.095]	[0.094]
Industry x year fixed effects	Y	Y	Y	Y	Y	Y
Other controls	N	Y	N	Y	N	Y
N	1,219,769	1,219,769	1,219,769	1,219,769	1,219,769	1,219,769
R^2	0.29	0.30	0.38	0.41	0.43	0.44

Notes: Standard errors in brackets. (*),(**),(***) indicate significance at 10%,5%,1%, respectively. Other controls include a cubic spline in plant size (measured by total employment) and an indicator of multi-plant firm. The omitted category is the plants that are more than twenty years away from their entry or exit, and the plants whose entry or exit points do not fall into the sample period.

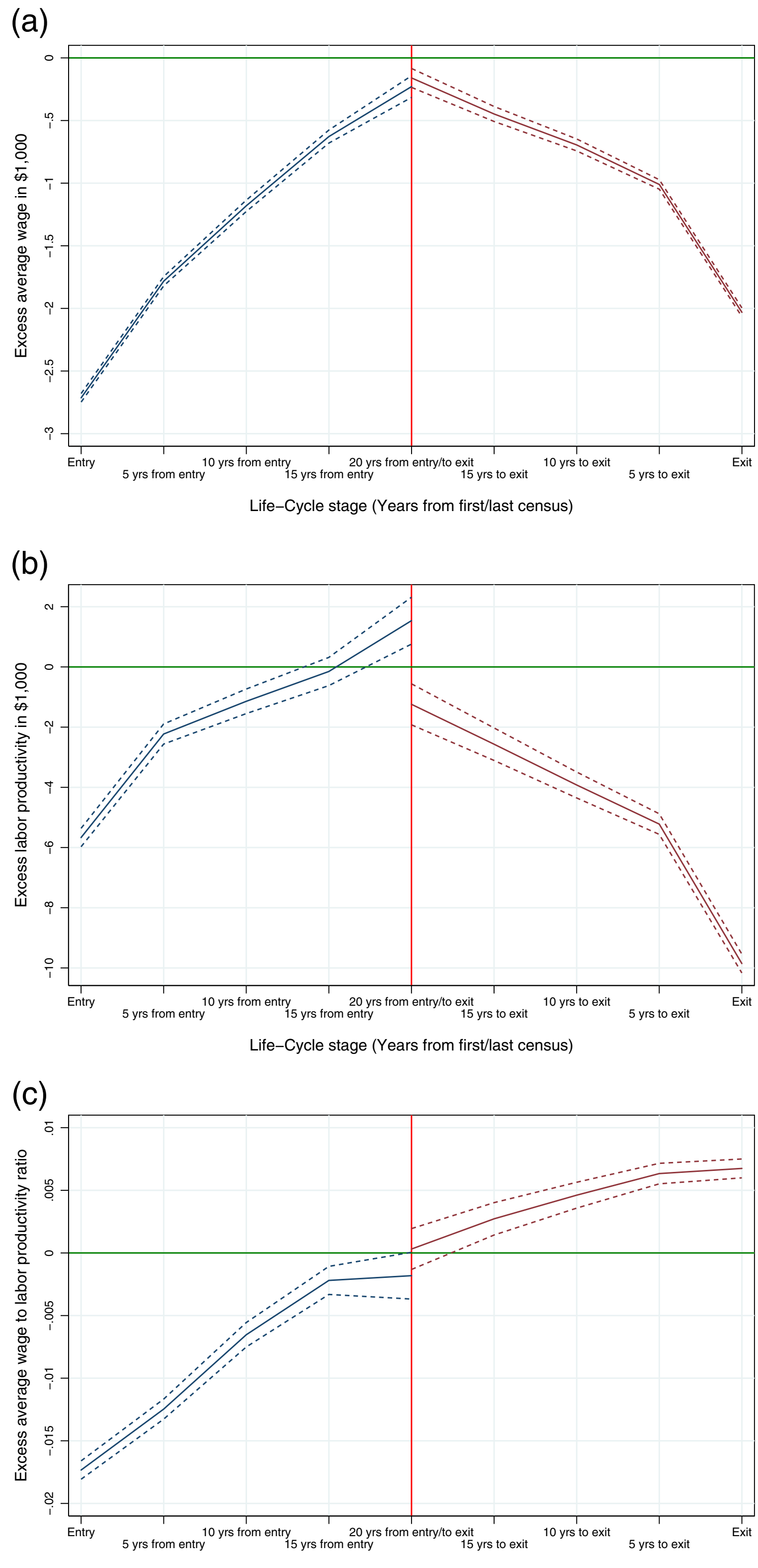

Figure 1 Plant life-cycle evolution of : (a) average wage, (b) labor productivity, (c) average wage to labor productivity ratio. Notes: The horizontal line at zero represents the normalized value for the omitted category. Dashed lines are +/− 2 std. errors.

The findings in Figures 1a and 1b together suggest the evolution of the ratio of a plant's wage bill to its revenue, equivalent to the fraction of a worker's productivity provided to the worker in the form of wages. The estimated life-cycle path for this ratio is shown in Figure 1c. New plants spend a lower fraction of their revenue on wage bill compared with the mature plants, although this gap largely disappears over the next fifteen years for surviving plants. Plants approaching exit, however, exhibit a small but statistically significant increase in this ratio. Failing plants on average spend a higher fraction of their revenue on their wage bill compared with the mature plants.

The findings continue to hold when other controls, $\mathbf{Z}_{it}$, are added. Specification II includes a cubic polynomial in plant size (employment), which is highly positively associated with wages (see, e.g., Brown and Medoff (1989)), in addition to an indicator of whether the plant is part of a multi-unit firm, and location (state) fixed effects. While the magnitudes of the life-cycle effects for the case of the average wage are now somewhat smaller in absolute value, their signs and significance resemble those in specification I. The most important difference is in the case of labor productivity for young plants. Compared with specification I, young plants now exhibit a much faster productivity growth, and seem to wipe out their productivity disadvantage vis á vis the mature plants by their fifth year after entry. As a result, the wage-bill-to-revenue ratio for entering plants is now lower, and stays lower longer as they age.

The overall theme of Table 1 can be summarized as follows. The average wage is low for entering plants, and gradually approaches that of the mature plants. As plants get closer to exit, the average wage falls, but not as fast as it increases for surviving and aging entrants. Labor productivity is also much lower for entering plants, but it rises as plants age. Plants nearing exit have a relative productivity disadvantage, visible even twenty years prior to exit. Griliches and Regev (1995) find a similar pattern in an early study of Israeli firms and dub this effect "the shadow of death": the firms that are due to exit in the future are less productive in the present.[10] The average wage rises slower than labor productivity does for young plants as they survive and age. It also falls slower than labor productivity does for failing plants. However, the relative rate of growth in the average wage versus labor productivity in young plants differs from the corresponding relative rates of decline in failing plants. This asymmetry manifests itself in the evolution of the wage-bill-to-revenue ratio. For young plants, the wage bill constitutes a smaller fraction of revenue compared with the mature plants, whereas plants approaching exit are burdened with a wage bill that claims a larger fraction of their revenue compared with the mature plants.

The evolutions depicted in Figure 1 can be interpreted as the typical or average evolutions that would take place if a plant goes through all stages of the life-cycle. One concern is a potential composition bias in these evolutions due to differences in plant life-span. For instance, short-lived plants may be a special group. They may be born with a much lower productivity and may live for a period of at most 2 or 3 censuses, and experience a monotonic decline in average wages and productivity over that period until exit. As a result, the latter part of the life-cycle trends in Figure 1 may be driven mainly by such plants. As a further robustness check for the patterns in Figure 1, and as an alternative to the panel analysis which pools all plants, the evolution of the average wage is plotted in Figure 2 over the life-span of plants that are born within the sample period and live for a given number of censuses; a minimum of 2, and a maximum of 6. This longitudinal analysis ensures that the same set of plants are observed over time for any given life-span.

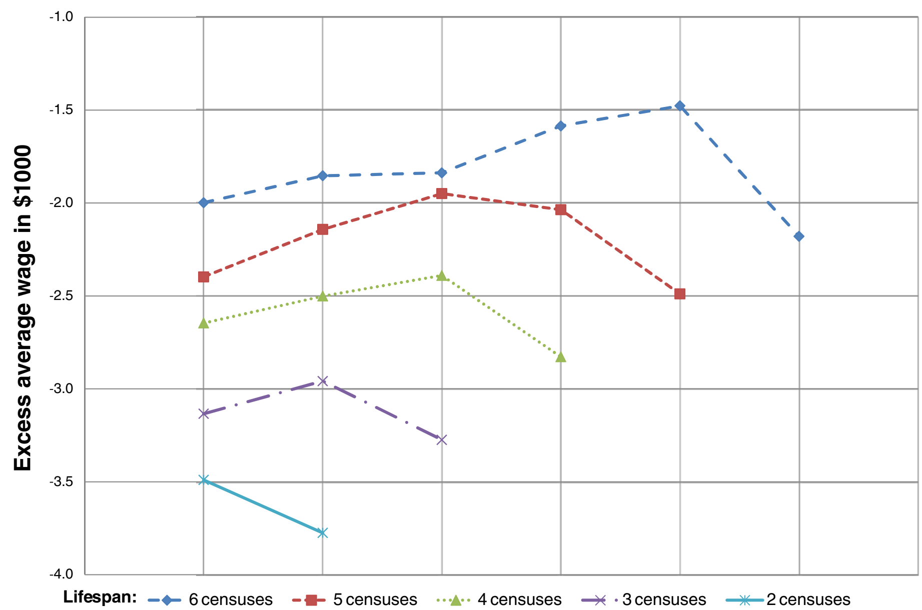

Figure 2 Plant life-cycle evolution of the average wage by plant life span. Notes: Excess average wage is measured with respect to the omitted category.

The estimated life-cycle effects in the case of the average wage plotted in Figure 2 are obtained using a similar regression specification to (1) with only a set of dummies that indicate the number of years from entry interacted by a life-span dummy.[11] The full set of results for this exercise are in Table 2. The inverted-U shaped pattern in Figure 1a also emerges for each life-span in Figure 2. Even relatively short-lived plants appear to experience an increase in the average wage after entry, and a decline before exit. Note also in Table 2 that the average wage declines slower than productivity does as plants approach exit, similar to the pattern found in Table 1. The results thus appear to be robust to life-span considerations.

Table 2 OLS estimates for the evolution of average wage, labor productivity, and wages to revenue ratio

Dependent variable:	Average wage ($1,000)		Revenue/Employment ($1,000)		Wage bill/Revenue (%)	
Independent variables	I	II	I	II	I	II
Lifespan = 2						
Entry	-3.490***	-3.042***	-9.638***	-5.740***	-1.159***	-1.661***
	[0.035]	[0.035]	[0.315]	[0.310]	[0.076]	[0.075]
Exit	-3.775***	-3.356***	-12.241***	-8.871***	-0.692 ***	-1.111***
	[0.035]	[0.035]	[0.315]	[0.310]	[0.076]	[0.075]
Lifespan = 3						
Entry	-3.134***	-2.713***	-8.227***	-4.762***	-1.125***	-1.561**
	[0.047]	[0.047]	[0.425]	[0.417]	[0.102]	[0.101]
5 years from entry	-2.958***	-2.570***	-8.118***	-5.077***	-0.651***	-1.025***
	[0.047]	[0.047]	[0.423]	[0.415]	[0.101]	[0.101]
Exit	-3.274***	-2.920***	-11.227***	-9.112***	-0.131	-0.362***
	[0.048]	[0.048]	[0.436]	[0.427]	[0.104]	[0.104]

Table 2 OLS estimates for the evolution of average wage, labor productivity, and wages to revenue ratio *(Continued)*

Lifespan = 4						
Entry	-2.646***	-2.283***	-6.716***	-4.280***	-0.883***	-1.158***
	[0.065]	[0.064]	[0.584]	[0.572]	[0.208]	[0.139]
5 years from entry	-2.501***	-2.157***	-5.009***	-3.662***	-0.773***	-1.043 ***
	[0.064]	[0.064]	[0.579]	[0.567]	[0.139]	[0.138]
10 years from entry	-2.390***	-2.078***	-7.191***	-5.444***	-0.132***	-0.305***
	[0.064]	[0.064]	[0.578]	[0.566]	[0.138]	[0.137]
Exit	-2.828***	-2.547**	-11.091***	-10.172***	0.391**	0.354**
	[0.066]	[0.065]	[0.592]	[0.579]	[0.142]	[0.140]
Lifespan = 5						
Entry	-2.397***	-2.081***	-6.466***	-4.957***	-0.838**	-0.967**
	[0.096]	[0.096]	[0.868]	[0.849]	[0.208]	[0.206]
5 years from entry	-2.142***	-1.824***	-5.009***	-3.140***	-1.003***	-1.196***
	[0.096]	[0.095]	[0.863]	[0.845]	[0.207]	[0.205]
10 years from entry	-1.949***	-1.665***	-5.775***	-4.353***	-0.064	-0.192
	[0.095]	[0.094]	[0.854]	[0.835]	[0.205]	[0.203]
15 years from entry	-2.036***	-1.469***	-7.734***	-7.087***	0.328**	0.323*
	[0.077]	[0.077]	[0.698]	[0.683]	[0.167]	[0.166]
Exit	-2.489***	-2.120**	-10.442***	-10.741***	0.246	-0.404
	[0.141]	[0.140]	[1.267]	[1.240]	[0.304]	[0.301]
Lifespan = 6						
Entry	-1.998***	-1.763***	-2.932**	-2.692***	-0.458	-0.964***
	[0.166]	[0.165]	[1.497]	[1.464]	[0.359]	[0.356]
5 years from entry	-1.853***	-1.581**	-2.053	-0.991	-0.896**	-0.151
	[0.166]	[0.165]	[1.501]	[1.468]	[0.360]	[0.094]
10 years from entry	-1.837***	-1.573***	-4.236**	-3.245**	-0.018	-0.077
	[0.164]	[0.163]	[1.480]	[1.448]	[0.355]	[0.351]
15 years from entry	-1.585***	-1.367**	-2.240*	-2.192	-0.062	-0.004
	[0.162]	[0.161]	[1.458]	[1.426]	[0.349]	[0.346]
20 years from entry	-1.477***	-1.287**	-3.559**	-3.889***	0.203	0.351
	[0.166]	[0.165]	[1.494]	[1.461]	[0.358]	[0.354]
Exit	-2.179***	-1.998***	-6.112***	-6.792***	0.181	0.374
	[0.167]	[0.165]	[1.502]	[1.469]	[0.360]	[0.356]
Industry x year fixed effects	Y	Y	Y	Y	Y	Y
Other controls	N	Y	N	Y	N	Y
N	1,219,769	1,219,769	1,219,769	1,219,769	1,219,769	1,219,769
R^2	0.29	0.30	0.38	0.41	0.43	0.44

Notes: Standard errors in brackets. (*),(**),(***) indicate significance at 10%,5%,1%, respectively. Life-span indicators were interacted with life-cycle indicators. Other controls include a cubic spline in plant size (measured by total employment) and an indicator of multi-plant firm. The omitted category is plants that are at least 20 years from entry and to exit.

3 The model

The model is motivated by the empirical findings which suggest an asymmetric evolution of the average wage for plants experiencing productivity increase versus decline. It explores the potential role of adjustment costs in the changes in the average wage across the life-cycle of a plant. Consider an industry with many plants. Both the quantity, L, and quality, q, of labor are factors of production for a plant.[12] Plants can be price-takers in the output market, or local monopolies which set prices given their downward sloping demand. There is an infinite number of discrete time periods, denoted by $t \geq 1$. Plants receive random shocks to their productivity each period. For a plant with employment L, workers are indexed on the interval $[0, L]$, and the quality of each worker $l \in [0, L]$ is $q(l)$. In a competitive labor market, there is a large number of workers with varying quality levels available for hire at the rate, w_t, per unit of quality, which a plant takes as given.[13] The rate w_t is subject to random fluctuations over time. There are thus two distinct channels through which a plant's average wage can change. First, a plant has to adjust its wage bill in response to changes in the wage rate per unit of worker quality. Second, a plant can choose to alter its average worker quality, which also affects its wage bill.

3.1 Adjustment cost for wages

A plant chooses the number and the average quality of its employees to generate output using a Cobb-Douglas production technology. The period profit of a plant is

$$\Pi(q_t, L_t; q_{t-1}, L_{t-1}, w_t, w_{t-1}, \theta_t) = \theta_t L_t^{\alpha} q_t^{\gamma} - w_t q_t L_t - A(q_t, L_t; q_{t-1}, L_{t-1}, w_t, w_{t-1}) - F. \quad (2)$$

In the production function represented by the first term on the right hand side of (2), L_t is the quantity of labor, q_t is the average quality per unit of labor defined by $q_t = \frac{1}{L_t}\int_0^{L_t} q(l)dl$, and $\theta_t \geq 0$ is a productivity shock that includes aggregate and idiosyncratic shocks, as well as the output price. The production function exhibits decreasing returns, $\alpha + \gamma < 1$. This formulation allows for different elasticities of output with respect to labor quality and quantity.[14]

A plant's total cost per period is represented by the remaining terms on the right hand side of (2). The first component is the wage bill, $w_t q_t L_t$. The second component is the adjustment cost

$$A(q_t, L_t; q_{t-1}, L_{t-1}, w_t, w_{t-1}) = \left[I_t^U \frac{\lambda^U}{2} + I_t^D \frac{\lambda^D}{2}\right] \left(\frac{w_t q_t - w_{t-1} q_{t-1}}{w_{t-1} q_{t-1}}\right)^2 w_{t-1} q_{t-1} L_{t-1}, \quad (3)$$

where $\lambda^U \geq 0$ and $\lambda^D \geq 0$ are the parameters of the quadratic adjustment costs associated with upward and downward adjustments in the average wage, $w_t q_t$, indicated by $I_t^U \equiv I(w_t q_t > w_{t-1} q_{t-1})$ and $I_t^D \equiv I(w_t q_t \leq w_{t-1} q_{t-1})$, respectively. The base to which adjustments in the average wage applies is the wage bill in period $t-1$, $w_{t-1} q_{t-1} L_{t-1}$. Changes in the average wage has two sources: changes in w_t, and the plant's choice of q_t. When w_t changes, the plant has to incur an adjustment cost in the average wage even when it does not alter q_t.[15] Finally, F is a fixed cost of operation that is avoidable only if the plant exits.

The distribution of θ_t is given by the *c.d.f.* $H_\tau(\theta_t|\theta_{t-1})$, which specifies the general dependence of the productivity shock on its previous value, and plant age, τ. The life-cycle effects on productivity are driven by the process $H_\tau(\theta_t|\theta_{t-1})$. There are several processes that can generate a life-cycle evolution of productivity similar to the dynamics pictured in Figure 1b.[16] The exact forms of the stochastic processes for θ_t and w_t are not specified, as such specifications are not needed for the model's estimation.

Denote the state variable for a plant by $\mathbf{s}_t = (q_{t-1}, L_{t-1}, w_t, w_{t-1}, \theta_t)$. The plant makes its decisions after observing θ_t and w_t. The exit decision is denoted by the discrete choice $X_t \in \{0, 1\}$ such that $X_t = 1$ if the plant exits. The value of a plant is then

$$V(\mathbf{s}_t) \equiv \max_{X_t, L_t, q_t} (1 - X_t) \left(\Pi(q_t, L_t; \mathbf{s}_t) + \beta E\left[V(\mathbf{s}_{t+1}) \right] \right), \tag{4}$$

where β is the discount factor and the plant's exit value is normalized to zero. Given the assumptions of the model so far, dynamic programming arguments in Stokey and Lucas (1989) guarantee the existence of a unique value function V in (4), which is strictly increasing in θ_t. Therefore, exit occurs the first time θ_t is such that $V(\mathbf{s}_t) \leq 0$.

At the beginning of every period, there is a large number (a continuum) of ex-ante identical potential entrants which can enter the industry by paying a sunk entry cost of $\kappa > 0$. The expected value from entry in any period is $V_t^e = E[\, V(\mathbf{s}_t)]$, where an entrant's initial state $\mathbf{s}_t = (0, 0, w_t, w_{t-1}, \theta_t)$ reflects the fact that its prior labor quality and quantity are both zero.

Let V_i denote the derivative of V with respect to its ith argument where it exists. At an interior solution, a continuing plant's choice of L_t satisfies

$$\alpha \theta_t L_t^{\alpha - 1} q_t^{\gamma} - w_t q_t + \beta E\left[V_2(\mathbf{s}_{t+1}) \right] = 0, \tag{5}$$

where

$$E\left[V_2(\mathbf{s}_{t+1}) \right] = -E\left[\left(I_{t+1}^U \frac{\lambda^U}{2} + I_{t+1}^D \frac{\lambda^D}{2} \right) \left(\frac{w_{t+1} q_{t+1} - w_t q_t}{w_t q_t} \right)^2 \right] w_t q_t. \tag{6}$$

Similarly, a continuing plant's choice of q_t satisfies

$$\gamma \theta_t L_t^{\alpha} q_t^{\gamma - 1} - w_t L_t - \left[I_t^U \lambda^U + I_t^D \lambda^D \right] \left(\frac{w_t q_t - w_{t-1} q_{t-1}}{w_{t-1} q_{t-1}} \right) w_t L_{t-1} + \beta E\left[V_1(\mathbf{s}_{t+1}) \right] = 0, \tag{7}$$

where

$$E\left[V_1(\mathbf{s}_{t+1}) \right] = E\left[\left(I_{t+1}^U \frac{\lambda^U}{2} + I_{t+1}^D \frac{\lambda^D}{2} \right) \frac{L_t}{w_t^2 q_t^2} \left(w_{t+1}^2 q_{t+1}^2 - w_t^2 q_t^2 \right) w_t \right]. \tag{8}$$

The first order conditions (5) and (7) implicitly determine a plant's labor quantity and quality policies, $L(\mathbf{s}_t)$ and $q(\mathbf{s}_t)$. Let $\Pi^*(\mathbf{s}_t)$ be the period profit evaluated at optimal policies $L(\mathbf{s}_t)$ and $q(\mathbf{s}_t)$. The exit policy is then

$$X(\mathbf{s}_t) = \begin{cases} 0 & \text{if } \Pi^*(\mathbf{s}_t) + \beta E\left[V(\mathbf{s}_{t+1}) \right] > 0, \\ 1 & \text{otherwise.} \end{cases}$$

Using (5), the wage bill can be expressed as a fraction of revenue as

$$f_t = \frac{L_t w_t q_t}{\theta_t L_t^{\alpha} q_t^{\gamma}} = \alpha + \beta \frac{E\left[V_2(\mathbf{s}_{t+1}) \right] L_t}{\theta_t L_t^{\alpha} q_t^{\gamma}}. \tag{9}$$

Using (6) in (9) and rearranging, one obtains

$$f_t = \frac{\alpha}{1 + \beta a_{t+1}}, \tag{10}$$

where

$$a_{t+1} = E\left[\left(I_{t+1}^U \frac{\lambda^U}{2} + I_{t+1}^D \frac{\lambda^D}{2} \right) \left(\frac{w_{t+1} q_{t+1} - w_t q_t}{w_t q_t} \right)^2 \middle| \theta_t, w_t \right], \tag{11}$$

is the expected value of the adjustment cost as a fraction of period-t wage bill. If the adjustment costs are zero ($\lambda^U = \lambda^D = 0$), the labor's share of revenue is $f_t = \alpha$ – this is the 'static' labor share when when no dynamic effects are present. An implication of (10) is that higher expected adjustment in the average wage in the next period is accompanied by a lower share of labor in current period revenue ($f_t < \alpha$). Consider now the case where the policies $L(\mathbf{s}_t)$ and $q(\mathbf{s}_t)$ are both strictly increasing in θ_t.[17] A high (low) productivity shock then implies an upward (downward) adjustment in both L and q. When $\lambda^U < \lambda^D$, downward adjustments are more costly then upwards adjustments. The average wage in declining plants can then decrease more slowly than it rises in growing plants. Thus, a_{t+1} can be lower for a plant adjusting downward, implying a higher f_t for plants experiencing decline in productivity.

3.2 Adjustment costs for the average wage and employment

Consider now an adjustment cost for employment, in addition to that for the average wage. A change in employment may not usually occur holding average worker quality constant, and vice versa. Incorporating both adjustment margins simultaneously can therefore account for some of the potential bias when only one of these two costs is considered. The adjustment costs now read as

$$A(q_t, L_t; q_{t-1}, L_{t-1}, w_t, w_{t-1}) = \left[I_t^U \frac{\lambda^U}{2} + I_t^D \frac{\lambda^D}{2}\right] \left(\frac{w_t q_t - w_{t-1} q_{t-1}}{w_{t-1} q_{t-1}}\right)^2 w_{t-1} q_{t-1} L_{t-1} + \left[J_t^U \frac{\nu^U}{2} + J_t^D \frac{\nu^D}{2}\right] \left(\frac{L_t - L_{t-1}}{L_{t-1}}\right)^2 L_{t-1}, \quad (12)$$

where $\nu^U \geq 0$ and $\nu^D \geq 0$ are the parameters of the quadratic adjustment cost associated with upward and downward employment adjustments, indicated respectively by $J_t^U \equiv I(L_t > L_{t-1})$ and $J_t^D \equiv I(L_t \leq L_{t-1})$. Note that the two margins of adjustment are interrelated. Adjustment in the average wage has an effect on a plant's current and future employment, and adjustment in employment influences the current and future average wage.

For a continuing plant, the first order condition for q_t is the same as (7). For L_t, the first order condition now becomes

$$\alpha \theta_t L_t^{\alpha-1} q_t^{\gamma} - w_t q_t - \left[J_t^U \nu^U + J_t^D \nu^D\right] \left(\frac{L_t - L_{t-1}}{L_{t-1}}\right) + \beta E\left[V_2(\mathbf{s}_{t+1})\right] = 0. \quad (13)$$

As an alternative specification, adjustment costs which allow for symmetric and bounded growth rates are also considered. These alternative specifications for the average wage and employment replace the denominators of the squared terms in (3) and (12) with $\frac{1}{2}(w_t q_t + w_{t-1} q_{t-1})$ and $\frac{1}{2}(L_t + L_{t-1})$, respectively. These specifications restrict the growth rates in the average wage or employment to the interval $[-2, 2]$, and are robust to outliers and to any biases due to mean reversion in plant employment and wage bill.

4 Estimation

4.1 Adjustment costs for the average wage

Consider first the model with the adjustment costs for the average wage only. Condition (7) can be rewritten after multiplying through by q_t as

$$\gamma \theta_t L_t^{\alpha} q_t^{\gamma} - w_t q_t L_t - \left[I_t^U \lambda^U + I_t^D \lambda^D\right] \left(\frac{w_t q_t - w_{t-1} q_{t-1}}{w_{t-1} q_{t-1}}\right) w_t q_t L_{t-1} + \beta E\left[V_1(\mathbf{s}_{t+1})\right] q_t = 0. \quad (14)$$

Multiplication by q_t ensures that the average wage, $w_t q_t$, appears in the first order condition, rather than just w_t. The former can be calculated using a plant's wage bill and employment, whereas the latter is not observed. Note that the labor quality q_t is also unobserved. Consequently, the parameters γ, λ^U, and λ^D, are identified from employment, wage bill, and revenue. This approach differs from those that use direct measures of labor quality based on observable worker characteristics, such as education and experience. The estimation of parameters associated with labor quality here does not require a specific measure or index of labor quality, or the estimation of an earnings function.

To implement the estimation, assume that the first order conditions are not exactly fulfilled, but hold subject to a non-systematic error that may stem from several sources, such as optimization errors, and the differences between anticipated and realized output price or the wage rate per unit of quality. These idiosyncratic errors are assumed to be randomly distributed over plants. Following Hansen and Singleton (1982), the ex-post error can be expressed, using (8) and (14), as a function of the parameters $\Phi = \{\alpha, \gamma, \lambda^U, \lambda^D\}$

$$\begin{aligned}\varepsilon_t(\Phi) = & -\gamma\theta_t L_t^{\alpha} q_t^{\gamma} + w_t q_t L_t + \left[I_t^U \lambda^U + I_t^D \lambda^D\right]\left(\frac{w_t q_t - w_{t-1}q_{t-1}}{w_{t-1}q_{t-1}}\right) w_t q_t L_{t-1} \\ & -\beta\left[I_{t+1}^U \frac{\lambda^U}{2} + I_{t+1}^D \frac{\lambda^D}{2}\right]\frac{L_t}{w_t q_t}\left(w_{t+1}^2 q_{t+1}^2 - w_t^2 q_t^2\right),\end{aligned} \tag{15}$$

The ex-post error in labor choice, after using (5) and (6), is

$$\eta_t(\Phi) = -\alpha\theta_t L_t^{\alpha-1} q_t^{\gamma} + w_t q_t + \beta\left[I_{t+1}^U \frac{\lambda^U}{2} + I_{t+1}^D \frac{\lambda^D}{2}\right]\left(\frac{w_{t+1}q_{t+1} - w_t q_t}{w_t q_t}\right)^2 w_t q_t. \tag{16}$$

For exiting plants, the decision variables are not observed for the period after they exit. However, the event of exit contains additional information, as the probability of exit also depends on the parameters of interest. Pakes (1994) shows that one can substitute the discrete exit policy $X(\mathbf{s}_t)$ into the expected discounted future profits, and proceed as in the case of continuing plants. Thus, for a plant that continues from period $t+1$ to $t+2$, $X(\mathbf{s}_{t+1}) = 0$ and the ex-post errors are as defined earlier. For a plant that exits in period $t+1$, $X(\mathbf{s}_{t+1}) = 1$ and the ex-post errors become

$$\varepsilon_t(\Phi) = -\gamma\theta_t L_t^{\alpha} q_t^{\gamma} + w_t q_t L_t + \left[I_t^U \lambda^U + I_t^D \lambda^D\right]\left(\frac{w_t q_t - w_{t-1}q_{t-1}}{w_{t-1}q_{t-1}}\right) w_t q_t L_{t-1}, \tag{17}$$

$$\eta_t(\Phi) = -\alpha\theta_t L_t^{\alpha-1} q^{\gamma} + w_t q_t. \tag{18}$$

Equations (15)-(18) can be used in a generalized method of moments (GMM) framework to estimate the parameters $\Phi = \{\alpha, \gamma, \lambda^U, \lambda^D\}$. Consider a system of moment conditions of the form

$$\begin{aligned} m_i^{\varepsilon}(\Phi) &= E[z_{it}\varepsilon_t(\Phi)] = 0, \\ m_j^{\eta}(\Phi) &= E[z_{jt}\eta_t(\Phi)] = 0, \end{aligned} \tag{19}$$

where z_{it}, z_{jt} denote instrumental variables $i = 1, ..., I$, $j = 1, ..., J$. The GMM estimation can be carried out using the empirical counterparts of the $I + J$ moment conditions in (19). The system used for estimation involves endogenous variables (revenue, employment, and wage bill) and has four unknown parameters and two equations that determine ex-post error terms. At least four instruments are needed to estimate the four parameter version of the model. The model suggests that the lagged values of decision variables, revenues, value added, and wage bill are predetermined in period t, and hence are orthogonal to both error terms, $\varepsilon_t(\Phi)$ and $\eta_t(\Phi)$. Any of these variables and their functions can serve as an instrument in both types of moment conditions in (19). The instruments used thus consist of lagged values of revenue, value added, wage bill, the average wage, their squares, and their interactions.[18] It is important to include exiting plants in the estimation as not doing so can induce bias in both the production function and adjustment cost parameter estimates. The estimation is done separately for continuing plants and all plants (continuing and exiting) to assess this bias. For each census year t, continuing plants are the ones that are observed consecutively in years $t-5$, t, and $t+5$. Similarly, the exiting plants are those that are observed in census years $t-5$ and t, but not in $t+5$. In the estimation, the discount factor is set to $\beta = 0.78$ for the quinquennial data, which corresponds to $\beta = 0.95$ for annual data. The estimation is repeated for the case of the adjustment costs with alternative growth rates using the corresponding first order conditions.[19] For the estimation, the iterated generalized method of moments estimator of Ferson and Foerster (1994) was used. Similar results were obtained when nonlinear two stage least squares estimation was used as an alternative.

4.2 Adjustment costs for the average wage and employment

For the case with both employment and the average-wage adjustment cost, the ex-post error for L_t is

$$\begin{aligned}\eta_t(\Phi) = & -\alpha\theta_t L_t^{\alpha-1} q_t^{\gamma} + w_t q_t + \left[J_t^U \nu^U + J_t^D \nu^D\right]\left(\tfrac{L_t - L_{t-1}}{L_{t-1}}\right) \\ & +\beta\left[I_{t+1}^U \tfrac{\lambda^U}{2} + I_{t+1}^D \tfrac{\lambda^D}{2}\right]\left(\tfrac{w_{t+1}q_{t+1} - w_t q_t}{w_t q_t}\right)^2 w_t q_t \\ & -\beta\left[J_{t+1}^U \tfrac{\nu^U}{2} + J_{t+1}^D \tfrac{\nu^D}{2}\right]\left(\tfrac{L_{t+1}^2 - L_t^2}{L_t^2}\right).\end{aligned} \tag{20}$$

The ex-post error for q_t is the same as (15).

For exiting plants, the ex-post error for L_t is

$$\eta_t(\Phi) = -\alpha\theta_t L_t^{\alpha-1} q^{\gamma} + w_t q_t + \left[J_t^U \nu^U + J_t^D \nu^D\right]\left(\frac{L_t - L_{t-1}}{L_{t-1}}\right),$$

and the ex-post error for q_t is the same as (17). The parameters to be estimated are now $\Phi = \{\alpha, \gamma, \lambda^U, \lambda^D, \nu^U, \nu^D\}$. The GMM estimation is carried out for the six parameter version of the model similar to the case with four parameters. In this case, at least six instruments are needed, and the instruments described in the previous section are used.

5 Results

5.1 Parameter estimates

The GMM estimates of the parameters using the entire sample of manufacturing plants are reported in Table 3. Two measures of revenue are used alternatively: the deflated total value of shipments (top panel) and the deflated value added (bottom panel). Adjustment costs with both the conventional and the alternative growth rates are considered. The estimates in specifications I and III pertain only to continuing plants. The estimates in specifications II and IV pertain to all plants, including the exiting ones. Both the model with the average-wage adjustment only (specifications I and II), and the model with the average-wage and employment adjustment (specifications III and IV) are estimated.[20]

Table 3 GMM estimates for the model's parameters using CM sample

	Revenue measure: Total value of shipments (deflated)							
	Adjustment costs (conventional growth rate)				Adjustment cost (alternative growth rate)			
	Wage adjustment		Wage and employment adjustment		Wage adjustment		Wage and employment adjustment	
Parameter	Continuing plants (I)	All plants (II)	Continuing plants (III)	All plants (IV)	Continuing plants (I)	All plants (II)	Continuing plants (III)	All plants (IV)
α	0.12***	0.11***	0.12***	0.09***	0.12***	0.13***	0.12***	0.14***
	[0.0005]	[0.0006]	[0.002]	[0.0006]	[0.0004]	[0.0004]	[0.0005]	[0.001]
γ	0.19***	0.18***	0.25***	0.24***	0.27***	0.42***	0.18***	0.13***
	[0.0004]	[0.0005]	[0.002]	[0.0007]	[0.0009]	[0.002]	[0.002]	[0.002]
λ^U	2.89***	2.62***	10.73***	-0.98***	5.94***	14.18***	1.25***	2.77***
	[0.05]	[0.04]	[0.41]	[0.01]	[0.11]	[0.15]	[0.03]	[0.08]
λ^D	35.61***	63.10***	20.81***	56.48***	9.55***	6.30***	10.10***	10.46***
	[0.25]	[0.42]	[0.74]	[0.33]	[0.07]	[0.06]	[0.12]	[0.33]
ν^U	-	-	8.62***	0.56***	-	-	1.97***	13.43***
			[0.52]	[0.03]			[0.42]	[0.72]
ν^D	-	-	23.17***	42.91***	-	-	8.90***	88.21***
			[4.82]	[1.03]			[0.12]	[1.94]
	Revenue measure: Value added (deflated)							
α	0.36***	0.39***	0.25***	0.33***	0.32***	0.37***	0.27**	0.39***
	[0.0005]	[0.0008]	[0.003]	[0.0007]	[0.0002]	[0.001]	[0.001]	[0.003]
γ	0.47***	0.44***	0.37***	0.39***	0.35***	0.27***	0.22***	0.42***
	[0.002]	[0.001]	[0.004]	[0.002]	[0.0002]	[0.001]	[0.002]	[0.002]
λ^U	1.39***	1.00***	3.73***	1.38***	3.44***	3.25***	1.04***	-0.54***
	[0.04]	[0.02]	[0.24]	[0.04]	[0.08]	[0.06]	[0.03]	[0.05]
λ^D	15.63***	13.95***	29.32***	19.25***	10.31***	8.34***	6.82***	1.37***
	[0.17]	[0.20]	[0.47]	[0.21]	[0.06]	[0.06]	[0.08]	[0.22]
ν^U	-	-	3.46***	1.13***	-	-	2.03***	17.74***
			[0.28]	[0.04]			[0.32]	[0.79]
ν^D	-	-	41.42***	47.60***	-	-	6.69***	58.32***
			[2.70]	[0.72]			[0.09]	[2.20]
N	804,245	986,977	804,245	986,977	804,245	986,977	804,245	986,977

Notes: Standard errors in brackets. (*),(**),(***) indicate significance at 10%,5%,1%, respectively.

In all specifications in Table 3, the estimates for the production function parameters α and γ have the expected signs, and fall in the interval $(0, 1)$. The average estimated value of $\alpha + \gamma$ when revenue is measured by the value of shipments is about 0.37. When value added is used as the revenue measure in the bottom panel, the estimates of α and γ are much higher, and still highly significant. The estimates of $\alpha + \gamma$ average 0.72 across specifications. The estimated magnitudes of γ are comparable to, and sometimes exceed, those of α. The importance of labor quality relative to quantity in production accords with Griliches and Regev's (1995) and Bahk and Gort's (1993) findings that labor quality plays an important role in explaining productivity differences across plants.

In most of the specifications in Table 3, the estimates of the adjustment cost parameters have the expected signs and they are highly significant.[21] The estimates reveal asymmetry in adjustment costs. Except for one case (specification II with alternative growth rate), downward adjustment cost parameters are higher than upward adjustment cost parameters, both for the average-wage and employment adjustment. The equality of the upward and downward adjustment cost parameters are rejected at high levels of significance across most specifications. Furthermore, the downward adjustment cost parameters are generally larger in absolute value when all plants are considered (specifications II and IV), compared with the case of continuing plants only (specifications I and III). This difference suggests that failing plants face higher downward adjustment costs. The adjustment cost parameter estimates are generally smaller under alternative growth rates.

5.2 The magnitude of the adjustment costs

Because the adjustments in the average wage and employment apply to different bases in various adjustment cost specifications, it is not appropriate to simply compare the estimated magnitudes of λ^U and ν^U, or λ^D and ν^D, to gauge the relative importance of different adjustment costs. The approach here is to assess the cost of adjustment for the average wage versus employment by comparing the shares of the wage and employment adjustment costs in a plant's initial revenue over a 5-year window between two censuses. The average annual adjustment costs are calculated over a 5-year period between two census years t and $t + 5$, whereas the current revenue is calculated for census year t.

Table 4 presents the quartiles of the revenue shares of adjustment costs based on the parameter estimates in Table 3. Rather than picking a specification arbitrarily, for each adjustment cost parameter its maximum estimate across all specifications for the case of total value of shipments in Table 3 is used to obtain the estimates in Table 4. This approach provides an upper bound on the revenue share of adjustment costs. Panel (a) considers estimates from the models using continuing plants only, corresponding to specifications I and III in Table 3. The estimated revenue shares of adjustment costs are calculated at the median of the corresponding adjustment cost distribution. For the model with the average-wage adjustment only, the average annual adjustment cost is 0.8% of revenue when both directions of adjustment are considered together, and around 0.4% and 2% when upward and downward adjustments are considered, respectively. For the model with both the average-wage and employment adjustment, the average-wage adjustment cost is about 1.0% of revenue, and the upward average-wage adjustment cost constitutes about 0.6% of revenue, while the downward average-wage adjustment cost makes up about 1.6% of revenue. The average annual employment adjustment cost has a significant share, nearly 4%, of revenue when downward employment adjustments are considered. For upward employment adjustments, this share is about 3%.

A similar pattern emerges in panel (b) of Table 4, which focuses on the estimated parameters using all plants, corresponding to specifications II and IV in Table 3. For the model with the average-wage adjustment only, upward and downward adjustment costs make up, respectively, about 0.8% and 3.5% of revenue. For the model with both adjustment margins, these shares are about 0.1% and 3.2%, respectively. For employment adjustment, upward adjustment cost is about 5.9% of revenue, whereas the downward adjustment cost constitutes about 8.2% of revenue.

Adjustment costs constitute a much larger fraction of revenue when only the exiting plants are considered, as panel (c) of Table 4 indicates. For almost all model specifications and for both upward and downward adjustment, the shares in panel (c) are much higher compared with panels (a) and (b). These magnitudes suggest that downward adjustment costs can potentially be a substantial burden for plants, especially for those nearing exit.

Table 4 Adjustment costs as a percentage of revenue

(a) Estimates using continuing plants only

		Model with wage adjustment only			Model with wage and employment adjustment				
	Adjustment Cost Percentile	**All**	**Upward**	**Downward**	**All**	**Upward (Wages)**	**Downward (Wages)**	**Upward (Employment)**	**Downward (Employment)**
Wage Adjustment	25	0.1%	0.1%	0.4%	0.2%	0.1%	0.3%		
	50	0.8%	0.4%	2.0%	1.0%	0.6%	1.6%		
	75	3.7%	1.5%	7.6%	4.2%	2.7%	6.2%		
Employment Adjustment	25				0.6%			0.6%	0.5%
	50				3.2%			2.9%	3.8%
	75				14.3%			12.6%	16.9%

(b) Estimates using all plants: Continuing plants only

		Model with wage adjustment only			Model with wage and employment adjustment				
	Adjustment Cost Percentile	**All**	**Upward**	**Downward**	**All**	**Upward (Wages)**	**Downward (Wages)**	**Upward (Employment)**	**Downward (Employment)**
Wage Adjustment	25	0.3%	0.2%	0.7%	0.0%	0.0%	0.6%		
	50	1.6%	0.8%	3.5%	0.4%	0.1%	3.2%		
	75	7.4%	3.5%	13.4%	3.4%	3.9%	2.9%		
Employment Adjustment	25				1.2%			1.2%	1.1%
	50				6.7%			5.9%	8.2%
	75				29.9%			26.0% 35.9%	

(c) Estimates using all plants: Exiting plants only

		Model with wage adjustment only			Model with wage and employment adjustment				
	Adjustment Cost Percentile	**All**	**Upward**	**Downward**	**All**	**Upward (Wages)**	**Downward (Wages)**	**Upward (Employment)**	**Downward (Employment)**
Wage Adjustment	25	0.5%	0.2%	1.3%	0.1%	0.0%	1.1%		
	50	3.0%	1.2%	6.7%	0.9%	0.1%	6.0%		
	75	14.2%	5.3%	25.7%	7.9%	0.5%	23.0%		
Employment Adjustment	25				2.4%			1.8%	3.4%
	50				14.8%			10.0%	22.4%
	75				70.6%			48.5%	94.7%

How much do adjustment costs in the average wage change over the life-cycle of a plant? The evolution of adjustment costs along the plant life-cycle is depicted in Figure 3 for continuing plants. These estimates are based on the largest adjustment cost parameter estimates from the model with wage adjustment cost only using all plants, corresponding to specifications labelled II in the left panel of Table 3. These specifications also generate the left side of panel (b) in Table 4. For the plants that are five years from their first census, the average-wage adjustment cost makes up about 2.3% of revenue annually at the median adjustment cost. This share increases slightly as new plants age and then declines to just

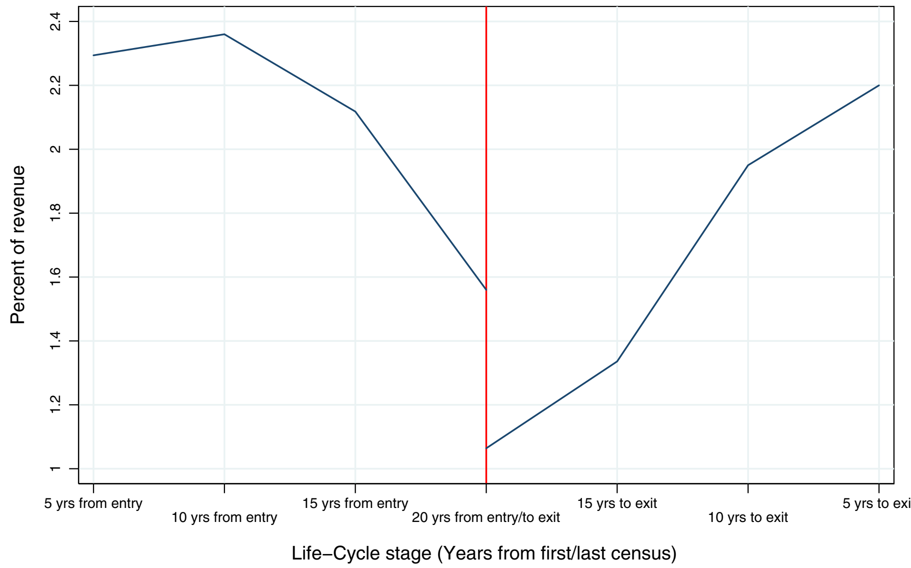

Figure 3 Plant life-cycle evolution of wage adjustment cost as a share of revenue. Estimates based on the model with wage adjustment (continuing plants only).

below 1.6% by the time a plant is 20 years away from entry. Somewhat reversal of this pattern is observed for the plants approaching exit. The average-wage adjustment cost grows to about 2.2% of a plant's revenue five years before its exit, doubling from about 1.1% when a plant stands twenty years from exit.

5.3 Estimation using annual data

The estimates for annual adjustment costs were so far obtained using data in CM, which has quinquennial frequency. A longer time period between two consecutive observations of a plant could lead to lower adjustment cost estimates, as plants may have more flexibility to adjust over a longer horizon. If adjustment costs are highly convex, plants would tend to spread adjustments over time. The estimation is repeated using annual frequency data from the US Census Bureau's Annual Survey of Manufactures (ASM) for the period 1972-2009. As in the case of the CM, plants are linked over time. The unbalanced panel constructed from the ASM has a number of important differences from the panel from the CM. First, ASM pertains mainly to the relatively large plants.[22] Furthermore, a plant may enter to or drop from the ASM panel simply because its size changes to a level that is above or below the threshold of inclusion with certainty in the ASM. Second, the sampling frame for the ASM changes every five years, implying that some plants may enter, whereas others may be dropped from the sample over time. Therefore, actual plant entry/exit do not necessarily coincide with entry to/exit from the sample. The results based on the ASM thus may differ from the ones based on the CM for reasons in addition to the differences in the frequency of observation.[23]

The results from the GMM estimation based on the ASM panel are in Table 5. Sample weights in the ASM are used to obtain the population estimates. The results appear to be qualitatively similar across Table 3 and Table 5. Most importantly, downward adjustment costs are still larger than upward adjustment costs, and upward adjustment costs

Table 5 GMM estimates for the model's parameters using ASM sample

Parameter	Adjustment costs (conventional growth rate): Wage adjustment: Continuing plants (I)	All plants (II)	Wage and employment adjustment: Continuing plants (III)	All plants (IV)	Adjustment cost (alternative growth rate): Wage adjustment: Continuing plants (I)	All plants (II)	Wage and employment adjustment: Continuing plants (III)	All plants (IV)
Revenue measure: Total value of shipments (deflated)								
α	0.11***	0.11***	0.10***	0.07***	0.14***	0.14***	0.09***	0.09***
	[0.00006]	[0.00006]	[0.002]	[0.0001]	[0.00007]	[0.00006]	[0.0004]	[0.0001]
γ	0.17***	0.17***	0.22***	0.20***	0.21***	0.31***	0.18***	0.12***
	[0.00007]	[0.00012]	[0.00008]	[0.0001]	[0.0003]	[0.0003]	[0.0003]	[0.0003]
λ^U	3.72***	1.72***	3.44***	0.83***	1.45***	1.32***	1.56***	1.31***
	[0.006]	[0.004]	[0.004]	[0.004]	[0.007]	[0.008]	[0.004]	[0.008]
λ^D	1.31***	2.33***	2.76***	1.46***	18.82***	2.89***	19.73***	2.89***
	[0.008]	[0.002]	[0.009]	[0.001]	[0.052]	[0.007]	[0.049]	[0.007]
ν^U	-	-	0.64***	2.77***	-	-	1.53***	1.77***
			[0.21]	[0.14]			[0.538]	[0.221]
ν^D	-	-	96.39***	32.65***	-	-	44.39***	43.49***
			[40.5]	[6.0]			[15.6]	[1.94]
Revenue measure: Value added (deflated)								
α	0.26***	0.26***	0.10***	0.17***	0.31***	0.32***	0.32***	0.33***
	[0.0002]	[0.0002]	[0.0005]	[0.0002]	[0.0001]	[0.0001]	[0.0001]	[0.0003]
γ	0.20***	0.19***	0.19***	0.19***	0.16***	0.17***	0.13***	0.17***
	[0.0001]	[0.0001]	[0.0001]	[0.0001]	[0.0003]	[0.0003]	[0.0004]	[0.0003]
λ^U	0.77***	1.14***	2.33***	0.33***	1.73***	1.17***	1.44***	1.21***
	[0.005]	[0.003]	[0.005]	[0.001]	[0.005]	[0.006]	[0.006]	[0.004]
λ^D	1.93***	1.24***	2.88***	0.24***	12.16***	1.81***	14.39***	1.82***
	[0.008]	[0.001]	[0.008]	[0.001]	[0.04]	[0.006]	[0.041]	[0.006]
ν^U	-	-	0.62***	0.33***	-	-	1.52***	1.48***
			[0.221]	[0.113]			[0.741]	[0.255]
ν^D	-	-	99.48***	32.84***	-	-	86.32***	37.10***
			[22.0]	[6.2]			[14.2]	[7.2]
N	3,926,908	3,927,407	3,926,908	3,927,407	3,926,908	3,927,407	3,926,908	3,927,407

Notes: Standard errors in brackets. (*),(**),(***) indicate significance at 10%,5%,1%, respectively. Number of observations reflect sampling weights used.

are generally small for both the average wage and employment. However, there are a few important differences. First, in Table 5 the estimates of the production function parameters α and γ are generally smaller. This discrepancy could be driven by the fact that the plants in the sample used for the results in Table 5 are much larger, and may have different production technologies compared with the smaller ones in the sample used for the results in Table 3. Second, the estimates of the downward employment adjustment cost parameters are much larger compared with those in Table 3, whereas the estimates of the downward average-wage adjustment cost parameters have comparable magnitudes.

5.4 A comparison with the prior findings

In general, the empirical regularities documented here agree with the earlier findings based on data from other countries and periods of time. Brixy et al. (2007) use the matched employee-employer data in Germany for the period 1997-2001, and find that the average wage is lower in new firms but rises as firms get older, similar to the findings here. Audretsch et al. (2001) also analyze the connection between wages, productivity and firm age in Netherlands, and obtain similar findings. The "shadow-of-death" effect, i.e. lower productivity observed in failing firms even many years before they exit, is also noted in a recent study by Carreira and Teixeira (2011) using data on Portuguese firms. Fackler et al. (2013) also find a similar effect in the cases of East and West Germany. In the case of French manufacturing firms over the period 1990-2002, Bellone et al. (2006) document that mature firms that have lower and declining productivity compared with other mature firms tend to exit with higher likelihood. They also observe that the growth of new entrants is gradual, and it takes time for them to catch-up with the mature firms. Combined with the findings for the U.S. documented here, these prior studies suggest that the life-cycle evolution of productivity and wages tend to be similar across countries.

How do the estimates of adjustments costs compare with some of the prior findings in the literature? There does not exist a sizeable prior literature on the estimation of the adjustment costs for the average wage, or individual wages. However, several studies have provided estimates of labor adjustment costs. These studies span a variety of model structures, samples, and aggregations, making the comparison inherently difficult. Nevertheless, most studies find positive labor adjustment costs, based on different specifications. Adjustment costs are positive and significant in studies using a quadratic or higher-order specification with or without interactions among different adjustment margins.[24] The estimates of labor adjustment costs here are within the range of the estimates found in these previous studies, though there is strong evidence of asymmetric adjustment costs here. The estimates indicate relatively large downward employment adjustment costs compared with the upward adjustment costs. This asymmetry in labor adjustment was also found in earlier work by Jaramillo et al. (1993) using large firms in Italy for the period 1958-1988, and by Nilsen et al. (2007) in the case of Norwegian manufacturing plants for the period 1986-1995. Kramarz and Michaud (2010) also present evidence of asymmetry in hiring versus terminating costs in the case of French establishments. Furthermore, as shown in Table 4, the average-wage adjustment costs are smaller when the average-wage adjustment costs are estimated together with the employment adjustment costs, suggesting that not controlling for labor quantity adjustments may introduce bias in the adjustment cost estimates for labor quality, and vice versa.

6 Conclusion

This paper investigated the dynamics of the average wage paid to employees along the life-cycle of a manufacturing plant. Some stylized facts emerge. New plants start with a lower average wage compared with the mature plants. A surviving plant's average wage increases and catches up with those of the mature plants. The average wage of a plant approaching exit falls, but not as steeply as it rises in the case of surviving new plants. The total wage bill constitutes a lower fraction of a young and growing plant's revenue, because its average wage does not increase as fast as it labor productivity does. For plants approaching exit, the average wage does not fall as fast as labor productivity does, implying that a higher fraction of revenue must be dedicated to wage bill.

A model of plant-level dynamics was introduced to explore the potential role of frictions in the form of adjustment costs in the average wage. In the model, changes in the average wage result from both changes in average labor quality and changes in the wage rate per unit of quality. The estimated parameters of the model reveal evidence of asymmetric adjustment costs for the average wage. The estimated upper bounds on the revenue share of the average-wage adjustment costs indicate economic significance of such costs at the plant level, especially those associated with downward adjustment. The estimates remain economically significant when the average-wage adjustment cost is considered jointly with the employment adjustment cost.

The relatively high cost of adjusting the wage bill downward when a plant's productivity falls persistently may increase the likelihood of exit and speed up the demise of failing plants. Further research can quantify the importance of these costs in exit. Such effects can potentially be larger in the case of plants in Europe, which tend to face stricter labor regulations than in the U.S. The movements in the average wage at the plant level can also be decomposed further. A challenge is to separately measure the cost of adjustments in the wage rate per unit of labor quality, and the cost of adjustments due to changes in average labor quality only. Finally, the co-evolution of the average wage and labor quality also suggest a theory of plant life-cycle that emphasizes organizational complexity and hierarchy. For instance, new plants may start with a simple worker hierarchy that progressively becomes more complex with the addition of workers of higher quality and wages. Plant decline triggers a sluggish dismantling of this hierarchy and slow reduction in labor costs due to potentially high costs of changing the employee composition and wages.

Endnotes

[1] Throughout this paper, the term "average wage" refers to a plant's total wage bill per employee, not the average hourly wage rate of employees. The average hourly wages are not available in the data used here.

[2] See, e.g., Brown and Medoff (2003) and Kölling et al. (2013), Griliches and Regev (1995), and Bahk and Gort (1993). The analysis here does not attempt to disentangle the effect of worker versus plant characteristics on wages.

[3] See, e.g., Bahk and Gort (1993) and Griliches and Regev (1995).

[4] Unions in manufacturing, while much weaker in recent times, were effective for much of the sample period used in this paper, which goes back to 1963. Union presence in a plant could thus have played a role in the volatility of plant-level average wage in the earlier part of the sample period. Unfortunately, there does not exist a comprehensive data on the union status of plants in the U.S.

[5] Most prior work focus on employment and capital adjustment, and either use relatively small samples or non-representative samples from the U.S. firm population. Other studies use aggregate data, which may hide patterns at the micro level. Examples of prior work include, among others, Alonso-Borrego (1998), Shapiro (1986), Pfann and Palm (1993), Hall (2004), and Merz and Yashiv (2007).

[6] See also http://www.census.gov/ces/dataproducts/economicdata.html.

[7] See http://www.nber.org/data/nbprod2005.html.

[8] The total employment of a plant was restricted to the range 5 to 10,000 employees. In addition, the top and bottom percentiles of the three dependent variables were trimmed to reduce the influence of any outliers.

[9] The regression specifications are similar to those used in Foster et al. (2008).

[10] Such effects were also found in studies using data from other countries. See, e.g., Carreira and Teixeira (2011), Fackler at al. (2013), and Bellone et al. (2006).

[11] The time-to-exit indicators are excluded in these regressions, as including them together with the time-from-entry indicators would lead to collinearity with the life-span indicator.

[12] Worker quality, q, can have alternative interpretations, such as a worker's skill level, human capital, effort (including hours worked), or the degree of essentiality of a worker in production.

[13] This wage rate is allowed to be plant-specific, reflecting, for instance, the plant's local labor market conditions.

[14] When there are no adjustment costs, the elasticity of output with respect to labor quantity and quality must be the same ($\alpha = \gamma$) for interior maximizers to exist for the plant's optimization problem. The presence of adjustment costs that differ across factors breaks this constraint, and allows interior maximizers when $\alpha \neq \gamma$.

[15] These two different adjustments are not separately identified in the data used here.

[16] Suppose that the productivity of new entrants have *c.d.f.* $H_0(\theta_t)$. Subsequent productivity draws come from $H_\tau(\theta_t|\theta_{t-1})$, which is strictly decreasing in θ_{t-1}, and $H_1(\theta_{t+1}|\theta_t) < H_0(\theta_t)$ for all θ_t. There can also be age effects, e.g. $H_\tau(\theta_t|\theta_{t-1})$ is strictly decreasing in τ for $\tau < \overline{\tau}$ and strictly increasing in τ for $\tau > \overline{\tau}$, for some $\overline{\tau} \geq 1$. An entrant thus starts with a productivity that is lower, in a first-order-stochastic sense, than that of an age-1 incumbent. A surviving plant's next period productivity is higher in a first-order-stochastic sense, the higher its current period productivity. Such a process can generate the gradual decline in average productivity of failing plants prior to exit, and the gradual increase in average productivity of surviving plants following entry. See Hopenhayn (1992) [Section 5] for a general characterization of stochastic processes that can generate the observed evolutions of productivity.

[17] Such monotonicity holds under certain restrictions on the parameters of the model.

[18] The results were not significantly different when twice-lagged versions of the variables were also used as instruments.

[19] The first order conditions for this case are available upon request.

[20] In all specifications in Table 4, the top and bottom 1% of the plant level distributions of average wage, wage bill-to-revenue ratio, and labor productivity were trimmed to reduce the influence of some major outliers. The total employment of a plant was also restricted to the range 5 to $10,000$ employees.

[21] In two cases, the estimated upward adjustment cost parameters are negative, with small absolute values. These cases also emerge in some prior work with quadratic adjustment costs (e.g. Hall (2004)) and may result from a combination of remaining outliers in the data and measurement error. An implicit constraint on the adjustment cost parameters is non-negativity. As a robustness check, the model was re-estimated subject to these constraints. If the model's specification is not largely at odds with the data, moving from the unconstrained to the constrained estimation should not result in drastic sign and significance changes in other parameters. The constrained estimates were zero for the negative parameter estimates in Table 3, and the other parameter values were very similar to those in Table 3.

[22] The Annual Survey of Manufactures (ASM) is a sample survey of approximately 50,000 establishments. A new sample is selected at 5-year intervals beginning the second survey year subsequent to CM. Large plants are sampled with certainty, and smaller plants are sampled according to a stratified random sampling with probabilities that vary with plant size. See http://www.census.gov/manufacturing/asm/how_the_data_are_collected/index.html.

[23] A minimum plant size requirement of 50 employees is imposed to ensure that the estimation is not unduly influenced by smaller plants.

[24] See, e.g., Shapiro (1986), Pfann and Palm (1993), Alonso-Borrego (1998), and Merz and Yashiv (2007)), with the exception of Hall (2004), who finds quadratic costs that are not significantly different from zero using sector level data.

Competing interests
The IZA Journal of Labor Economics is committed to the IZA Guiding Principles of Research Integrity. The authors declare that they have observed these principles.

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