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Sebastian Buhai, Miguel Portela, Coen Teulings and Aico van Vuuren

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Sebastian Buhai, Miguel Portela, Coen Teulings and Aico van Vuuren †

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Abstract

This study documents two empirical facts using matched employer-employee data for Denmark and Portugal. First, workers who are hired last, are the first to leave the firm. Second, workers' wages rise with seniority (= a worker's tenure *relative* to the tenure of her colleagues). The identification problems for the wage return to tenure are shown not to apply to the return to seniority because seniority is not a deterministic function of time. Controlling for tenure, the probability of leaving the firm decreases with seniority. The increase in expected seniority with tenure explains a large part of the negative duration dependence of the hazard. Using a variety of estimation methods, we show that a 10% increase in seniority raises your wage by 0.1-0.2%, depending on the country and the method applied. Conditional on ten years of tenure, one standard deviation of seniority raises your wage by 0.5 to 1.6 percent.

Keywords: wage dynamics, tenure, seniority, LIFO

JEL-codes: J31, J41, J63

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†Buhai: Aarhus University and Northwestern University, CCP, LMDG, sbuhai@northwestern.edu; Portela: NIPE and University of Minho, IZA, mangelo@eeg.uminho.pt; Teulings: CPB Netherlands Bureau for Economic Analysis, University of Amsterdam, Tinbergen Institute, CEPR, CESIFO, IZA, C.N.Teulings@cpb.nl; Van Vuuren: VU University Amsterdam, Tinbergen Institute, avuuren@feweb.vu.nl.

1 Introduction

Why does Lars earn a lower wage than Jens, while they have the same human capital and work at the same firm? And why is Pedro fired and his colleague Miguel allowed to stay, when their employer has to scale down employment? Some might think that the answer to these questions is obvious: it is because Jens and Miguel are more *senior* than Lars and respectively Pedro, that is, Jens and Miguel have a longer tenure than Lars and Pedro, respectively. This paper provides empirical evidence supporting these popular convictions. Using matched worker-firm data for Denmark and Portugal, we show that a *worker who is hired last, is likely to be fired first* (Last In, First Out; LIFO henceforth). Analogously, we show that there is a return to *seniority* in wages. Seniority is different from tenure, in that it measures the *worker's tenure relative to the tenure of her colleagues*. The worker's seniority is thus her rank in the tenure hierarchy of the firm. When we claim that seniority affects your firm separation risk, we mean that on top of the negative duration dependence of the hazard rate, being a senior worker with many more junior colleagues has a further negative effect on your separation rate. Similarly, when we claim that there is a return to seniority in wages, we mean that on top of the return to tenure, there is a return to seniority. To the best of our knowledge, this paper is the first to document the existence of a return to seniority in wages.

Why would firms and workers agree on applying a LIFO layoff rule, and why would that lead to a return to seniority in wages? Kuhn (1988) and Kuhn and Robert (1989) develop a model that can explain these phenomena. Consider the standard monopoly union/right to manage model, where the union bargains for a wage rate above the market wage and where the firm decides on employment, taking this wage rate as given. It sets employment below the efficient level. This outcome implies that gains from trade between the union and the firm are left unexploited, since the firm would be willing to hire additional workers for a wage in between the market wage and the wage rate negotiated by the union. Kuhn and Robert suggest that the firm and the union could achieve a Pareto superior outcome by agreeing on a hiring order based on seniority, and a wage schedule that is increasing in seniority. This agreement would oblige the firm to hire workers in a particular order, the most senior worker, with the highest wage rate, first. If the wage schedule is properly set, the marginal worker hired by the firm receives exactly the market wage, so that employment is at its efficient level. The higher wage for inframarginal senior workers allows these workers to capture part of the firm's producer surplus. Kuhn and Robert elaborate these ideas in a static framework. In the working paper version of this paper, we use the dynamic model of Bentolila and Bertola (1990). We show that the firm and its workers agree on a wage profile where the most senior workers earn higher wages and are fired last.

Establishing a rate of return to seniority in wages is an exercise at the crossroad of two topics discussed extensively in the literature on the earnings function, namely the return to tenure on the one hand, see for example Altonji and Shakotko (1987), Topel (1991), Altonji and Williams (1997), Dustmann and Meghir (2005), and Buchinsky et al (2010), and the firm size-wage effect on the other hand, see for instance Brown and Medoff (1984). Moreover, Neal (1995) has shown that the return to tenure at the firm as measured by these authors is partly a proxy for a return to tenure in the industry or occupation. Seniority is related to tenure, since a worker's seniority is defined as her tenure relative to the tenure distribution of the rest of the firm's workforce. Hence, within a firm, seniority is positively related to tenure by definition. Changes in seniority are related to changes in firm size: an increase in firm size will always raise the seniority level of the firm's incumbent workers, since the newly hired workers have a lower tenure than the incumbents. It is therefore crucial to adequately control for both the return for tenure and the firm size-wage effect when estimating the return to seniority. The literature on the return to tenure suffers from a serious identification problem: the within-job spell variation in tenure is perfectly correlated to the within-job spell variation in experience. Hence, the first order effects of experience and tenure cannot be identified separately using solely within-spell variation. At the same time, the between-job spell variation is endogenous, since workers decide to change jobs at least partly based on a comparison of the wages in their current and their new job. Various papers have tried different strategies to solve this endogeneity problem. The estimation of the return to seniority as defined here does not face this identification problem, since the within-spell variation of seniority is not perfectly correlated to experience. We line up to this literature by applying the methods of both Altonji and Shakotko (who use job spell fixed effects) and Topel (who uses within spell first differences) in our estimations. In our empirical analysis, a worker's seniority at a particular point in time is defined as a function of the ratio of people hired before the worker and the total number of people in the firm. The latter is equal to firm size. Hence, the return to seniority can be distinguished from the firm size-wage effect by variation in the number of people hired before the respondent. We enter log firm size as a regressor next to our seniority measure to make sure that the estimated effect of the seniority is not a proxy for the firm size wage effect. We need exhaustive linked employer-employee data for establishing the workers' seniority index, as we need to know the tenure rank of each worker in any firm of our estimation sample. A full set of controls is added for the elapsed tenure in the estimation of the separation rate. We find strong effects of seniority on the job exit hazard, such that the expected increase in seniority with tenure explains a large part of the negative duration dependence of the hazard. Depending on the estimation method that we apply, we find highly significant returns to seniority, in the order of magnitude of 0.1 to 0.2% for every 10% increase in seniority for Portugal, and half that range for Denmark. Conditional on 10 years of tenure, a one standard deviation increase in seniority raises your wage by 0.5-0.6% in Denmark and 1.0-1.6 % increase for Portugal.

Section 2 discusses our estimation strategy, Section 3 describes the data, Section 4 presents the estimation results, and Section 5 concludes.

2 Estimation strategy

Define the rank q_{ijt} to be the log number of workers in firm j with tenure greater than or equal to worker i (including worker i) at time t and define n_{jt} to be the log total number of workers in the firm j at time t. Then, the seniority index r_{ijt} is defined as:

$$r_{ijt} = n_{jt} - q_{ijt}. \tag{1}$$

Hence, the seniority index for the most senior worker is equal to the log firm size n_{jt}, while the seniority index of the least senior worker is zero. If the LIFO separation rule were to apply literally, then the seniority index r_{ijt} would be the only determinant of separation since only workers with $r_{ijt} = 0$ would separate. In that case, a simple test for LIFO would be to check whether there are workers leaving a firm with a rank different from 0. In practice, this is not the case for several reasons. First, the workforce of the firm is not completely homogeneous, so that a firm may wish to diminish its workforce in one skill category, but not necessarily in other skill categories. This may disrupt a strict application of the LIFO separation rule. Second, workers separate not only because of shocks to the demand for the firm's product, but also due to worker-specific shocks, e.g., when a worker's partner gets a new job and moves to another city. A particularly important worker-specific factor in this context is retirement.

The seniority index r_{ijt} varies mostly in the upper part of the seniority distribution. The index for the most senior worker is $\log 2$ higher than that of the one but most senior worker. The same difference applies to the 100^{th} and 200^{th} worker in the seniority distribution. An alternative index shifts most of the variation in the index to the lower part of the distribution. Define q^*_{ijt} as the log number of workers in firm j with tenure less or equal than worker i at time t. Then, the alternative seniority index is specified as:

$$r^*_{ijt} = q^*_{ijt} - n_{jt}. \tag{2}$$

In the remainder of this section we only use r_{ijt} as the seniority index, but all our empirical models are also estimated for the alternative seniority index r^*_{ijt}.

2.1 The LIFO separation rule

We model the job separation process by a mixed proportional hazard (MPH) model with discrete-time periods. The probability of leaving the firm conditional on T_{ijt} years of elapsed tenure is specified as:

$$\theta_{ijt} = \frac{\exp\left(\gamma_0 r_{ijt} + \gamma_1 \Delta n_{jt} + \gamma_2 Z_{ij,t-T_{ijt}} + \psi_T + \chi_j + v_i\right)}{1 + \exp\left(\gamma_0 r_{ijt} + \gamma_1 \Delta n_{jt} + \gamma_2 Z_{ij,t-T} + \psi_T + \chi_j + v_i\right)}, \tag{3}$$

where T_{ijt} is the elapsed tenure and $Z_{ij,t-T_{ijt}}$ is a vector of observed characteristics of the worker and the job at the moment of job start (e.g., education and experience at job start), and where v_i represents the unobserved worker heterogeneity. The parameter χ_j is a firm effect to allow for heterogeneity in turnover between firms. We include a full set of dummies ψ_T for every tenure category (years), which is equivalent to a fully flexible specification of the baseline hazard. This baseline also picks up the impact of experience within a spell and also allows for the existence of a learning effect, see Jovanovic (1979). Identification of the parameter γ_0 of the seniority index r_{ijt} separately from the parameters of the baseline hazard ψ_T requires variation in r_{ijt} that is independent of the tenure T_{ijt}. Such independent variation is available since the seniority index also depends on the hiring and firing of other workers. Hence, it is a non-deterministic function of tenure. We add the change in firm size as a regressor to control for heterogeneity between growing and shrinking firms, since shrinking firms are expected to have higher separation rates. The LIFO-separation rule implies that controlling for the growth rate of the firm, the separation rate is higher for junior workers, i.e. γ_0 is expected to be negative. We assume v_i to follow a discrete distribution with a flexible number of mass points. In our estimation procedure, we use the likelihood ratio to determine the number of mass points. We use up to 10 spells of an individual, which helps to estimate the unobserved heterogeneity distribution. We use a discrete-time model, since workers are observed only once per year. Hence, we cannot observe the exact moment at which the worker enters or leaves the firm.[1] It also implies that short spells are underrepresented in the duration data, since a worker has to stay at least till the next period of observation for a spell to be recorded.[2] We cannot correct for these problems with the data at hand.

[1]For Portugal, tenure is reported in months. We use this information in the estimation. For the rest the modeling is the same for both countries.

[2]Note that this problem does not affect our measurement of the seniority index r_{ijt}, since for that purpose we only need the distribution of tenure at a particular point in time.

Equation (3) cannot be estimated with a full set of firm-fixed effects due to the non-separability of the model and the large number of firms. Hence, we include fixed effects only for the largest about 400 firms. In addition we also allow the coefficient of r_{ijt} (i.e. γ_0) to be different for these larger firms than for the smaller firms. What are the consequences of omitting fixed firm effects for smaller firms? The estimate of γ_0 will be biased upwards, making it less likely that we find a LIFO effect (since γ_0 is expected to be negative). The reason for this bias can be understood by considering the case without seniority effect, $\gamma_0 = 0$. For the sake of the argument, we first ignore worker heterogeneity. Consider two firms that differ only in their hazard rate, firm 1 having a higher hazard rate than firm 2. Compare two workers with equal tenure, one in firm 1 and the other in firm 2. The worker in firm 1 will have a higher seniority than the worker in firm 2. Not correcting for firm-fixed effects thus implies that the worker in firm 1, with the higher seniority, is expected to leave that firm more rapidly and hence the estimate of γ_0 is expected to be positive. Worker unobserved heterogeneity has an opposite effect because a worker who is still in a 'high-hazard-rate' firm after T years is more likely to have a lower level of v_i than a worker in a 'low-hazard-rate firm'. This shows the importance of correcting for worker unobserved heterogeneity, as we do in the paper.

In our empirical analysis, we follow the convention to delete spells that are left censored in order to omit the initial conditions problem, see, e.g., Lancaster (1990).

2.2 The return to seniority

The existence of a return to seniority in wages can be tested by extending the standard specification of the log earnings equation with the seniority index r_{ijt}:

$$w_{ijt} = \beta_0 + \beta_1 X_{ijt} + \beta_2 T_{ijt} + \beta_3 r_{ijt} + \beta_4 n_{jt} + \beta_5 Z_{ijt} + \varepsilon_{ijt}, \tag{4}$$

where w_{ijt} is log wage and X_{ijt} is experience. Higher order terms in experience and tenure are included in the vector Z_{ijt}. The coefficient β_4 captures the firm size wage effect documented by Brown and Medoff (1989). Substitution of r_{ijt} as defined in (1) into (4) yields:

$$w_{ijt} = \beta_0 + \beta_1 X_{ijt} + \beta_2 T_{ijt} + \beta_3 q_{ijt} + (\beta_3 + \beta_4)\, n_{jt} + \beta_5 Z_{ijt} + \varepsilon_{ijt}.$$

The coefficient on the seniority index is identified separately from the coefficient on the firm size by the variation in the log number of workers in the firm with tenure greater than or equal to worker i. It is therefore important to include log firm size in the model to make sure that the estimated effect of seniority is not merely a proxy for firm size.

Following Topel (1991) the unobservable term can be decomposed into four orthogonal components: a match, a firm, a worker, a time, and an idiosyncratic effect:

$$\varepsilon_{ijt} = \varphi_{ij} + \psi_j + \mu_i + \tau_t + \nu_{ijt}. \tag{5}$$

The idiosyncratic effect ν_{ijt} includes measurement error. There are all kinds of reasons for ϕ_{ij}, ψ_j, and μ_i to be correlated to T_{ijt}, see, e.g., Topel (1991) or Altonji and Williams (2005). Learning and search theories imply that good worker-firm relationships tend to survive as the worker and the firm learn about the quality of their match, and bad matches are broken up, leading to positive correlation between $\varphi_{ij} + \psi_j + \mu_i$ and T_{ijt}. However, Topel (1991) showed that there is also a reason for a negative correlation between φ_{ij} and T_{ijt}, since workers change jobs to get a higher wage. Hence, workers who recently changed jobs are likely to have found a job that at least made up for the loss of their returns to seniority. There are two solutions to the problem of the endogeneity of tenure: either using within job spell first differencing (FD), as applied by Topel (1991), or adding fixed effects for every job spell (FE), as applied by Altonji and Shakotko (1987). First differencing yields:

$$\Delta w_{ijt} = (\beta_1 + \beta_2) + \beta_3 \Delta r_{ijt} + \beta_4 \Delta n_{jt} + \Delta \tau_t + \Delta \nu_{ijt}. \tag{6}$$

Adding fixed effects per job spell is equivalent to taking deviations from the mean over a job spell:

$$\widetilde{w}_{ijt} = (\beta_1 + \beta_2)\, \widetilde{T}_{ijt} + \beta_3 \widetilde{r}_{ijt} + \beta_4 \widetilde{n}_{jt} + \widetilde{\tau}_{ijt} + \widetilde{\nu}_{ijt}, \tag{7}$$

where the upper tilde denotes deviations from the mean per job spell, e.g. $\widetilde{w}_{ijt} = w_{ijt} - \overline{w}_{ij\cdot}$, with $\overline{w}_{ij\cdot}$ the mean of w_{ijt} over a job spell. We exclude $\widetilde{X}_{ijt}$ from (7) because it is identical to $\widetilde{T}_{ijt}$. In both specifications above it is obvious that the first-order effects of tenure and experience are not separately identified. This problem has troubled all attempts to estimate the wage return to tenure. It led to a debate between Altonji and Shakotko (1987) and Topel (1991), and a large stream of subsequent papers. The perfect multicollinearity of experience and tenure within a job spell rules out estimating the return to tenure using within-spell variation. Hence, researchers had to revert to between-job spell variation. Topel (1991) establishes β_1 by calculating $w_{ijt} - (\beta_1 + \beta_2)\, T_{ijt}$ and regressing this variable on initial experience. Altonji and Shakotko (1987) use $\widetilde{T}_{ijt}$ as an instrument for T_{ijt} in the regression of w_{ijt}; see Altonji and Williams (2005) for a discussion of the arguments in favor of and against both methods. Happily, this problem does not affect the estimation of the return to seniority, β_3, since the seniority index r_{ijt} (or rank q_{ijt}, for that matter) is not perfectly correlated to T_{ijt}. This means that we can identify β_3 using only within-job spell variation in wages, and we do not have to bother about the selectivity problems that plague the estimation of the return to tenure. For the sake of comparison, we report the estimated return to tenure using both Topel's and Altonji and Shakotko's methodologies.

The choice between the FE and FD estimators depends on the error structure of v_{ijt} and on the lag structure of the effect of r_{ijt} on w_{ijt}. The closer v_{ijt} is to a unit root, the more efficient is the FD method. Previous empirical studies have typically found a high degree of autocorrelation in v_{ijt}, even close to a unit root, see for instance Abowd and Card (1979), Topel and Ward (1992), or Meghir and Pistaferri (2004). From that perspective, equation (6) is likely to be most efficient. However, suppose there is a lag in the effect of r_{ijt} on w_{ijt}, for example:

$$w_{ijt} = \beta_0 + \beta_1 X_{ijt} + \beta_2 T_{ijt} + \beta_3 \frac{1}{2}\left(r_{ijt} + r_{ij,t-1}\right) + \beta_4 n_{jt} + \beta_5 Z_{ijt} + \varepsilon_{ijt}. \tag{8}$$

Suppose that both w_{ijt} and r_{ijt} are close to a random walk. By incorrectly excluding the lagged value of r_{ijt} from the model and by first differencing the equation, the estimated coefficient will be underestimated by a factor two, since Δr_{ijt} and $\Delta r_{ij,t-1}$ are uncorrelated. The lagged impact of r_{ijt} will not be captured by first differencing. The same applies for the lagged impact of n_{jt}. From that perspective, equation (7) is preferred, since there $\widetilde{r}_{ijt}$ and $\widetilde{r}_{ij,t-1}$ are highly correlated and hence whether equation (4) or (8) is the right specification of the relationship between wages and seniority hardly affects the estimated level of β_3. Hence, one would expect higher estimates for β_3 and β_4 from using equation (7) than from (6).[3]

Abowd, Kramarz, and Margolis (1999) found evidence for heterogeneity in the return to tenure between firms and between workers. We can adjust equation (4) to allow for this heterogeneity:

$$w_{ijt} = \beta_0 + \beta_1 X_{ijt} + \beta_{2ij} T_{ijt} + \beta_3 r_{ijt} + \beta_4 n_{jt} + \beta_5 Z_{ijt} + \varepsilon_{ijt}.$$

Note that this specification allows for more than just firm heterogeneity, since it even allows every spell to have its own linear coefficient for the return to tenure.[4] In this

[3] We report robust standard errors, so that correlation between the residuals over time implied by the unit root does not affect the validity of the standard errors.

[4] The cost of introducing this type of flexibility is that the second order terms of experience and tenure are not identified using within spell differences in wages. Using assumptions comparable to Topel, it is possible to estimate these in a second stage regression using the second order term of the

case, the parameter β_3 can be estimated by first performing within-spell differences and then taking deviations from the within spell mean:

$$\widetilde{\Delta w}_{ijt} = \beta_3 \widetilde{\Delta r}_{ijt} + \beta_4 \widetilde{\Delta n}_{jt} + \widetilde{\Delta \tau}_{ijt} + \widetilde{\Delta \nu}_{ijt}. \tag{9}$$

We also report estimates for this method.

3 The data

For Denmark, we use the *Integrated Database for Labor Market Research* (IDA), for 1980-2001, which has been often used previously, e.g., by Mortensen (2003). IDA tracks every single individual between 15 and 74 years old. The labor market status of each person is recorded at November 30 of each year. The dataset contains a plant identifier, which allows the construction of the total workforce of a plant, and hence of the firm as a whole. We use information on hourly gross earnings, education, age, and on the plant's location, firm size, and industry. Industry is defined as the industry employing the largest share of the firm's workforce. Firm size is defined as the number of individuals holding primary jobs in that firm, and earning a positive wage.[5] The tenure of workers hired since 1980 can be calculated directly from the IDA. For workers hired between 1964-1980 the tenure can be calculated from a second dataset on the contribution histories to *ATP*, a mandatory pension program. Tenure in job spells started before 1964 is left censored (less than 3% of the observations, which we discard), but that still allows us to construct seniority for everybody else. Potential experience is age-schooling-6.[6]

For Portugal, we use *Quadros de Pessoal*, for 1986-2009, provided by the Ministry of Labour and Social Solidarity, also often used in earlier research, e.g. by Cabral and Mata (2003). It is based on a compulsory survey of firms, establishments and all their workers; compulsory participation enhances the data quality. The information available is similar to Denmark's except that workers' tenure is directly reported; the industry is the industry with the highest share of firm's sales or, when allocation by sales is not possible, the industry with the highest employment share. We use all full-time employees in their main job, and working for a firm located in Portugal's mainland. As noted in Cardoso and Portugal (2005) the wage variable is registered with exceptional accuracy.

For both countries we use data for all private sector jobs, except for agriculture,

initial experience. Details of this procedure are available from the authors.

[5]We performed a robustness check using the number of registered workers at the firm instead of this definition. The main results are not affected by this.

[6]For Denmark– but not for Portugal– we can construct actual experience. Using actual rather than potential experience does not make a difference for the coefficients on tenure and seniority. For the sake of consistency, we report results using potential experience for both countries.

fishing and mining. We eliminate outliers by deleting all wage observations lower than the legal minimum wage and dropping the top 1% of the wage distribution, for each year. Unless otherwise stated, for both countries we use employment spells of men aged over 25 years of age. The main reason to exclude younger individuals is to omit those who are still in education; their wage increases within a job are unlikely to be affected only by experience or tenure. We exclude women from our main analysis since they are more likely to leave their job for reasons which are not captured by our model. In addition, we use the location at the start of the spell and the same for industry. We also exclude workers above the age of 55 from the LIFO duration analysis (but not from the construction of seniority and the wage analysis), and spells started before the age of 55 and finished afterwards are taken as right censored. Note that the seniority variables r_{ijt} and r^*_{ijt} are calculated before any data deletion.

Table 1: Descriptive statistics Denmark and Portugal

	DK 1980-2001	DK 2000	PT 1986-2009	PT 2000
Variable				
Age	40.9	41.51	40.51	40.51
	(10.54)	(10.65)	(10.49)	(10.52)
Years of education	12.35	12.87	6.86	6.85
	(3.14)	(2.81)	(3.73)	(3.63)
Tenure	6.15	5.77	9.30	9.26
	(6.04)	(6.08)	(9.04)	(9.28)
Experience	22.93	23.41	24.04	24.05
	(11.14)	(10.73)	(10.81)	(10.85)
Log seniority	0.7	0.66	0.86	0.86
	(0.75)	(0.75)	(0.85)	(0.84)
Log firm size	4.7	4.77	4.14	4.05
	(2.33)	(2.35)	(2.11)	(2.14)
Log wage	3.15	3.2	1.52	1.61
	(0.3)	(0.32)	(0.53)	(0.52)
Sample size				
Observations	12634236	626867	15371019	725729
Workers	1412646	626867	2931323	725729
Firms	221807	60236	458888	124621
Spells	3456711	626867	4662627	725729

Notes: Standard deviations of variables in parentheses under their means. Log wages are expressed in euro and deflated to year 2000 prices.

Summary statistics for both countries are presented in Table 1, both for the pooled data, and for the year 2000 separately. While some statistics like the mean age or mean potential work experience are similar in both countries, there are also several striking differences. For instance, in 2000, the education level in Denmark is five years higher than in Portugal and at the same time, Danes stay on average almost 3 and a half years less at one firm than the Portuguese. The number of firms in the sample is more than double in Portugal relative to Denmark, but the average firm size in Portugal is only half of that in Denmark. Finally, Danes earn on average almost five times more than Portuguese.

4 Results

4.1 The LIFO-separation rule

Table 2 lists the estimation results for the discrete-time MPH model described in section 2.1 using the seniority index r_{ijt} and Table 3 lists the results for that model using the alternative seniority index r^*_{ijt}. The vector Z_{ijt} includes start-of-spell levels of education and experience and dummies for region and industry. We include 333 firm dummies for Denmark and 413 for Portugal. About 20 percent of the Danish workforce is employed in these firms and the smallest of these firms employs 273 workers; these figures are 8 percent and 177 for Portugal. We estimate the impact of the varying seniority index on the hazard rate for all firms with an additive term for the large firms. For computational reasons, we use a sample of 5 percent of the total population to estimate the MPH model.[7]

Table 2: Results of the discrete-time mixed proportional hazards rate model using r_{ijt} as the seniority measure

Country	Denmark				Portugal			
# of mass points	1	2	3	4	1	2	3	4
r_{ijt}	-0.2903	-0.2950	-0.2748	-0.2769	-0.1103	-0.1107	-0.1148	-0.1138
	(0.0091)	(0.0102)	(0.0106)	(0.0106)	(0.0104)	(0.0118)	(0.0121)	(0.0122)
r_{ijt} for large firms	0.1990	0.2467	0.1838	0.2076	-0.0824	-0.0765	-0.0729	-0.0732
	(0.0219)	(0.0221)	(0.0242)	(0.0241)	(0.0406)	(0.0452)	(0.0468)	(0.0471)
Δ firm size	-0.0088	-0.0092	-0.0087	-0.0088	0.0072	0.0064	0.0065	0.0065
	(0.0008)	(0.0008)	(0.0008)	(0.0008)	(0.0012)	(0.0014)	(0.0015)	(0.0015)
Education	-0.1169	-0.1586	-0.1666	-0.1653	-0.1979	-0.2327	-0.2364	-0.2361
	(0.0015)	(0.0021)	(0.0022)	(0.0022)	(0.0025)	(0.0026)	(0.0031)	(0.0031)
Experience	-0.5249	-0.5954	-0.6325	-0.6198	-0.2063	-0.2473	-0.2545	-0.2653
	(0.0069)	(0.0100)	(0.0092)	(0.0092)	(0.0229)	(0.0259)	(0.0270)	(0.0271)
Experience^2	0.0269	0.0281	0.0309	0.0298	-0.0072	-0.0083	-0.0083	-0.0076
	(0.0007)	(0.0010)	(0.0010)	(0.0009)	(0.0017)	(0.0019)	(0.0020)	(0.0020)
Experience^3 (x100)	-0.0571	-0.0555	-0.0644	-0.0327	0.0528	0.0610	0.0622	0.0599
	(0.0028)	(0.0035)	(0.0034)	(0.0043)	(0.0050)	(0.0057)	(0.0059)	(0.0059)
Experience^4 (x1000)	0.0033	0.0027	0.0037	0.0033	-0.0076	-0.0087	-0.0089	-0.0087
	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0005)	(0.0006)	(0.0006)	(0.0006)
Number of observations	355197				355841			
Mean log likelihood	-2.8441	-2.8432	-2.8124	-2.8122	-1.4549	-1.4382	-1.4369	-1.4369

Notes: The estimation also controls for region, industry indicators and dummies for the largest firms (333 for Denmark and 413 for Portugal). Standard errors in parentheses.

For both countries, we find a negative impact of the seniority index r_{ijt} on the

[7]The subset is made after the calculation of the seniority indices. We sample individuals eliminating the risk that we oversample short spells while still being able to use the repeated spells of every individual in our dataset.

Table 3: Results of the discrete-time mixed proportional hazards rate model using r^*_{ijt} as the seniority measure

Country	Denmark				Portugal			
# of mass points	1	2	3	4	1	2	3	4
r^*_{ijt}	-0.0497	-0.0104	-0.0004	-0.0047	-0.1354	-0.1225	-0.1223	-0.1223
	(0.0081)	(0.0092)	(0.0095)	(0.0095)	(0.0083)	(0.0095)	(0.0095)	(0.0095)
r^*_{ijt} for large firms	-0.0236	-0.1434	-0.0887	-0.1224	0.0051	0.0078	0.0113	0.0114
	(0.0120)	(0.0138)	(0.0139)	(0.0139)	(0.0273)	(0.0304)	(0.0310)	(0.310)
Δ firm size	-0.0085	-0.0088	-0.0088	-0.0086	0.0051	0.0064	0.0067	0.0067
	(0.0007)	(0.0008)	(0.0008)	(0.0008)	(0.0027)	(0.0014)	(0.0015)	(0.0015)
Education	-0.1148	-0.1630	-0.1650	-0.1666	-0.1997	-0.2339	-0.2339	-0.2339
	(0.0015)	(0.0021)	(0.0022)	(0.0022)	(0.0025)	(0.0030)	(0.0031)	(0.0030)
Experience	-0.5167	-0.6236	-0.6270	-0.6155	-0.1982	-0.2400	-0.2420	-0.2419
	(0.0070)	(0.0101)	(0.0093)	(0.0094)	(0.0229)	(0.0258)	(0.0267)	(0.0267)
Experience^2	0.0266	0.0308	0.0308	0.0297	-0.0078	-0.0087	-0.0087	-0.0087
	(0.0007)	(0.0010)	(0.0009)	(0.0009)	(0.0017)	(0.0019)	(0.0019)	(0.0019)
Experience^3 (x100)	-0.0567	-0.0654	-0.0644	-0.0609	0.0540	0.0620	0.0623	0.0623
	(0.0028)	(0.0035)	(0.0035)	(0.0035)	(0.0052)	(0.0057)	(0.0058)	(0.0059)
Experience^4 (x1000)	0.0033	0.0039	0.0037	0.0033	-0.0077	-0.0081	-0.0089	-0.0089
	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0005)	(0.0006)	(0.0006)	(0.0006)
Number of observations	355197				355841			
Mean log likelihood	-2.8489	-2.8478	-2.8241	-2.8239	-1.4539	-1.4377	-1.4367	-1.4367

Notes: The estimation also controls for region, industry indicators and dummies for the largest firms (333 for Denmark and 413 for Portugal). Standard errors in parentheses.

hazard rate, which is fairly precisely measured, in line with a LIFO-rule. Based on the likelihood ratio test, a specification with more than 4 mass points does not significantly improve the fit of the model. Moreover, adding more mass points does not have much of an effect on the estimated effect of the seniority index. The differential effect of seniority for large firms has opposite sign for both countries. In Denmark, seniority has a smaller impact for large firms, while in Portugal, it is the other way around. For the alternative seniority index r^*_{ijt} the results are somewhat mixed. The alternative index yields a substantially lower likelihood for Denmark, implying that the index r_{ijt} is better capable of explaining the hazard then the alternative index. Hence, we discredit these results. The effect for small firms becomes insignificant, while the effect for large firms changes signs. For Portugal, the likelihood is somewhat higher for the alternative index, although the difference is tiny, in particular for 3 and 4 mass points.

Figure 1 illustrates the impact of tenure on the hazard rate. The solid line is the baseline hazard ψ_T. In contrast to what is usually found, the baseline hazard is not decreasing for both countries, at least not before ten years of tenure for Portugal, while it is increasing for Denmark. As expected, this result is highly sensitive to the number of mass points that is used to control for unobserved heterogeneity: if we do not include unobserved heterogeneity (the model with one mass point), then the baseline hazard is sharply decreasing. The absence of a clear pattern of negative duration dependence is also due to the inclusion of seniority in the model. Seniority is positively correlated with tenure. Hence, the negative impact of seniority substitutes for the negative duration dependence. The dotted line is the effect of mean seniority on the hazard, i.e. the average seniority level for that level of tenure times the coefficient of seniority for the small firms. We find that this negative impact roughly neutralizes the positive impact of the baseline hazard in Denmark, while it has only a minor impact on the tenure related outflow in Portugal.

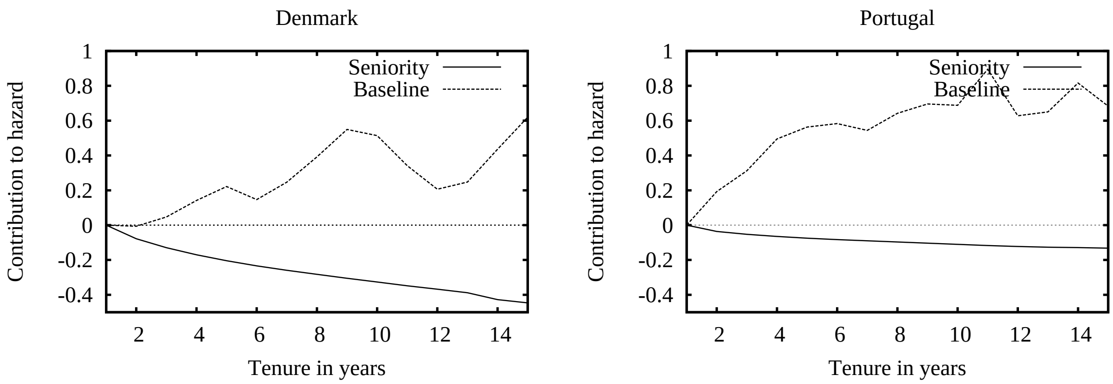

Figure 1: Baseline hazards and the contributions of average seniority to the hazard for different levels of the tenure. The baseline hazards are for the model with 4 different mass points

4.2 The return to seniority

First, we check the characteristics of the dynamic process of v_{ijt}. Table 4 reports the variance-covariance of Δv_{ijt} for the first six lags. For both countries, the covariance of ε_{ijt} with its first lag is substantial, the covariance with higher lags is negligible. Hence, the process is well approximated by an MA(1) process, made up of a mixture of permanent and transitory shocks. Abowd and Card (1979) and Topel and Ward (1992) find similar results for the United States. The standard deviation of the permanent shocks can be calculated as 0.10 for Denmark and 0.12 for Portugal.[8] These numbers are of the same order of magnitude as for the United States.

This evidence suggests that in terms of efficiency we prefer the first differencing method as introduced by Topel, while in terms of allowing for a lagged effect of r_{ijt} on w_{ijt}, we prefer the method of Altonji and Shakotko. Hence, we report results of both

[8] Let q_{ijt} and u_{ijt} be the transitory and permanent shock respectively. Then $\Delta v_{ijt} = u_{ijt} + q_{ijt} - q_{ij,t-1}$. Hence, $\text{Var}(\Delta v_{ijt}) = \text{Var}(u_{ijt}) + 2\text{Var}(q_{ijt})$ and $\text{Cov}(\Delta v_{ijt}, \Delta v_{ij,t-1}) = -\text{Var}(q_{ijt})$, so that $\text{Var}(u_{ijt}) = \text{Var}(\Delta v_{ijt}) + 2\text{Cov}(\Delta v_{ijt}, \Delta v_{ij,t-1})$.

Table 4: Residual autocovariances for within-job log wage innovations

Lag	Denmark 1980-2001	Portugal 1986-2009
0	0.0195	0.0355
	(0.00002)	(0.00007)
1	-0.0043	-0.0108
	(0.00001)	(0.00005)
2	-0.0004	-0.0009
	(0.00001)	(0.00002)
3	-0.0002	-0.0005
	(0.00001	(0.00003)
4	-0.0003	0.00001
	(0.00001)	(0.00003)
5	-0.00002	-0.00002
	(0.00001)	(0.00003)
6	-0.00009	-0.0005
	(0.00001)	(0.00003)
Number of observations	8902997	9884371

Notes: The generating regressions are the Topel regressions with seniority index included, controlling for time, industry, and location indicators. Only the first 6 lags are displayed here. Standard errors in parentheses.

methods in Table 5, Denmark in the upper, and Portugal in the lower panel. Our regressions control for up to quartic terms in tenure and experience, for log firm size, and for industry and region dummies.[9] We present the estimation results for three specifications: the first specification excludes log seniority, the second specification includes the seniority index r_{ijt}, and the third specification includes both seniority indices r_{ijt} and r^*_{ijt}.[10] All coefficients for the seniority index r_{ijt} are positive and statistically significant and the coefficient for r^*_{ijt} in most cases. The results for a straightforward OLS stand out in their magnitude. This is the only method that also uses the between job spell variation to identify the effect of seniority. The coefficients are larger for Altonji and Shakotko's method than Topel's. This was expected because the method of Altonji and Shakotko allows for a lagged effect of r_{ijt} on w_{ijt}, while the Topel first differencing method does not. Comparing the estimation results with and without seniority, including seniority reduces the coefficients for tenure and log firm size by $5-30\%$ (except for the effect of tenure in Denmark, which is small anyway). The coefficients for experience are hardly affected by including seniority.[11] The effect of tenure and log firm size on wages is at least partly a proxy for the effect of seniority. Finally, the effect of seniority is twice as high in Portugal as in Denmark.

[9] Time effects are also accounted for in all subsequent wage analyses.

[10] The fourth possibility, using r^*_{ijt} only, did not add new insights and is therefore not reported.

[11] Apparently, initial experience is not correlated with seniority, while tenure and firm size are highly correlated.

Table 5: Wage regressions for males

	Denmark											
	OLS			Topel			Altonji and Shakotko			Topel with spell fixed effects		
	I	II	III	I	II	III	I	II	III	I	II	III
r_{ijt}		0.0416	0.0367		0.0077	0.0070		0.0104	0.0081		0.0104	0.0117
		(0.0004)	(0.0005)		(0.0003)	(0.0003)		(0.0002)	(0.0002)		(0.0004)	(0.0004)
r_{ijt}			0.0197			0.0040			0.0188			-0.0058
			(0.0003)			(0.0003)			(0.0002)			(0.0004)
Log firm size	0.0126	0.0120	0.0129	0.0176	0.0126	0.0125	0.0308	0.0246	0.0246	0.0167	0.0095	0.0095
	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0003)	(0.0003)	(0.0001)	(0.0002)	(0.0001)	(0.0037)	(0.0004)	(0.0004)
Experience	0.0308	0.0299	0.0297	0.0443	0.0464	0.0460	0.0000	-0.0004	-0.0005	0.0164	0.0163	0.0166
	(0.0003)	(0.0003)	(0.0003)	(0.0004)	(0.0004)	(0.0004)	(0.00004)	(0.00003)	(0.00003)	(0.0003)	(0.0003)	(0.0003)
Tenure	0.0148	0.0007	0.0089	-0.0021	-0.0042	-0.0052	0.0067	0.0044	0.0008	-0.0099	-0.0030	-0.0055
	(0.0002)	(0.0002)	(0.0002)	(0.0001)	(0.0002)	(0.0002)	(0.0001)	(0.0001)	(0.0001)	(0.0005)	(0.0006)	(0.0006)
Tenure^2	-0.1327	-0.0243	-0.0774	0.1004	0.1181	0.1279	-0.0320	-0.0141	0.0182	0.1152	0.1109	0.1157
	(0.0029)	(0.0031)	(0.0030)	(0.0026)	(0.0027)	(0.0028)	(0.0010)	(0.0013)	(0.0011)	(0.0027)	(0.0027)	(0.0029)
Tenure^3	0.0498	0.0084	0.0276	-0.0523	-0.0590	-0.0633	0.0057	-0.0008	-0.0132	-0.0515	-0.0574	-0.0512
	(0.0016)	(0.0016)	(0.0016)	(0.0015)	(0.0015)	(0.0015)	(0.0005)	(0.0005)	(0.0006)	(0.0019)	(0.0019)	(0.0019)
Tenure^4	-0.0059	-0.0006	-0.0029	0.0083	0.0092	0.0098	0.0003	0.0010	0.0027	0.0081	0.0088	0.0080
	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0001)	(0.0001)	(0.0001)	(0.0003)	(0.0003)	(0.0003)
	Portugal											
r_{ijt}		0.0452	0.0575		0.0145	0.0208		0.0220	0.0173		0.0115	0.0043
		(0.0002)	(0.0002)		(0.0004)	(0.0004)		(0.0002)	(0.0002)		(0.0015)	(0.0015)
r^*_{ijt}			-0.0298			0.0166			0.0146			0.0183
			(0.0002)			(0.0003)			(0.0002)			(0.0012)
Log firm size	0.0519	0.0499	0.0443	0.0266	0.0173	0.0208	0.0561	0.0431	0.0466	0.0222	0.0146	0.0177
	(0.0001)	(0.0001)	(0.0001)	(0.0003)	(0.0004)	(0.0004)	(0.0002)	(0.0002)	(0.0002)	(0.0011)	(0.0014)	(0.0015)
Experience	0.0540	0.0563	0.0530	0.0685	0.0695	0.0677	0.0663	0.0654	0.0651	0.0134	0.0139	0.0146
	(0.0003)	(0.0003)	(0.0003)	(0.0006)	(0.0007)	(0.0006)	(0.0002)	(0.0003)	(0.0002)	(0.0215)	(0.0132)	(0.0115)
Tenure	0.0310	0.0235	0.0273	0.0187	0.0166	0.0124	0.0160	0.0135	0.0110	0.0426	0.0346	0.0280
	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0004)	(0.0002)	(0.0001)	(0.0001)	(0.0001)	(0.0217)	(0.0140)	(0.0130)
Tenure^2	-0.1803	-0.1283	-0.1534	-0.0757	-0.0578	-0.0236	-0.0391	-0.0235	-0.0057	-0.2427	-0.2336	-0.1636
	(0.0011)	(0.0011)	(0.0011)	(0.0020)	(0.0021)	(0.0021)	(0.0007)	(0.0007)	(0.0007)	(0.0054)	(0.0054)	(0.0061)
Tenure^3	0.0508	0.0331	0.0400	0.0227	0.0163	0.0557	0.0079	0.0029	-0.0022	0.1019	0.0989	0.0733
	(0.0004)	(0.0004)	(0.0004)	(0.0008)	(0.0009)	(0.0009)	(0.0003)	(0.0003)	(0.0003)	(0.0072)	(0.0072)	(0.0074)
Tenure^4	-0.0047	-0.0029	-0.0037	-0.0023	-0.0016	-0.0005	-0.0040	0.0000	0.0005	-0.0088	-0.0085	-0.0055
	(0.00005)	(0.00005)	(0.00005)	(0.0001)	(0.0001)	(0.0001)	(0.00003)	(0.00003)	(0.00003)	(0.0010)	(0.0010)	(0.0010)

Notes: The dependent variable is the log real hourly wage. All regressions also control for experience up to a quartic term, region and industry. Standard errors in parentheses.

We also report estimates of a method that first takes within-spell differences and then takes deviations from the within spell mean to allow for match specific heterogeneity in the tenure coefficient (as in equation (9)). The estimated returns to seniority are hardly affected by this method as the return to seniority is identical to the method of Altonji and Shakotko for Denmark while it is close to the return to seniority estimated by the method of Topel for Portugal.

Might measurement error in tenure explain our results? Measurement error in tenure is a general problem in the literature on the return to tenure. Apart from reporting errors, the main source of measurement error in tenure is who exactly is the relevant employer. Some job changes might either be classified as between firms, justifying the tenure clock being set back to zero, or as within the firm, which does not affect the tenure clock. In general, this type of measurement error decreases the returns to tenure, while it may overestimate the returns to any variable that is correlated with tenure, such as experience in the original papers that try to estimate the returns to tenure. But what happens if both seniority and tenure are included in the same regression equation as we do in this paper? We expect the measurement error of seniority to be larger than the measurement error of tenure because misclassification of the years of tenure of even a single worker affects the measurement of the seniority of all other workers in the firm. The same is true for the log firm size. Moreover, the empirically relevant seniority index might not be based on the total workforce of the firm, but on subgroups. Therefore, seniority is not likely to pick up a part of the returns to tenure but instead it is the other way around: part of the estimated effect of tenure and log firm size might still be a proxy for measurement error in the seniority variable and the actual effect of seniority on wages can be expected to be larger than estimated here.

Table 6 illustrates the impact of seniority on the wage increments within a job for different years of tenure. We find that the wage increments are highest in Portugal: based on the results of the methods of Topel and Altonji and Shakotko, we find that after 10 years of tenure the wage is almost 14 percent higher than at the start of the job spell. This is only 4 percent in Denmark. In addition, we find that a one standard deviation increase in seniority (from the perspective of the mean seniority level of individuals with a tenure of 10 years) results in a wage increase of 0.5-0.6 percent in Denmark and 1.0-1.6 percent in Portugal.

4.2.1 Returns to seniority within gender and education subgroups

The LIFO layoff rule is unlikely to apply unconditionally. One would expect the firm to apply separate layoff rules for different subgroups of its workforce. For example, a

Table 6: The effect on log wages of tenure (at mean seniority) and of one standard deviation of seniority

Tenure (in years)	OLS		Topel		Altonji and Shakotko		Topel with firm effects	
	Tenure	Std. dev. rank	Tenure	Std. dev. rank	Tenure	Std. dev. rank	Tenure	Std. dev. rank
Denmark								
2	0.0168	0.0109	-0.0020	0.0020	0.0109	0.0027	0.0012	0.0027
5	0.0372	0.0189	0.0007	0.0035	0.0254	0.0047	0.0154	0.0047
10	0.0482	0.0244	0.0350	0.0046	0.0408	0.0061	0.0515	0.0061
15	0.0527	0.0284	0.0613	0.0053	0.0504	0.0071	0.0873	0.0071
20	0.0594	0.0314	0.0770	0.0059	0.0581	0.0079	0.1134	0.0078
Portugal								
2	0.0556	0.0235	0.0376	0.0067	0.0362	0.0103	0.0465	0.0054
5	0.1049	0.0302	0.0806	0.0087	0.0777	0.0132	0.0860	0.0070
10	0.1552	0.0358	0.1369	0.0104	0.1363	0.0156	0.1169	0.0082
15	0.1785	0.0377	0.1818	0.0109	0.1844	0.0164	0.1513	0.0086
20	0.1976	0.0401	0.2252	0.0116	0.2296	0.0175	0.2341	0.0092

Note: Both the mean and the standard deviation of seniority are calculated conditional on tenure.

construction firm is unlikely to fire its secretaries if it has an excess supply of bricklayers, whatever the seniority of both groups of workers. One can therefore expect the theory to work better using separate seniority indices computed for broad groups of workers.[12] We use males versus females, and low versus higher educated workers. For gender we look at the seniority relative to all workers within the firm, while for education level it is the seniority relative to workers within the same education class.

The results are reported in Table 7. The results for the group of men are similar to the results in Table 5. The differences between men and women are small. In Denmark, seniority has a higher impact for women than for men while in Portugal this is the reverse. The effect of seniority is larger for higher educated workers than for low educated workers, except for Portugal when using the method of Altonji and Shakotko. These results are consistent with the fact that high educated workers have steeper wage-tenure profiles than their low-educated peers. At the same time, they give support to the idea that the relevant seniority index is not defined for the firm as a whole, but for various subgroups within the firm.

[12] One could calculate separate indices for each occupation. Apart from the fact that we do not have a good classification of occupations in our data, we hesitate to distinguish workers by their occupation, since that might change endogenously. The wage increase due to a rise in the worker's seniority is likely correlated with a relabeling of her occupation.

Table 7: FE and FD Regressions by Gender and Education Rank Groups

	Denmark				Portugal			
	Gender Categories							
	Females		Males		Females		Males	
	Topel	AS	Topel	AS	Topel	AS	Topel	AS
Seniority index (r_{ijt})	0.0109	0.0107	0.0077	0.0104	0.0117	0.0122	0.0145	0.0220
	(0.0004)	(0.0005)	(0.0003)	(0.0004)	(0.0005)	(0.0002)	(0.0004)	(0.0002)
Log firm size	-0.0004	0.0122	0.0126	0.0246	0.0154	0.0463	0.0173	0.0431
	(0.0004)	(0.0005)	(0.0003)	(0.0004)	(0.0005)	(0.0006)	(0.0004)	(0.0002)
Experience	0.0337	0.0005	0.0464	-0.0004	0.0516	0.0534	0.0695	0.0654
	(0.0006)	(0.00004)	(0.0004)	(0.00003)	(0.0006)	(0.0002)	(0.0007)	(0.0003)
Tenure	-0.0015	0.0039	-0.0042	0.0044	0.0206	0.0163	0.0166	0.0135
	(0.0006)	(0.0001)	(0.0004)	(0.0001)	(0.0001)	(0.0005)	(0.0004)	(0.0001)
Number of observations	5049388	7745676	9858509	14618407	2300767	4353808	3457888	6389436
	Education Categories							
	High educated		Low educated		High educated		Low educated	
	Topel	AS	Topel	AS	Topel	AS	Topel	AS
Seniority index (r_{ijt})	0.0124	0.0207	0.0037	-0.0044	0.0226	0.0122	0.0140	0.0196
	(0.0003)	(0.0002)	(0.0004)	(0.0005)	(0.0015)	(0.0002)	(0.0004)	(0.0002)
Log firm size	0.0098	0.0207	0.0172	0.0299	0.0140	0.0463	0.0148	0.0381
	(0.0004)	(0.0002)	(.0005)	(0.0003)	(.0017)	(0.0002)	(.0004)	(.0002)
Experience	0.0450	0.0034	0.0304	0.0003	0.0723	0.0697	0.0471	0.0464
	(0.0005)	(0.00004)	(0.0012)	(0.0002)	(0.0006)	(0.0002)	(.0001)	(.0002)
Tenure	-0.0053	-0.0009	-0.0024	0.0028	0.0206	0.0163	0.0159	0.0130
	(0.0005)	(0.0001)	(0.0012)	(0.0001)	(0.0002)	(0.0002)	(.0001)	(.0001)
Number of observations	9567345	14054988	5268672	8309095	259793	536920	5492034	10206324

Notes: The dependent variable is the time-detrended log real hourly wage. Seniority index has been computed separately for each category. Low educated stands for category of people with at most 12 years of education. All regressions include also up to 4th order polynomials in tenure and experience and indicators for region and industry. AS stands for Altonji and Shakotko. Standard errors in parentheses.

5 Conclusion

We have shown that there exists a return to seniority in wages in both Denmark and Portugal, with an elasticity in the order of magnitude of 0.01– 0.02: a 10% increase in your seniority (10% in the number of workers more senior than you) raises your wage by 0.1 to 0.2%, depending on the estimation method and on the country or subgroup under consideration. Conditional on your tenure, a one standard deviation increase in your seniority raises your wage by 0.5-1%. We have also shown, for both countries, that the last workers hired are the ones most likely to separate from the firm. While we have established these two facts for Denmark and Portugal, whether they exist in other countries– in particular in the United States– remains an open question. On the one hand, one might argue that the returns to seniority might be largely driven by legal institutions, which are different in the United States. On the other hand, the economic mechanisms leading to a layoff rule operate everywhere and legal institutions are just a formalization of rules of conduct that would have emerged anyway. Hence, repeating this analysis for the United States and other countries is a worthwhile exercise.

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