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Meredith Paker, Oxford; Judy Stephenson, UCL;
and
Patrick Wallis, LSE

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Economic History Department, London School of Economics and Political Science,
Houghton Street, London, WC2A 2AE, London, UK. T: +44 (0) 20 7955 7084.

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Meredith Paker, University of Oxford; Judy Stephenson, University College London; and Patrick Wallis, LSE

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Abstract:
The Industrial Revolution is seen as a major turning point in the management of labour, bringing about employment practices that gave structure and stability to the workforce. This paper provides evidence that employers were using hiring and retention strategies to stabilize the unskilled workforce at least a century before industrialization. We exploit the comprehensive employment records that survive from the rebuilding of St. Paul's Cathedral in London (1672–1748) to reconstruct and analyse the employment history of over one thousand general building labourers, the benchmark category of unskilled workers for economic historians. We show that St. Paul's was able to stabilize its workforce by establishing a core group of long-standing workers. Tenure was incentivized with more days of work each month on the site, priority in the queue for retention and rehiring in periods of low labour demand, and the opportunity to earn additional income as watchmen. These strategies reduced turnover and may have allowed the Cathedral to retain the most productive workers, reshaping our understanding of when modern employment practices emerged.

1. Introduction

Just over 350 years ago, St. Paul's Cathedral was destroyed in the Great Fire of London. Under the guidance of Sir Christopher Wren, the Cathedral was entirely rebuilt between 1672 and 1711 into the baroque masterpiece that stands today. This pre-industrial mega-project left not only a legacy on the London skyline, but also detailed individual-level records of the employment and remuneration of building labourers. With these records, unparalleled in continuity and scope for this period, we reconstruct and analyse the employment histories of over one thousand workers employed during a seventy-year period. We find that the project structured employment in order

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to retain workers and to reduce turnover, giving a core group of labourers more work, priority in rehiring after slowdowns, and access to additional ways to earn. Despite the volatility that characterized pre-industrial labour demand, these strategies meant that St. Paul's was able to establish a stable workforce by incentivizing tenure and rewarding longstanding labourers. Uncovering this type of labour management practice in the seventeenth century challenges the standard connection between industrialisation, advanced capitalism and firm-level labour retention strategies.

In analyses of labour relations and management, the Industrial Revolution is seen as a turning point which eradicated centuries old customs (Polyani 1957; Hobsbawm 1968; Berg 1980; Landes 1986; Clark 1994; Szostak 1989; Thompson 1963; Pollard 1965), precipitated the modern management revolution of corporate scale and scope (Chandler 1977), and brought institutionalisation and stability to employment relations through new hierarchies and new legal and contractual restrictions (Seltzer and Sammartino 2009; Howlett 2004; Naidu and Yuchtman 2013; Craven and Hay 1994: Clark 1994). In the period before industrialisation, unskilled labour is often assumed to have been allocated through spot or auction markets in which casual and unskilled employment entered transient, short-term contracts (Scholliers 2003; Grantham 2004; Williamson 1987; Rule 1981, Wallis 2014). Despite a large body of work that uses wages as a proxy for economic growth in this period (Allen 2001, 2009; Clark 2005, 2007; Van Zanden 1999, 2009), the development of hiring, supervision and personnel management remain largely unstudied (Pollard 1965; Thompson & Wilson 2006; Huberman 1996; cf Chandler 1977:52-54). However, increasingly, economic historians concerned with labour markets are becoming more interested in varying types of employment contract and duration of employment (Humphries & Weisdorf 2019).

Our study makes a novel contribution by offering the first in-depth analysis of actual pre-industrial hiring practices in construction work in England. We examine the characteristics of hiring at St. Paul's Cathedral through the main period of construction, 1672-1711, and for workers retained for maintenance until 1748. Our digitized employment records encompass almost every day that general labourers worked at the Cathedral over these 76 years. These data are unusual not only because of the architectural distinction of the building on which the labourers toiled, but also because the Cathedral's accounting records listed each labourer's name. We can therefore reconstruct the individual employment histories of 1,011 general labourers during the Cathedral's construction and maintenance period. With this unique longitudinal

dataset, we are able to identify individual labourer's days worked, earnings, absences, and duration of employment. We then explore econometrically the relationship between tenure and the number of days of work awarded, the consistency of employment, and access to additional income earning opportunities.

Our results indicate that St. Paul's was able to stabilize its workforce by incentivizing and rewarding tenure. The Cathedral privileged a core group of workers whose access to additional and more consistent income increased with tenure. These core labourers were given more days of work each month than others—workers with the most tenure were more than three times as likely as those with the least tenure to be fully employed for a month. We also find that these tenured labourers had more consistent access to employment. Longstanding labourers were less likely to have periods in the year in which they were not hired at all and were also more likely to be rehired after seasonal breaks in construction. Finally, the labourers with the most tenure were twice as likely as newer labourers to be given the benefit of additional shifts as watchmen, which increased earnings in a month by up to 15 percent. These results indicate that St. Paul's pursued management strategies to reduce turnover or to retain the most productive workers, much earlier than is usually thought.

Our findings for unskilled labourers complement an emerging body of work identifying institutional adaptability in the economy and organizational innovation in skilled labour markets in the centuries before the industrial revolution (de La Croix et al. 2016; Kelly & O'Grada 2014). Recent studies have argued that large organizations operating in a pre-industrial context were capable of creating internal labour markets for skilled workers (López Losa and Garcia-Zuniga 2020; Murphy 2010, 2015). In a similar vein, studies have revealed strong performance-related incentives in eighteenth century navies (Allen 2002). That a Cathedral should introduce similar mechanisms is consistent with arguments about the creative potential of early-modern administrative elites in the face of shocks (Dittmar & Meisenzahl 2020) and novel challenges in scale and scope (Harris 2020).

The case also speaks to contemporary research in labour economics which seeks to understand the source and effects of labour market frictions, particularly those of recruitment and retention costs and associated employer power (Manning 2011; Falch 2010; Dube et al 2010, Dube et al 2020, Azar Berry Marinescu 2019; Naidu et al 2018), and which considers supply elasticity in response to factors other than the wage (Machin and Manning 2004; Naidu and Yuchtman 2013

pp.111-113; Bhaskar et al 2002; Staiger et al 2010). Our results suggest that institutional or firm level responses to these problems are not entirely modern management strategies, but have long run antecedents, and highlight the value of duration of employment or security of tenure in early modern employment contracts. Our findings may also be relevant the sources of monopsony in today's advanced and developing markets (Abebe et al 2018).

We also contribute to ongoing debates about labour's share of income and living standards in the long run. The economic history literature typically assumes that unskilled, manual labourers such as the construction workers at St. Paul's were homogenous and interchangeable, rewarded with the same wage. Our data does show that the day wage at St Pauls was the same for 70 years, but the core group of longstanding labourers at the Cathedral received an income premium through additional shifts and greater consistency of employment that was inaccessible to newcomers. In other words, labourers' incomes were not as homogenous as their wages imply. If income was a function of tenure, this raises questions about how to derive annual earnings or estimate standards of living from building labourers' day wage series, a process that is central to several common methods for understanding long run growth (Allen 2001; Clark 2005).

The paper proceeds as follows. In the next section, we provide historical background on the reconstruction of St. Paul's and describe the data set sourced from the project. In Section III, we present descriptive statistics on employment churn and turnover the Cathedral, demonstrating the stabilization of St. Paul's workforce over the construction phase. In Section IV, we analyse the relationship between tenure and the number of days worked each month, the consistency of employment, and access to watchmen shifts. Section V discusses possible motivations behind the Cathedral's strategies. Section VI concludes.

2. Historical Context and Data

St Paul's was the largest construction site in London from 1675 to 1711. The Cathedral had been destroyed by the Great Fire of 1666, and, after several years of planning and demolition work, Sir Christopher Wren's design for the new Cathedral was finally approved in 1675. As Surveyor to the Crown, Wren was also responsible for the management of many other projects around the City of London: the City Churches, Greenwich Hospital, and, later, Westminster Abbey (Campbell 2007). The project took place against the backdrop of a rapidly expanding city that was experiencing substantial long-term growth, driven by trade and services (Broadberry et al.

2015), and a prolonged building boom, boosted by the architectural ambitions of the City and the restored Crown after the Fire (Barras 2009).

The Cathedral's accounts are exceptionally detailed and well maintained, largely because of its funding model.[2] The rebuilding was funded by the approval of a new tax on coal imported into the city. Parliament and the City expected strict oversight and auditing, requiring records to account for all expenditures. The accounts were compiled from rough journals and call books that recorded weekly pay. The full accounts were counter-signed as an accurate record of wages and were subject to audit, giving some reassurance about their quality. The available records from 1672–1748 that we use cover the main period of construction to 1711, the period to 1720 when some masonry and other work were still being carried out, and nearly three decades of general maintenance and upkeep of the building to 1748.

Our dataset covers all 402 surviving sets of accounts from 1 October 1672 to the 24 June 1748. The accounts begin with the start of the reconstruction and continue after its completion, with labourers retained for maintenance work. There are full accounts for all periods from 1672 to 1748 with the exception of two short breaks, lasting for two years in the construction period and three years in the maintenance period.[3] The dataset ends with the cessation of accounts containing nominal data. The majority of accounts (73%) cover periods of one month. The rest run over longer periods, with 5% covering full years.[4] The shorter duration accounts are all from the construction period, giving us finer grained information for that time.

In each account book, the labourers who were hired directly by the Cathedral's clerk-of-works were listed by name, with the number of days they worked and the rate they were paid. The accounts record that the labourers carried out general tasks such as moving stone, dragging goods, and sorting and carrying rubbish, but they also carried out demolition work; mixed mortar; watched doors (took deliveries); rammed and cut walls; stripped tiles and plumbing and assisted the specialist contractors. Their tasks included some that involved a measure of skill and experience, alongside brawn, but the accounts do not cover the most skilled workers on the site.

[2] London Metropolitan Archives, CLC/313/I/B/25473
[3] October 1674 – October 1675 and June 1710 – June 1714
[4] Unfortunately, the books do not run neatly in yearly runs. Accounts were kept quarterly at first, and then monthly from 1674 until January 1683. From January 1683 through April 1686, accounts were quarterly again. From April 1686, monthly reporting resumed for a decade. Then, from October 1696 until June 1701, the Cathedral again used quarterly accounts. Monthly accounting restarted in June 1701 and lasted until June 1710, when bi-annual accounts began to be used. From December 1726, accounts were drawn up annually.

Most specialized tasks such as brickwork, masonry, and plastering were supplied by skilled subcontractors who hired their own workers directly and kept separate, private accounts for wages. This system of general labourers working alongside skilled subcontractors was common in the building industry in this period.[5]

St. Paul's was operational every week of the year, and the normal working week was six full days, as at other sites in London. However, not all active labourers worked every day. The number of days worked and labourers hired varied with project intensity and with the seasons. The number of labourers employed in January was about 60% of the number employed in July.

The decision of whom to hire, and other aspects of the organization of employment, were in the hands of the clerk-of-the-works, a position held by John Tilson until 1685 and by Lawrence Spencer thereafter. The clerk-of-the-works was responsible for the day-to-day co-ordination of materials, contractors and workers on site, cost management, and record-keeping. The clerk hired at will from an available pool of potential labourers. Employment seems to have been agreed verbally on a weekly or daily basis—there are no surviving contracts for labourers, and probably none ever existed. Labourers thus had no contractual expectation about ongoing employment, but there is ample evidence that men freely entered the employment relationship.[6]

We extracted the labourers' names, number of days worked, and pay from the St Paul's account books for all 402 accounting periods. We identify 1,033 unique labourers whose employment histories on the project appear in 21,793 entries.[7] 4.69% of entries lacked names or were excluded because two active labourers share the same name.[8] 69 labourers are identified as disabled, and there are no female names in the dataset.

[5] Although the record keeping was idiosyncratic and unique, this system was found across the industry in England (Woodward 1995; Stephenson 2020). Trade-specific labourers hired by specialist sub-contractors worked alongside general labourers employed centrally at Westminster Abbey 1712-1719 and Greenwich Hospital 1696-1706. There are not comparable named records at either site, however. Labour organization was similar in private housebuilding (McKellar 1999).

[6] Some men signed for task work (see below), indicating they had the opportunity to work for others. Campbell 2007 pp.35 -39 describes various types of work undertaken by labourers even before the rebuilding began.

[7] The small sample and consistent format allowed us to manually identify repeat appearances based on unique forename and surname combinations with a high degree of confidence. We restrict linkage to allow individuals a maximum period of absence of five years, after which we assume we are observing two same-named individuals.

[8] 14 entries were unnamed; 1,022 entries are ambiguous, in that two individuals may have been active simultaneously, based on the repetition of names within an account. These ambiguous entries relate to 19 distinct names, and almost half (537) are from one, John Scott.

Most entries report days of labouring work, but 14% are for shifts as night watchmen on the site, a common practice intended to prevent trespass and theft. Labourers acted as watchmen in addition to their regular labouring shifts. This additional duty was potentially lucrative—a night's watch paid 8d. until 1700 and 12d. thereafter, equivalent to half to two-thirds of the daily wage. However, the number of shifts a labourer could take was capped at two per week or ten per month, limiting the monthly income premium from serving as a watchman to about 15%.

Labourers were paid a day rate that was almost entirely uniform across workers. During the winter months (late October through early March), labourers earned 16d. per day. During the spring, summer, and early autumn (March to early September), they earned 18d. per day. These rates were similar to those recorded at a number of sites around the city, including for labourers working directly for contractors and sub-contractors at St Paul's.[9] Thus, a labourer's income was a simple function of how many days he worked. These day wage rates were nominally rigid for 76 years despite moderate price inflation, sustained growth in GDP per capita, and sharp economic shocks (Allen 2009; Broadberry et al. 2015, pp. 239-242; Hatcher 1998 pp. 70, 74; Boulton 2000). The Cathedral spent nothing on beer, food, or other perks or provisions for labourers. Whilst labourers used the Cathedral's drogues, ramps, barrows, scaffold and rope, we do not know whether the tools they dug with were their own or the Cathedral's.

Labouring work offered limited progression. A very small number of labourers worked as foremen, receiving higher wages (20 to 24d.).[10] It is not clear whether foremen were always present, but they were used during periods in which the greatest amount of work was being carried out. Forty-four labourers also acted as sub-contractors for labouring tasks that required more skill or were more dangerous during the demolition phase of the Cathedral.[11]

Evidence on the external labour market is limited. We know the period under investigation saw a great deal of construction across the city and high labour mobility (Brett James 1935; Barras 2009; Wrigley 1967). It is likely that labourers were able to find work at any number of building

[9] One contractor paid 18d. per day all year round to most of his labourers and 16d. per day to a smaller number of men assisting layers. By contrast, craftsmen's wages varied substantially between individuals (see Stephenson 2020, chapter 6.)

[10] Only 10 men over the 35 years of the main construction period earned above 18d. per day and all for short periods, associated with specialist or supervisory work.

[11] These labourers agreed task contracts worth between £1 and £150 between 1676 and 1690, acting as petty entrepreneurs. The contracts specified the length or volume of material to be removed, without the difficulty of the work being known, offering a chance for profit if it could be done in fewer days work than estimated, or loss or lower pay per day if not. Many of them signed their contracts, indicating relatively high human capital in a period where male literacy was still low.

sites, albeit none that equalled the scale and duration of St. Pauls.[12] Construction accounted for about 10% of male employment in the city; the share of labourers within that is unclear. In this period, skilled and unskilled construction work was not subject to guild restrictions on access (Beier 1986), and even at the Cathedral itself, labourers were able to work directly for specialist contractors and suppliers.[13] However, the scale and longevity of the rebuilding of the Cathedral offered the potential for more continuous work for labourers than they could find on specialist contracts or other sites. Therefore, a higher position in the queue for work at the Cathedral was a potentially important incentive.

3. Descriptive statistics on the St. Paul's workforce

The employment records from St. Paul's reveal that the Cathedral was able to stabilize its workforce over time, despite the generally precarious nature of pre-industrial employment relations. Though there were large variations in demand for labourers at the Cathedral, monthly hiring and separation rates trended downward over the construction period, and the share of labourers new to the project each year strictly declined through 1710. When we explore the data on an individual level, large differences in the total length of time that labourers worked at the Cathedral emerge—some workers were employed only briefly at St. Paul's, while other workers served for many years.

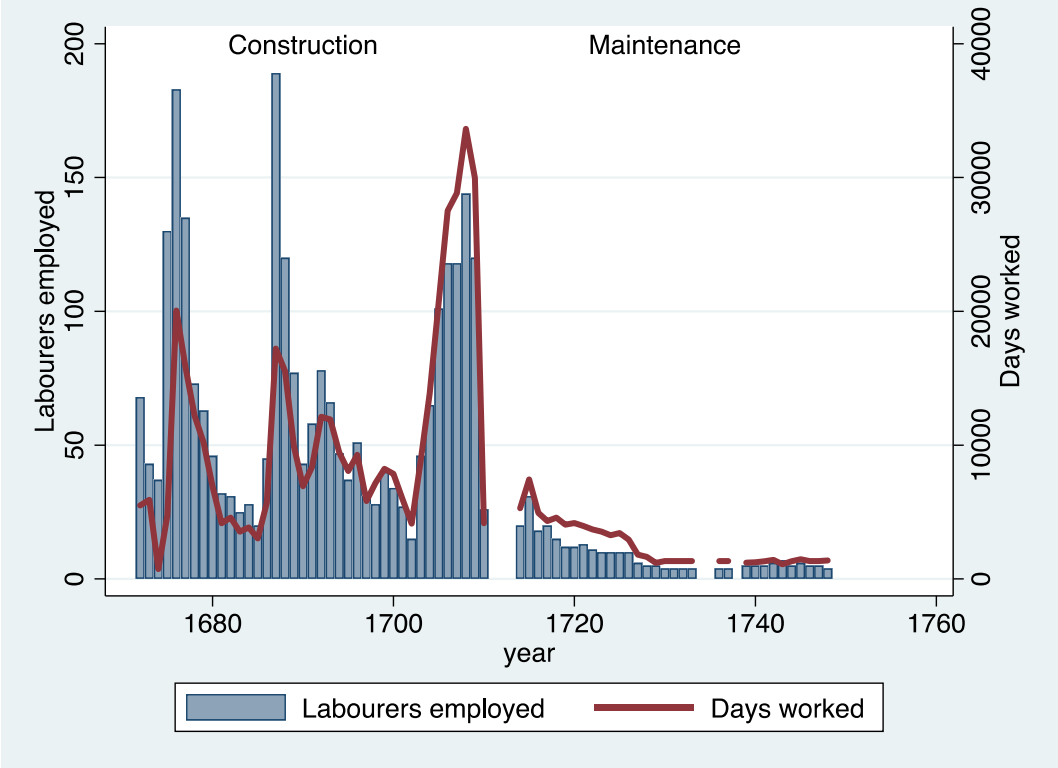
3a Variation in demand for labour at St. Paul's

In addition to regular seasonal patterns, the amount of labouring work available at the Cathedral varied greatly throughout the construction period with multi-year peaks and troughs of labour demand. This high level of demand volatility is consistent with what we know of construction on other similar sites.[14] The main driver of demand appears to be project centred. This was a period of sharp economic cycles, but they are only weakly associated with the pattern observed here. Figure 1 plots the total number of labourers on site and the number of days work they provided during the period of the rebuilding, from the commencement of work in 1674 to declared completion in 1711.[15] Labourers' work peaked three times, in the late 1670s, between 1687 and

[12] The surviving records of other major sites, such as Westminster Abbey and Greenwich, indicate a maximum of 10 labourers hired per week paid on day rates. More were presumably hired on task contracts.
[13] For example, 11 of the 68 men working for the specialist mason William Kempster from 1708 to 1709 also worked as labourers at the Cathedral (Stephenson 2018, pp.120-121).
[14] See Stephenson 2020a pp. 50 -62; 173-192.
[15] Broadly speaking from 1667 to the late 1670s the foundations of the old cathedral were cleared, and new foundations laid (Campbell, 2007). From the 1680s onwards, the walls were raised and the west front and towers were added from 1694 to 1705. The Dome was erected and plastered between 1705 and 1709.

1693, and most of all between 1705 and 1709, when several years saw around 30,000 days of work by labourers costing the Cathedral more than £2,000 each year. By contrast the demand for labourers in the early 1680s was low, with annual employment at about one quarter of the level seen in 1676. Because construction work is stage dependant, and subject to the vagaries of supply chains, weather and finance, such peaks and troughs of demand are typical of any building site or large project.

Figure 1: Total numbers of labourers on site and total number of days worked, per annum, 1676 to 1748



Source: See text

3b. Stabilization of the workforce at St. Paul's

Despite the volatility in the amount of labour demanded by the Cathedral, over the decades in which the Cathedral was constructed, the workforce stabilised. We observe a downward trend in hiring and separation rates over the construction period, as well as a decline in the share of labourers new to the project each year.

Our individual-level data permit the calculation of monthly hiring and separation rates at the Cathedral, following Davis et al. (2006).[16] We calculate 'all transition' figures for each month, including all labourers who worked in an accounting period, no matter how long they stayed at the Cathedral. This means that workers who were only hired for a few days on one occasion count as a hire and a separation in these calculations. These figures also include temporary separations, as separated workers may have returned in later months.

Table 1: Monthly hiring and separation rates at the Cathedral

	Hiring Rate			Separation Rate				
	Mean	Std. Dev.	Max	Mean	Std. Dev.	Max	Months Observed (n)	Share of Months Observed (%)
1675-1679	14.23	13.42	51.43	16.77	14.75	48.78	51	85.00
1680-1684	9.79	14.83	74.19	12.34	13.32	52.83	33	55.00
1685-1689	11.04	13.13	57.94	12.96	14.05	54.95	43	71.67
1690-1694	8.03	6.35	34.78	5.5	7.6	38.6	50	83.33
1695-1699	3.68	4.22	13.33	6.96	10.09	28.57	17	28.33
1700-1704	6.41	9.48	42.11	4.69	10.55	60	42	70.00
1705-1709	9.42	21.46	120.61	8.06	21.61	134.18	60	100.00
Overall	9.58	14.26	120.61	9.83	15.19	134.18	295	70.24

Table 1 reports the average hiring and separation rates for the quinquennia that cover the construction of the Cathedral. The hiring and separation rates can be interpreted as the percent of laborers who were brought on or who departed each month. Over the whole period, an average of about ten percent of labourers arrived or departed each month. Peak turnover was much higher—in some months, half or more of the workforce had not worked in the previous month, and in other months, a third of labourers were not employed in the following month. Today, construction is a high turnover industry, with worker flows three times higher than manufacturing firms (Davis et al. 2006, pp.7-8; US Bureau of Labor Statistics 2020). Even without the effect of firms opening and closing, the monthly job flows for St. Pauls are roughly twice the level seen in modern US data, where the hiring and separation rates are about 4 to 5 per cent on average (US Bureau of Labor Statistics 2020).[17]

[16] Further details are in Appendix 1. These calculations are restricted to periods for which two sequential accounts are of one-month duration, representing 295 account books in the construction period. Quarterly and quarterly quasi-census calculations are included in Appendix 1.

[17] The quarterly hiring and separation rates at St. Pauls, presenting in Appendix 1, are about 17 per cent, compared to about 14 per cent in modern US data (Davis et al. 2006, p. 8).

Table 1 demonstrates that turnover trended downward over the construction period at St. Paul's. From 1675 to 1680, the average hiring rate was 14%, whereas from 1705-1709, the average hiring rate was only 9%. Likewise, the average separation rate decreased from 17% in 1675-1680 to 8% in 1705-1709. This downward trend in both the hiring and the separation rate at the Cathedral indicates that turnover declined significantly over the construction period.

Because hiring and separation rates include labourers who many have been temporarily separated from the Cathedral, we also examine the share of labourers who joined the St. Paul's workforce each year. We find that the share of labourers who had never before worked at St. Paul's also declined over time. For instance, in 1687, a period of high demand, more than 80 per cent of labourers were new to the project. Twenty years later in 1708, the year with the largest single amount of work, only a quarter of labourers were new. This stabilisation of the workforce is demonstrated in Table 2, which presents decadal averages (after the initial five years) tracking the gradual decline in the share of new labourers to the project each year.

Table 2. Labourers new to the project each year

Decade	New labourers per year (%)			Mean number of labourers employed per year (n)
	Mean	Min	Max	
1675-9	40.75	12.70	79.23	116.80
1680-9	28.88	6.25	84.66	61.30
1690-9	27.98	13.51	46.15	47.90
1700-9	25.40	0.00	47.83	78.80
1710-9	10.42	0.00	29.03	20.29
1720-9	4.44	0.00	20.00	9.20
1730-9	10.00	0.00	25.00	4.14
1740-9	12.96	0.00	40.00	5.11

Note: the table presents decadal averages of the share of new labourers within the labouring workforce each year for ten-year periods from 1680, as well as the minimum and maximum annual share of new labourers observed within each period. For the 1670s, we exclude the initial 2 years of data, where the entire workforce is new, and present the average over the five-year period 1675-9.

The increasing stability of the workforce was not just a function of the number of workers who had previously worked at St. Paul's expanding as time passed. Given the short tenure of the great majority of labourers, there was no lack of labourers to rehire after the earliest years of the 1670s, which we exclude in the calculations in Table 2. Further, the size of the pool of labourers who had previously worked at St. Paul's had no effect on the hiring and separation rates presented in Table 1, which show the same general trend of stabilization.

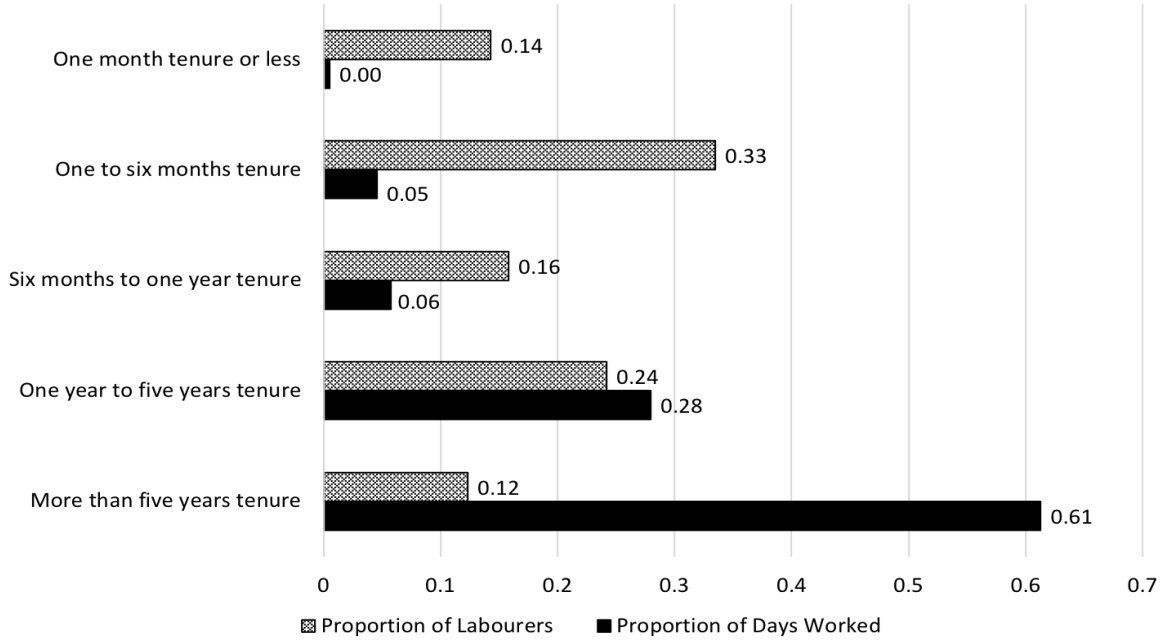
3c. Tenure at St. Paul's

Our individual-level reconstructions of the employment histories of labourers at St. Paul's allow us to examine differences in the length of time which individuals worked at the Cathedral. These differences are given in Figure 2, which includes all labourers who worked during the construction phase at St. Paul's. Tenure is calculated as the amount of time between a labourer's first and last appearance in the Cathedral's account books.

The patterned bars in Figure 2 give the proportion of all labourers with each length of tenure. 14% of all labourers stayed for less than one month, and almost half of all labourers (47%) stayed for six months or less. This accords with historical perceptions of fleeting, precarious employment relations. However, at the other end of the distribution, some labourers were involved over much longer periods. Almost one quarter of labourers (24%) were associated with St. Paul's for between one and five years. A further 12% of labourers worked at the site for over five years. Overall, twelve men appear in the accounts for a period of thirty or more years, with one, Simon Satchell, active for 43 years in total. Thus, for some workers, labouring at St. Paul's was fleeting, while for others, it was a long-standing arrangement.

The vast majority of labouring days was taken by the group of longer-lasting workers. The black bars in Figure 2 indicate that the 12% of labourers who worked at St. Paul's for more than five years conducted over 60% of all labouring days at the Cathedral during the construction period. The labourers who appeared only briefly at the Cathedral accounted for less than one per cent of all labouring days at St. Paul's.

Figure 2. Proportion of labourers and days worked according to length of tenure



Source: See text

The distribution of work at St. Paul's was polarized. As is generally expected of the pre-industrial period, much of the labouring workforce faced enormous instability of employment, with highly variable demand and high turnover rates. However, some labourers were attached to the site for periods of several years or more, and it was this group that provided most of the labour needed for the reconstruction. Taken with the downward trend in the hiring and separation rate at the Cathedral and the decline in the share of new workers in the Cathedral's workforce, it appears that St. Paul's was able to stabilise its workforce over the forty-year construction period.

4. Econometric results on hiring, retention, and tenure

Despite the volatility that characterized pre-industrial labour markets, the descriptive statistics in the previous section show that St. Paul's was able to stabilize its workforce. In this section, we explore econometrically the hypothesis that stability was achieved by incentivizing and rewarding tenure, which would be consistent with this being the outcome of employer strategy. We analyse the relationship between tenure and the number of days of work awarded, the consistency of employment, and access to additional income earning opportunities. Our results indicate that the Cathedral privileged a core group of workers who were given priority in access to work as their tenure increased.

4a. Method

How did labourers' prior tenure affect their intensity of work, consistency of work, and access to additional earning opportunities? Our individual-level data allows us to explore these questions using a series of logit and conditional logit models.

We capture prior tenure in these models in two ways. Our first measure is based on the cumulative number of days the labourer had worked at the site before the account in question. The absolute number of days previously worked strictly increases with time, so we model the cumulative days worked relative to the rest of the St. Paul's workforce who were active at that each point in time. Specifically, we calculate the percentile rank of all workers who were active at the Cathedral during the accounting period according to their cumulative days worked up unto that point. This standardizes our measurement of relative prior tenure across time and over accounting periods of differing lengths. Our second measure is constructed in the same way, as a percentile rank, but is based on the elapsed time in days since the labourer first began working at the site. The percentile rank of elapsed time in days differs from the cumulative days worked because many workers had gaps in employment (seasonal or otherwise) or did not work the maximum number of days in prior account books.

Throughout the analysis, we also exclude the first three years of the accounts, before January 1675, to remove the attenuating effect that the earliest periods, when all workers had little experience, would otherwise have produced. We also limit our main analysis to the construction period, that ended in 1711, which saw the majority of employment. Finally, we rely on a panel construction of the dataset where all active workers are represented in each accounting period, including those given no days of work.

The dependent variable in our models is always a binary indicator. In subsection b, this variable takes on 1 if a labourer worked over 85% of possible days in a period. In c, the dependent variable reflects whether a worker was not hired at all in the accounting period. Finally, in d, the dependent variable is whether a labourer was given watchmen shifts in additional to their general labouring work.

Our basic model is thus a logit model:

$$y_{it} = \beta_0 + \beta_1 x_{it} + \beta_3 M_t + \beta_4 T_t + \epsilon,$$

where y_{it} is a binary variable which equals 1 if a labourer worked over 85% of possible days in a period (subsection b), if a labourer was given work in an accounting period (subsection c), or if a labourer was given a watchman shift (subsection d). x_{it} is the labourer's tenure as a percentile rank of all active labourers in an accounting period, measured either by cumulative days previously worked or by elapsed time since beginning to work at St. Paul's. T_t are year dummies and M_t are month dummies to control for seasonality.

4b. The Intensive Margin: Work Allocation Between Labourers

The clerk of works hired labourers for different numbers of days in each accounting period. For example, in May 1687, a peak month of construction in which 71 labourers worked for 1,103 days, John Denhurst was hired for just 1.5 days and Anthony Minshaw for 5 days. This was the only time Denhurst was hired, while it was Minshaw's last appearance after eight months of consistent work on site. Conversely, a group of five labourers each worked for 23 days: two of them, John Hudson and Dan Northam, would be active for more than 20 years. The median labourer during the construction of the Cathedral worked 66 per cent of the days available. In the maintenance period, this fell to 58 per cent of the days available. This produced a substantial amount of potential inequality in the amount of work that labourers received, and gives us a simple and important test of the structure of employment at the Cathedral. If labourers were undifferentiated (differentiated) in the eyes of the clerk, then the amount of work they were given should be uncorrelated (correlated) with prior experience. In short, were long-standing labourers given the most work?

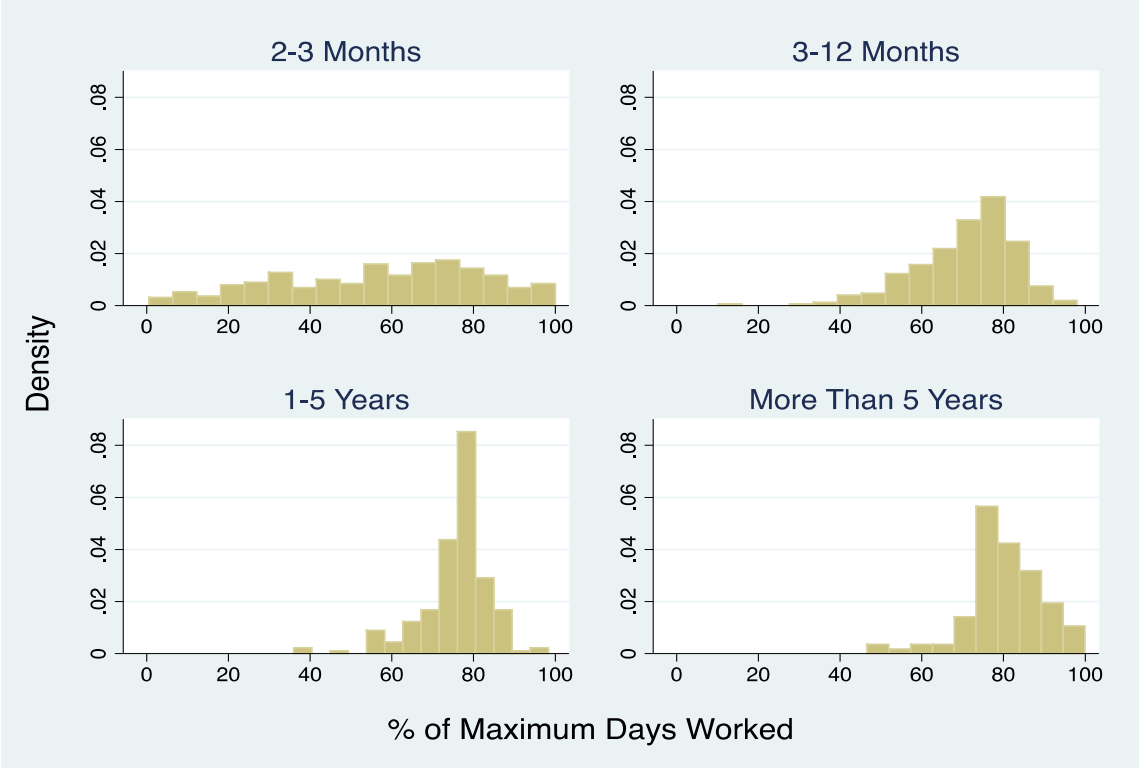
A strong visual indication that the clerk favoured long-serving labourers when choosing who to hire can be found in Figure 3, which shows how the share of work given to labourers varied according to the time they had worked on the site. The share of work is the ratio between the number of days each labourer worked and the maximum possible in the entire period they were active.[18]

[18] To calculate this, we sum the total number of days that each labourer worked from their first to last appearance. We then divide this by the sum of the maximum number of labouring days worked by a labourer in each accounting period in which the labourer was active. Note that this analysis is conducted only for labourers in the construction period of the Cathedral who worked for more than one accounting period. In a small number of cases, the clerk recorded paying wages for more days than existed in the calendar period covered by an accounting period. These have been capped at the number of days in the calendar period covered, as it is unclear if they were errors, days worked in other periods, unidentified duplicate entries or additional over-payments.

The labourers who were on site for the shortest periods, between two and three months, were given the lowest share of work. Some of these labourers were only on site for a few days each month; they were truly casual labour. In contrast, labourers who were present on the site for longer periods, especially those for a year or more, generally worked more intensely, with a convergence to a mode of around 80 percent of the maximum available days. Among the longest-serving labourers, those who stayed more than five years, many worked most if not all possible days during their tenure.

For analytical simplicity, we estimate the effect of prior tenure on the probability of working "full-time" during a given accounting period. We define full-time generously to include anyone working between 85% and 100% of the maximum days any labourer was reported to have worked during the accounting period. In a few cases where the clerk recorded paying wages for more days than existed in the calendar period covered by an accounting period, we capped the maximum number of days at the number of days in the calendar period.

Figure 3. Share of maximum work given to labourers by length of tenure at separation



Source: See text

A limitation of our data is that we cannot see which day in an accounting period a labourer began work at a Cathedral. The first time a worker is hired, the number of days they worked may

have been censored if they were hired after the start of the accounting period. For this reason, we drop the first observation of each worker. Unfortunately, this also means that we lose in this part of the analysis 160 individuals who only work at the Cathedral for one accounting period, as John Denhurst did in the example above.

The three models presented in Table 3 estimate the effect of a labourer's prior tenure, in terms of days worked and elapsed time at the Cathedral, on the probability of the labourer working full-time during the accounting period. All of the models have year fixed effects to account for time trends as well as month fixed effects for seasonality, with standard errors clustered at the individual worker level.

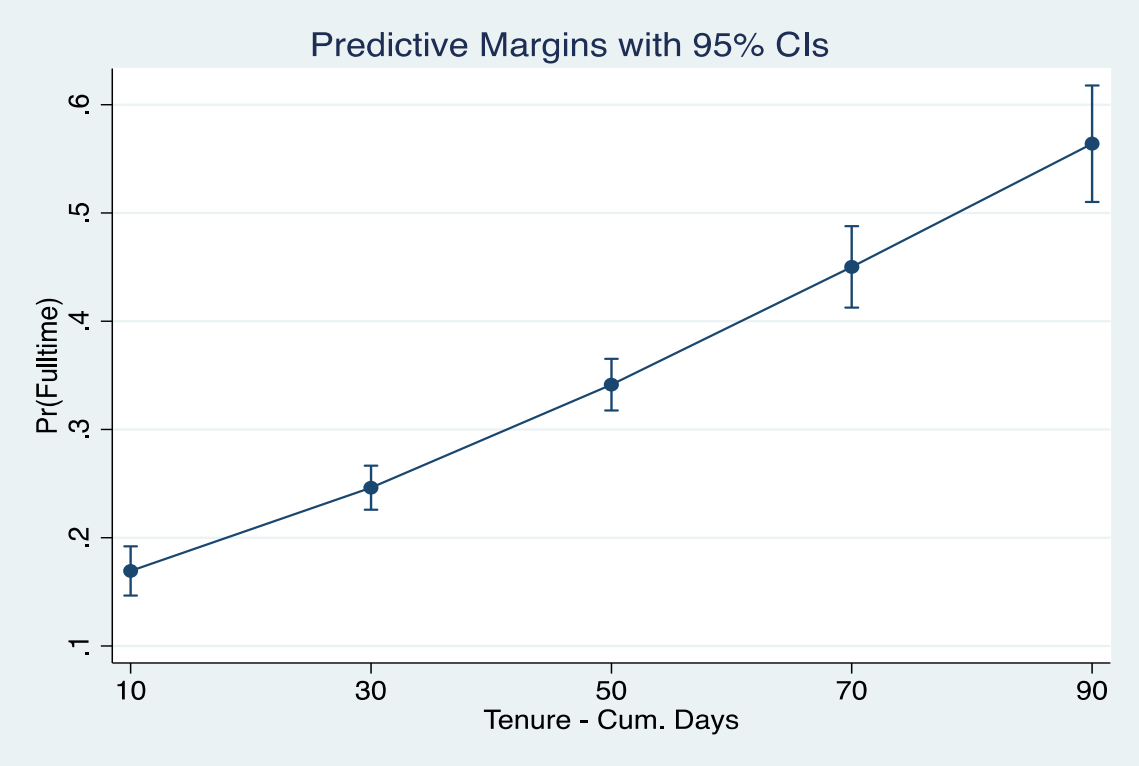
Columns (1) and (2) give our primary results. The estimates indicate that long-standing workers were significantly more likely to work full-time during each accounting period. The marginal effects in column (2) imply that a one quartile increase in the percentile rank of a labourer's tenure increases their probability of working full-time by 12.25 percentage points ($p < 0.001$, $25 * 0.0049 = 0.1225$). Figure 4 shows that a worker in the 10^{th} percentile in terms of cumulative days worked has only a 16.9% chance of working full-time in a given period, while a worker in the 90^{th} percentile has a 56.4% chance. Column (3) shows that these results are robust to the incorporation of labourer fixed effects, though the effect size is slightly smaller. Columns (4) and (5) present the results with the labourer's elapsed time percentile rank as the independent variable of interest. The results for the logit model are significant and again slightly smaller, but they are not robust to the inclusion of labourer fixed effects in column (6).

Table 3: Probability of a labourer working full-time

	Cum. Days Logit - Coef (1)	Cum. Days Logit - Margins (2)	Cum. Days Cond. Logit (FE) - Coef (3)	Elap. Time Logit - Coef (4)	Elap. Time Logit - Margins (5)	Elap. Time Cond. Logit (FE) - Coef (6)
Tenure - Cum. Days	0.0267***	0.0049***	0.0117*			
	(0.0023)	(0.0004)	(0.0059)			
Tenure - Elap. Time				0.0180***	0.0035***	0.0092
				(0.0026)	(0.0005)	(0.0068)
Constant	-3.7217***			-2.8929***		
	(0.2213)			(0.2206)		
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Month Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Labourer Fixed Effects	No	No	Yes	No	No	Yes
Num. of observations	19861	19861	18921	19861	19861	18921
Num. of individuals	798			798		
Pseudo R2	0.172		0.156	0.131		0.155

* p<0.05, ** p<0.01, *** p<0.001. Robust standard errors, adjusted for clustering by individual, are presented in parentheses. Tenure given in percentile.

Figure 4: Cumulative days worked and chance of working full-time in a given period.



Source: See text

The results in Table 3 strongly support the hypothesis that the Cathedral favoured longer-standing labourers when allocating employment. This relationship is robust to alternative measures of allocation, including varying the threshold for 'full-time' and continuous measures of the share of work given to each labourer (Appendix B.1 and B.2). It is also robust to the inclusion of controls for external shocks which could have affected hiring at St. Paul's, including wars, variation in temperature, mortality, and financial volatility (Appendix B.3). The relationship grew stronger in periods where the project was at a more critical and potentially risky stage, as with the construction of the Dome (Appendix C). The same pattern of preferential treatment, albeit weaker, persisted in the period from 1714 to 1748 among labourers hired for maintenance work (Appendix E).

4c. The Extensive Margin: Persistence of Employment

As well as deciding how many days to give labourers in each week, the clerk chose who would be hired again the next week. As the estimates of churn presented in Table 1 indicate, the Cathedral saw high levels of hiring and separation from month to month. This offers us a second, critical test of the structure of employment. If the clerk saw labourers as undifferentiated (differentiated), then the amount of time they had spent on the site should be uncorrelated

(correlated) with the probability they would be hired in the future. In short, were long-standing labourers more likely to be retained month by month at St. Paul's?

The consistency of employment was a pressing concern for labourers. The peaks and troughs of labour demand on the site (Figure 1) left few untouched. Breaks in employment at the Cathedral were commonplace: we can identify 840 periods of temporary separation in our panel, when a labourer was absent for one or more accounting period before reappearing in a later period. Because we do not observe separations below a month, this is likely to be an under-estimate. Almost all the absences (89%) we observe were for less than a year, and the median absence was two months (62 days). Long-serving workers did not escape periods without work—four-fifths of labourers employed for more than a year had at least one break in employment.

Given these breaks in employment, we model how prior tenure affected whether labourers were hired in each accounting period. In each time period, we focus on the supply of possible labourers from among those individuals who were existing active workers at the Cathedral, i.e. those who had worked one shift at the Cathedral previously and who had not yet made their final appearance in the records. This population includes the 160 workers dropped from the analysis in the previous section who appeared in the accounts only once (p.17). These estimates do not speak to the choice of who to hire from outside that pool. Nor can we examine the determinants of a labourers' final exit from the site. In effect, this analysis can be interpreted as how tenure affected the chance that workers had periods in which they were not hired from among the general labouring pool.

In the three models presented in Table 4, the dependent variable is a binary indicator equal to 1 if the worker was given work in an accounting period, and 0 otherwise. Our independent variable of interest is the percentile rank of the worker's prior tenure among all possible existing workers in that period, in terms of cumulative days worked and in terms of elapsed time. As above, all of the models have year and month fixed effects with clustered standard errors.

Our main results in (1) and (2) demonstrate that long-standing workers were more likely to be given work in each accounting period. Column (1) gives the coefficient estimates from a logit model. The marginal effects, given in column (2), indicate that a one quartile increase the labourer's tenure percentile rank in terms of days worked increases the probability being given employment by 8.75 percentage points ($p<0.001$, $25 * 0.0035 = 0.0875$). Figure 5 plots how the

probability of not being hired during a period changes with the tenure percentile rank, all else constant. A worker in the 90th percentile in terms of cumulative days worked prior to a given accounting period had a 92.2% chance of be hired, while a worker in the 10th percentile had only a 64.5% chance.

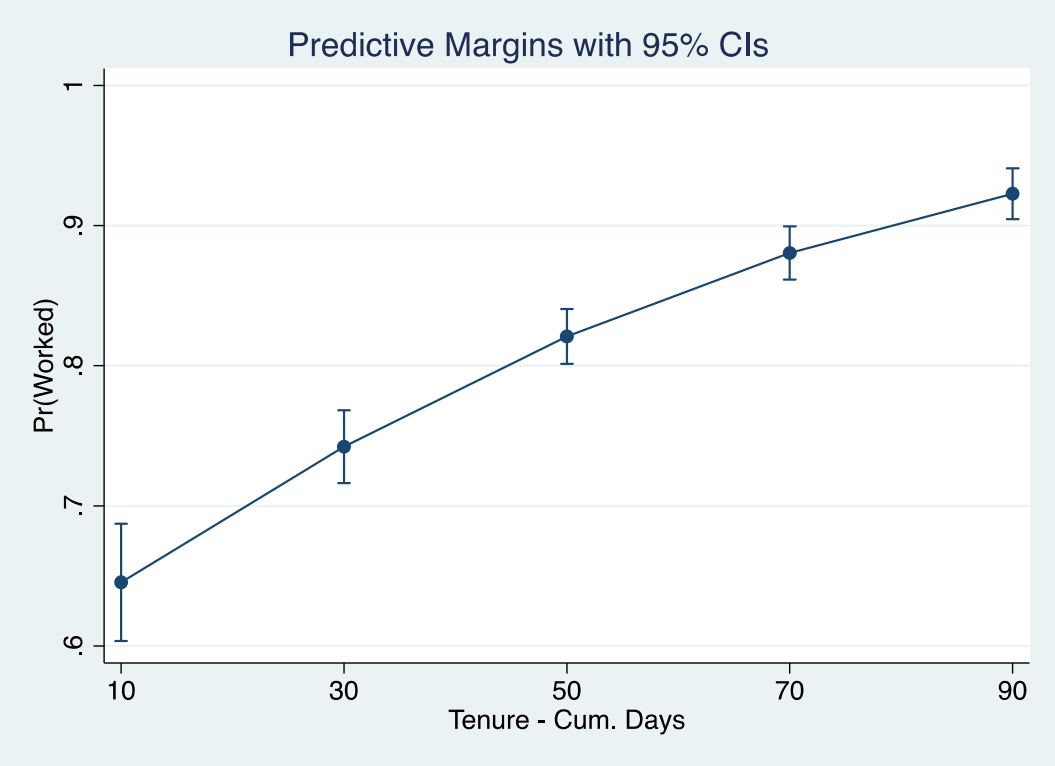
Table 4: Probability of a labourer working during the period

	Cum. Days Logit - Coef (1)	Cum. Days Logit - Margins (2)	Cum. Days Cond. Logit (FE) - Coef (3)	Elap. Time Logit - Coef (4)	Elap. Time Logit - Margins (5)	Elap. Time Logit (FE) - Coef (6)
Tenure - Cum. Days	0.0260***	0.0035***	0.0275***			
	(0.0025)	(0.0003)	(0.0084)			
Tenure - Elap. Time				0.0184***	0.0026***	0.0440***
				(0.0027)	(0.0004)	(0.0084)
Constant	-1.0639***			-0.3757		
	(0.2196)			(0.2043)		
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Month Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Labourer Fixed Effects	No	No	Yes	No	No	Yes
Num. of observations	20780	20780	17839	20780	20780	17839
Num. of individuals	955			955		
Pseudo R2	0.154		0.151	0.119		0.185

* p<0.05, ** p<0.01, *** p<0.001. Robust standard errors, adjusted for clustering by individual, are presented in parentheses. Tenure given in percentile.

Column (3) presents estimates from a conditional logit model with individual labourer fixed effects. The effect of the cumulative days worked percentile is robust to the inclusion of labourer fixed effects. Columns (4) and (5) give the coefficients and marginal effects of a logit model using our alternative measure of tenure percentile based on elapsed time. The effect size is significant but slightly smaller— a one quartile increase in the labourer's elapsed time percentile rank increases the probability of being hired by 6.50 percentage points ($p<0.001$, $25*0.0026 = 0.065$). Column (6) indicates that these results are also robust to the inclusion of labourer fixed effects.

Figure 5: Probability of a labourer being hired during with tenure percentile rank.



Source: See text

The models in Table 4 indicate that long-standing workers were given more consistent employment at St. Paul's. Of all active labourers, it was those with the least tenure who were most likely to face periods in which they were not hired. Longer-standing labourers, in contrast, were the last to be stood down.

Suggestive evidence that these longer-term workers were prioritized by the clerk exists in the accounts. The order in which labourers were named indicates that hiring occurred in a sequence. Long-term labourers were taken on first and are listed higher in the accounts than less-tenured or new labourers. Table 5 gives the position in the accounts for new labourers, those who had worked at the Cathedral for a number of months, and those who had worked at the Cathedral over a year. Two-thirds of new labourers were listed in the bottom quartile of the accounts. If they remained on site for the next few months, they shifted up the order, but almost half were still in the last quartile for the rest of their first trimester on the site.[19] By the time labourers had accrued 9–12 months of experience at the Cathedral, most were in the middle of the list. Those labourers who stayed for over a year were most often found in the top quarter of the clerk's list.

[19] That their position in the accounts was still low after their first appearance makes it clear that these patterns were not just contingent on the time within the month that a labourer was first taken on.

These patterns suggest that the clerk possessed a clear idea about who was to be hired, enacting preferences for labourers who had accrued more tenure at the site.

Table 5: Share of labourers in each quartile of the clerk's list by time since entry to workforce

Position in account (quartile)	New	2-3 months	4-6 months	7-9 months	10-12 months	>1 year
0-25	3.38	3.15	7.80	12.50	14.64	31.10
26-50	10.41	20.40	29.93	37.50	37.38	25.27
51-75	46.27	55.19	43.84	34.34	30.37	18.20
76-100	39.94	21.26	18.44	15.66	17.60	25.43
Total	100	100	100	100	100	100
N	3.38	3.15	7.80	12.50	14.64	31.10

Note: table reports labourers recorded in non-alphabetical accounts produced during the period of construction, from January 1675. For more information, see Appendix E.

Many breaks in employment were a by-product of the seasonally volatile demand for labour during construction work. Most absences began when the Cathedral was sharply decreasing the numbers of labourers on site, as the arrival of winter brought the peak building period to a close. Almost 40 per cent began in January; another 10 per cent began in December. Those labourers who reappeared did so between February and June, as weather improved and work intensified. In the peak month of July, there was on average 1,466 days of general laboring work conducted by 49 labourers. In the month with the least work, January, there was about half as much labour, averaging 784 days of work conducted by 32 labourers. Using these seasonal patterns, we can probe deeper into whether work for more tenured labourers was more consistent over the calendar year by exploring whether they were more likely to be kept on during the winter months and, if they did have a seasonal break, whether they were more likely to be rehired in the spring than less tenured laborers. We consider specifically the month of March, which is when labor typically picked up again after the steep seasonal decline in January and February.

In Table 6, we present two models over the sample of labourers active in the month of March in any year during the construction period. The first model in columns (1) and (2) explores whether workers with longer tenures were more likely to have worked over the seasonal downturn. The dependent variable is an indicator for whether the labourer had worked at the Cathedral in the preceding months of January and February. The positive and statistically significant coefficient in column (1) indicates that tenure was positively related to the probability of working in these months. The size of this effect is substantial—the marginal effect in column (2) indicates that a one quartile increase in the labourer's tenure percentile rank increases the probability of working

in January and February by 18.75 percentage points ($p<0.001$, 25 * 0.0075 = 0.1875). Longer-standing labourers at the Cathedral were thus much more likely to be kept on when work slowed over the winter months.

Table 6: Tenure and seasonal hiring patterns for active workers in the month of March

	Prob. of Working in Jan and Feb - Coef (1)	Prob. of Working in Jan and Feb - Margins (2)	Prob. of Rehiring in March - Coef (3)	Prob. of Rehiring in March - Margins (4)
Tenure - Cum. Days	0.0467***	0.0075***	0.0341***	0.0053***
	(0.0032)	(0.0003)	(0.0051)	(0.0006)
Constant	-2.9451***		-1.2371*	
	(0.2546)		(0.4814)	
Year Fixed Effects	Yes	Yes	Yes	Yes
Num. of observations	1613	1613	565	565
Num. of individuals	533		282	
Pseudo R2	0.298		0.323	

* $p<0.05$, ** $p<0.01$, *** $p<0.001$. Robust standard errors, adjusted for clustering by individual, are presented in parentheses. Tenure given in cumulative days percentile.

Columns (3) and (4) look exclusively at labourers who did not work in either January or February of a year. Were more tenured workers more likely to be rehired in March than less tenured workers? The dependent variable indicates whether an active labourer was hired in the month of March. The coefficient estimate in column (3) and marginal effect in column (4) suggest that more tenured laborers were more likely to be rehired in the spring. Among workers who were not hired in January or February, a one quartile increase in the labourer's tenure percentile rank increases the probability of being hired in March by 13.25 percentage points ($p<0.001$, 25 * 0.0053 = 0.1325). Long-standing labourers at the Cathedral thus had more stable employment, with an increased ability to return to work after seasonal downturns in hiring. The seasonality of building work strongly suggests that labourers were not absenting themselves for better offers on other sites. They were laid off in periods when low demand would be widespread across the sector, making a seamless transition to another site unlikely.

4d. Access to additional income earning opportunities

Finally, how did the clerk distribute the chance to earn additional income from watch work? Watchman shifts could be a lucrative perk for labourers working at St. Paul's, giving them an easy way to earn additional income. However, because shifts were constrained to eight or ten per month, watch work added at most a 15% supplement to a full-time worker's income. Our test is the same as we employed in the previous sections: were long-standing labourers more likely to be given watchman's shifts at St. Paul's?

Overall, just 8% of all labourers served as watchmen.[20] Watch shifts were associated with longer tenure—the median tenure for workers who were given watch shifts was nine years, whereas the median tenure for workers who were not given watch shifts was only six months. Two-thirds of those put on watch had been involved as labourers for more than a year before their first watch shift. However, the majority of long-standing labourers still did not get any watch work—only 32% of labourers who were employed for longer than two years in the construction period took watch shifts. In general, watch work seems to have been a valuable privilege that probably reflected information about trustworthiness.

Table 7 suggests that watch shifts were an important way that labourers with longer tenure were rewarded at the Cathedral. In the three models in Table 7, the dependent variable is whether or not a labourer was given a watch shift during an accounting period. Tenure is measured as before. The final years of the construction phase (1708-1711) are excluded because watchman shifts are not recorded in these years.

[20] The exception was the quiet years of the 1690s; in these slump years just under half of labourers took work as watchmen. In years when construction peaked, this fell to as low as 7% of labourers.

Table 7: Probability of a labourer having a watchman shift in an accounting period

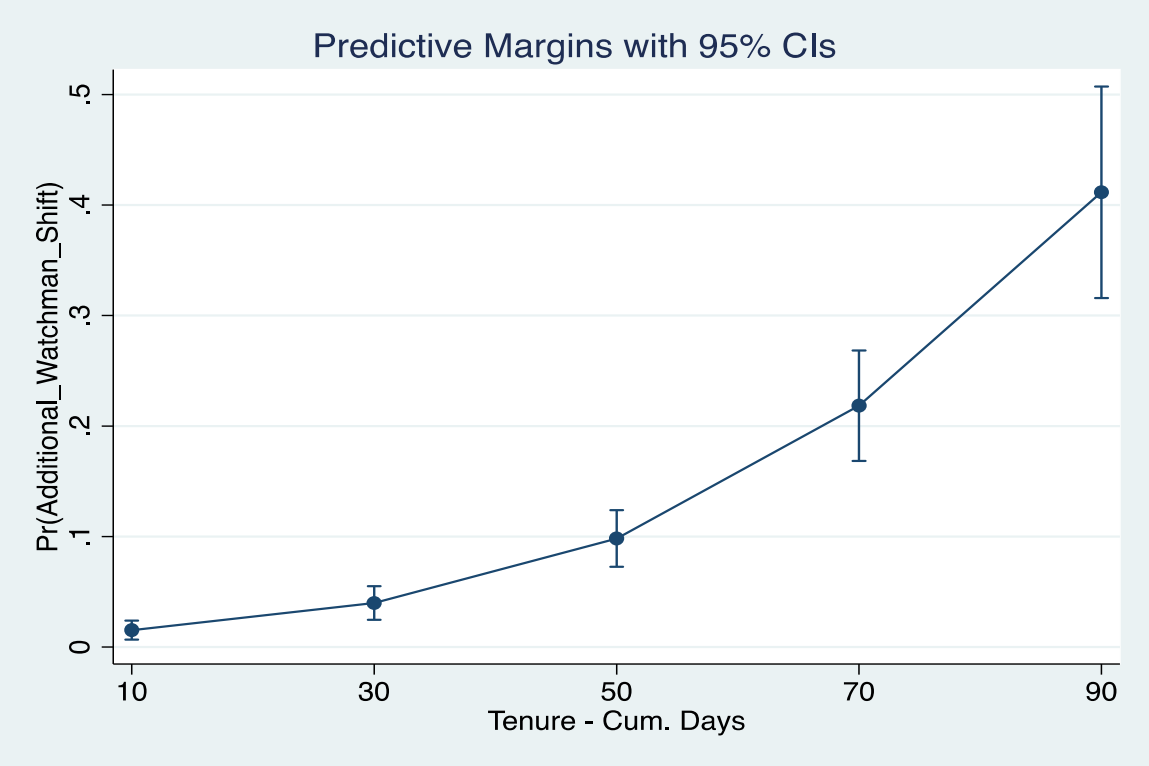
	Cum. Days Logit - Coef	Cum. Days Logit - Margins	Cum. Days Cond. Logit (FE) - Coef	Elap. Time Logit - Coef	Elap. Time Logit - Margins	Elap. Time Cond. Logit (FE) - Coef
	(1)	(2)	(3)	(4)	(5)	(6)
Tenure - Cum. Days	0.0497***	0.0053***	0.0871***			
	(0.0054)	(0.0006)	(0.0145)			
Tenure - Elap. Time				0.0431***	0.0048***	0.0591**
				(0.0055)	(0.0007)	(0.0194)
Constant	-5.6099***			-4.7720***		
	(0.5309)			(0.5134)		
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Month Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Labourer Fixed Effects	No	No	Yes	No	No	Yes
Num. of observations	16903	16903	7388	16903	16903	7388
Num. of individuals	746			746		
Pseudo R2	0.228		0.214	0.188		0.168

* p<0.05, ** p<0.01, *** p<0.001. Robust standard errors, adjusted for clustering by individual, are presented in parentheses. Tenure given in percentile.

Columns (1) and (2) give the coefficients and marginal effects of our main logit model. The marginal effect of tenure rank, measured by cumulative days previously worked, is 0.0053 (p<0.001). This means that a one quartile increase in the percentile rank of a labourer's tenure increases the probability that a labourer is given a watchman shift by 13.25 percentage points (25*0.0053 = 0.1325). Figure 6 plots how the probability of being awarded a watchman shift changes with a labourer's tenure percentile. New labourers in the 10th percentile in terms of tenure had only a 15.3% chance of being given a watchman shift, while those in the 90th percentile had a 41.2% chance. Column (3) gives the coefficients from a conditional logit with labourer fixed effects. This model needs to be interpreted cautiously, as over half of the observations are dropped. This is because the within-labourer effect of tenure on the probability of getting a watchman shift cannot be estimated for labourers who are never given a watchman shift over their career at the Cathedral. Keeping this in mind, the within-labourer effect of tenure on getting a watchman shift is very large and significant. Columns (4) and (5) give the estimates

and marginal effects where tenure rank is measuring in elapsed time. The effect is robust to this alternative measure of tenure and is of a similar magnitude. Column (6) indicates that this relationship is robust to the inclusion of labourer fixed effects, with the same qualifications as the model in column (3).

Figure 6. Probability of being awarded a watchman shift with a labourer's tenure percentile.



Source: See text

4e. Implications for labourer income

Long term labourers were advantaged at both the extensive and intensive margin. The impact of this on employment and income over the year was substantial. The median number of days worked per year for all labourers in any year just 145, but for those who were active at the Cathedral for more than two years, the median was 200 days.[21] With longer tenure, labourers could achieve something like full-time work. Because wages were nominally rigid, this differential in hiring determined the level of income that labourers could achieve. Current standard estimates of annual income for this period are generally based on day rates of 20d to 24d earned for a standard 250 days a year (Allen 2009; Broadberry 2015). This implies an average labourer earned £20 -£25 per annum. At St. Paul's, daily rates were lower and labourers were given widely varying amounts of work.

[21] Calculations for the construction phase, excluding watch shifts.

Table 8. Average annual income (£) for labouring and watch at St Paul's, by tenure

	Tenure Percentile			
	1st-24th	25th-49th	50th-74th	75th-99th
Construction				
1675-9	£3.61	£7.73	£11.16	£10.31
1680-4	£6.31	£9.79	£13.38	£13.53
1685-9	£4.11	£9.63	£11.33	£14.84
1690-4	£4.95	£11.32	£14.08	£17.98
1695-9	£8.72	£15.47	£15.86	£20.56
1700-4	£11.56	£16.21	£19.79	£22.85
1705-9	£9.78	£16.42	£18.71	£22.34
Maintenance 1711-1748	£15.75	£19.09	£18.57	£19.25

Tenure based on the elapsed time since a labourer began working at St. Paul's. Percentile rank is calculated each year relative to all labourers who worked in that year.

The dispersion in labourers' income is apparent in Table 8, which summarises the average income of labourers according to their tenure for each half decade of the construction period, 1675-1709, and for the maintenance period, 1711-1748. These calculations include pay for days worked as a labourer as well as any additional income from watch shifts. In each period, labourers who had worked at the Cathedral the longest had higher annual incomes than those who were relatively new to the project. Their access to more days of work, more consistent working patterns, and watchman shifts paid off in substantially higher average annual incomes than those in the bottom half of the tenure distribution.

During the early years of construction, Table 8 indicates that even the most tenured workers earned less than £20 per year in nominal terms. These workers needed to find work on multiple sites or in a variety of by-employments each year if they were to earn enough to support themselves and a family, an achievement which the seasonality of construction work must have made difficult. However, with the stabilization in hiring at the Cathedral, labourers' incomes grew markedly. By 1700-9, the majority of labourers were employed for enough days each year on this site to earn over £18. As work moved to maintenance after 1711, and the labouring workforce dwindled to a few men in each month, the average labourer at the Cathedral was employed for over 300 days a year, and even labourers in the lowest quartile of tenure were earning £16 or more. In real terms this would have fluctuated considerably, as this was a period of highly volatile price inflation and deflation.[22]

[22] See price series in the Bank of England's, "A millennium of macroeconomic data," https://www.bankofengland.co.uk/statistics/research-datasets

To summarize, during the period of construction at St. Paul's, employment was highly polarised, with longer-standing labourers at St. Paul's receiving preferential treatment in four ways. First, they were rewarded with more days of work in each period in which they were present. Second, they were more likely to be retained. Third, they were more likely to be rehired after periods of low demand. Finally, they were given access to lucrative watchman shifts. As this system developed, the workforce stabilized, turnover fell and average tenure increased.

5. Discussion

We have observed a split in the labour force at St. Paul's, where a core set of workers achieved relative job stability and access to additional income opportunities, while a periphery of temporary workers experienced short tenure and lower incomes. The day wage rate was almost identical for all workers in both groups. There are two plausible explanations for these findings.

First, these divergent experiences could simply reflect productivity differences between labourers. To the best of our knowledge, at St. Paul's all of the general labourers recorded in the accounts were doing similar work requiring a similar skill level. In this context, the decision to reward longer-tenure building labourers with more days or watchman shifts suggests workers may have had differences in their innate productivity which the clerk was able to learn about, or that labourers at St. Paul's gradually built up firm-specific human capital. In a competitive market, we would expect these differences among workers to be acknowledged in differences in the wage rate. As wages were rigid, offering extra work could have been a compensating differential for the relatively low wages the most productive workers received.

A second explanation is that the early modern building market in London had more frictions than has been previously assumed. The extreme nominal wage rigidity we observed could be an efficiency wage strategy in order to address principal-agent problems (Shapiro and Stiglitz, 1984), to minimize turnover costs (Stigliz, 1974), or to overcome information asymmetries with adverse selection (Weiss 1980). The efficacy of these strategies varies with workers' tenure, possibly explaining the different experiences of tenured and non-tenured workers at the Cathedral. This explanation could also be consistent with a view of St Paul's as a monopsonistic employer whose market power derives from both its size (as the largest site in the city) and a high variance and level of elasticity of labour supply. However, none can be directly tested with our data.

Our results are most obviously consistent with a model in which St. Paul's faced high costs of hiring and training workers. To reduce the costs of turnover, some workers were given access to additional income. This ensured enough worker retention to minimize these costs and these workers then achieved higher levels of tenure. High turnover costs could also explain the additional benefits tenured workers received such as more consistent work and a higher probability of being rehired after seasonal breaks. If turnover costs were significant at St. Paul's, there would be incentive to create long-term bonds such as implicit contracts that could provide this form of job security.

The employment patterns we observe at St. Paul's could reflect pure productivity differences between workers, a turnover-reduction strategy, or some combination of both. We must leave the identification of which was actually in play to future research. In either case, our results considerably revise our understanding of labour markets during this period. Labourers were likely non-homogenous in important ways, and their income varied according to the amount of days worked rather than their wage rate. The Cathedral optimized the structure of its pool of general labourers in order to retain the most productive workers and to reduce turnover costs. This early modern firm thus appears to be a lot more modern than has been previously assumed.

Given the difference between our findings and earlier assumptions, the question arises of how much we can surmise about the market for and employment of unskilled labour more generally from St. Paul's. The very existence of the records we study, and the argument we pursue, suggests employment patterns may have been different at this site because its scale and duration offered the opportunity for longer-term working relationships than other projects.

The Cathedral certainly was unusually large and created unusually detailed records. However, it does not seem unrepresentative. We know that other aspects of building work on the Cathedral operated in the same way as on other large sites in the city (Stephenson 2020a: 35-64, 79-106). The wharving of the Fleet ditch in the early 1670s reputedly used hundreds of labourers contracted by Thomas Fitch, but the project only lasted two to three years, and no named records survive (Skempton 2002: 228). The numbers of labourers hired at Westminster Abbey, 1712-13, and Greenwich, 1696-1706, which were two of the largest contemporaneous sites, indicate fewer than ten general (not trade specific) labourers on site at any one time.[23] Similarly, Woodward (1995:100-106) offers evidence of some labourers' long term association with sites.

[23] Westminster Abbey Muniments cat. no.34513; The National Archives, Greenwich Hospital ADM 68/4,

There would have been other places such as the dockyards that operated similar systems of hiring as St. Paul's, but it is impossible to test whether the same trends in tenure and hiring occurred. However, the records of the contractors who operated such sites indicate a positive relationship between tenure and the annual numbers of days worked (Stephenson 2020b, p. 424). Therefore, although St. Paul's is unique, the operation of its hiring and contracting were broadly representative of the market.

6. Conclusion

Workers on London's largest building site in the later seventeenth-century faced high levels of uncertainty about whether or not they would be given work in the next week or month. The needs of the project varied dramatically, and with it the chance of hiring. However, work was not allocated in a pure spot market. Instead, the Cathedral prioritized a core of long-term workers, who were put at the head of the queue in hiring, offered additional work as watchmen, and allotted a larger share of the available work than their less-experienced peers, who received short and insecure periods of work. Tenure—as we might generously term what remained a tenuous and intermittent relationship—was rewarded by the Cathedral with access to larger amounts of work, and so a higher and more reliable income. Building labourers' incomes were thus more varied than their wage rates per day imply.

We argue that this is explicable if St. Paul's was using its hiring strategy to deal with the heterogeneity of labourers attracted to the site. Wages did not adjust to shifts in demand for long periods, rather the nominal wage rates persisted for eight decades of urban expansion, persistent GDP growth, and structural change. Labourers were incentivized to return by the prospect of higher incomes not higher wages: more work, not more money per day. Our sources do not allow us to observe what it was about these particular labourers that the Cathedral preferred: they may have been more productive, disciplined, diligent or quiescent; all we can say is that they were treated preferentially because of it. St. Paul's thus presents a phenomenon that is, in the context of the existing literature, unexpected for a pre-industrial labour market. The mechanism used to reward and retain workers may have been distinctive, but clearly the idea of organizing employment to secure a specific cohort of workers did not need to wait for large corporate firms or scientific management practices. Rather, they seem to emerge endogenously as a response to the standard challenge of supplying large numbers of workers of a suitable quality in a volatile labour market. While St. Paul's is architecturally unique, it represents a broad category of major

institutional construction projects. This indicates that some of the characteristics of modern management practices could emerge organically in pre-industrial labour markets, even those that appear to be characterised by 'casual' hiring and no progression.

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Appendix A: Worker Churn at St. Pauls

This appendix explains our approach to churn at St Paul's Cathedral. Worker churn has three main components. Firms add or cut jobs, as demand increases or falls. Firms fire some workers while other workers quit, and replacements are hired. And firms are established or fail. Measures of turnover depends on how many of these channels of hiring and separation are observed, and the basis for measuring worker churn varies in important ways between studies.

Measures of turnover also depend on how employment is captured. Where employment is measured via a quasi-census at intervals, some types of churn are omitted. For example, present day measures for Germany and other settings utilize data that capture employment at sequential cross sections: Bachmann et al (2020) consider a labourer to be working for an establishment if she is employed at the end of the quarter. The number of jobs at the end of the quarter follows from this (J_{it}); the number of hires (H_{it}) is the number of workers who were not working at the end of the previous quarter; and the number of separations (S_{it}) is the number who had been working at the end of the previous quarter and who have now left (Bachman et al:5, 25-28). Turnover *within* a quarter is not observable in this approach. Alternatively, some sources, such as the LEHD dataset studied by Davis et al (2006), include all worker transitions of whatever duration. Measures of this kind produce much higher rates of hiring and separation than those that focus on 'full quarters' (Davis et al 2006:6).

Our dataset is organized into periods of one or more month's duration and reports all workers employed in an accounting period (month, quarter or longer) as labourers and watchmen, including short employment spells. We construct measures of job and worker flow within St Paul's based on the available accounting periods. Where the duration of the accounts is a month, we define the number of jobs, $J_{it,}$ as the number of workers employed as day labourers within that month (excluding workers employed solely as watchmen). The number of labourers who appear in the records in that month but not in the previous month gives us our count of hires, H_{it}. The number of labourers who were not retained from the previous month is our count of separations, S_{it}. We compute net monthly job flow as $JF_{it} = J_{it} - J_{it-1}$. Job creation JC_{it} occurs where employment increases ($JF_{it}>0$) and job destruction JD_{it} occurs when it falls ($JF_{it}<0$). Because more workers may be hired or separated in a period than jobs (i.e. $H_{it}>JC_{it}>0$), we also report the churn (Ch_{it}), as defined by Burgess et al (2000).

$$Ch_{it}=(H_{it}-JC_{it})+(S_{it}-JD_{it})$$

We follow the normal convention (Davis et al 1996) in converting hiring and separation flows into rates by dividing totals by the average of employment in the previous and current period, so the hiring rate is defined as:

$$HR_{it}=H_{it}/(J_{it}+J_{it-1})*1/2$$

Other rates (separation, job creation, job destruction and churn) are defined in the same manner. This approach constrains growth rates to between -200 and +200 percent. We report rates based on monthly accounts which survive for much of the construction phase. These calculations are restricted to periods for which two sequential accounts are of one-month duration. For quarterly estimates, the period commonly found in the modern literature, we carry out the same calculation using three-month windows and taking the first quarter as January to March, to align with general practice.

The measures we report are the equivalent to 'all transition' figures, because they count every person employed, no matter how long they stayed. Workers who were only hired for a few days

on one occasion still count as a hire and a separation, even though they just appeared in a single month or quarter, respectively. Workers who had been employed previously, but had been absent for a period, are also counted as new hires.

For comparison, we also compute 'full quarter' figures. We report two variants on the quarterly data. First, in our 'quarterly (any)' calculations we treat workers as employed if they are hired at any point within a quarter. From this definition, follows the number of jobs at the cathedral, the number of hires (workers who had not been active in the previous quarter), and separations (workers who were no longer active from the previous quarter). These figures have the advantage of observing all transitions of any period.

Second, in our 'quarterly, (quasi-census)' calculations we treat workers as employed if they are employed in the final month of a quarter (March, June, September, December). This is the closest we can come to the approach taken by Bachmann et al (2020) who define employment based on a worker being employed at the end of a quarter. These figures neglect short-term employment in other months and are oriented towards identifying longer-term hiring. These figures are useful for comparison, but should be treated with caution, given that short periods of work were the norm and they will be particularly shaped by the specifics of hiring in the final month of each the quarter.

The number of months falling into observation in the monthly series is reported in the main text. The number of quarters in observation is given in Table A.1. To estimate churn, we require a quarter to be part of a continuous sequence of accounts, ensuring we observe the previous and the next quarter in order to work out hiring and separations.

Table A.1: Quarters in observation for churn estimates by quinquennia.

Period	Quarters observed (n)	Share of quarters observed (%)
1675-	17	85
1680-	11	55
1685-	15	75
1690-	20	100
1695-	7	35
1700-	14	70
1705-	20	100
Total	97	69

Our data allow us to distinguish permanent from temporary separation and hiring. Permanent hiring and separation are defined as occurring on a workers' first and last appearance in the Cathedral records. Because temporary absences where workers appear in one period and then return to work after a period of absence are common in the St Pauls records, the permanent hiring and separation rates are substantially below the job creation and job destruction rate.

Where the numbers employed increased, this is job creation. Where the numbers decrease this is job destruction. When there is no creation/destruction, the figure is set to zero. The closest modern equivalent would be the flow of workers into and out of zero-hours contracts with highly unstable monthly labour demand. Aggregate rates in the literature are calculated using

seasonally adjusted series. We do not adjust for seasonality, given that we are dealing with a single site with highly volatile employment.

Table A.2: Churn Estimates, Monthly

Job Creation Rate (monthly)

	mean	sd	min	max	count
1675-	7.78	12.21	0	51.43	50
1680-	6.86	14.14	0	70.97	33
1685-	7.50	12.55	0	54.21	43
1690-	5.53	6.38	0	34.78	50
1695-	3.03	4.49	0	13.33	17
1700-	5.46	9.90	0	43.90	42
1705-	7.24	21.75	0	120.61	60
Total	6.54	13.68	0	120.61	295

Job Destruction Rate (monthly)

	mean	sd	min	max	count
1675-	10.28	15.35	0	48.78	50
1680-	8.91	13.28	0	49.06	33
1685-	8.45	14.16	0	54.95	43
1690-	2.89	7.28	0	38.60	50
1695-	5.08	9.35	0	28.57	17
1700-	2.74	9.83	0	60.00	42
1705-	5.88	21.60	0	134.18	60
Total	6.34	14.69	0	134.18	295

Hiring Rate, first starts (monthly)

	mean	sd	min	max	count
1675-	4.96	6.52	0	30.86	50
1680-	1.40	3.68	0	16.13	33
1685-	8.69	12.26	0	54.21	43
1690-	4.30	4.30	0	15.73	50
1695-	1.49	2.33	0	6.90	17
1700-	3.89	6.47	0	27.59	42
1705-	3.45	5.37	0	35.90	60
Total	4.34	7.04	0	54.21	295

Hiring Rate, starts & returns (monthly)

	mean	sd	min	max	count
1675-	14.23	13.42	0	51.43	50
1680-	10.06	14.68	0	74.19	33
1685-	11.67	13.42	0	57.94	43
1690-	8.57	7.38	0	34.78	50
1695-	4.09	4.49	0	13.33	17
1700-	7.30	11.01	0	43.90	42
1705-	9.42	21.46	0	120.61	60
Total	9.88	14.34	0	120.61	295

Separation Rate, final (monthly)

	mean	sd	min	max	count
1675-	7.66	8.01	0	32.89	50
1680-	3.73	5.52	0	23.53	33
1685-	8.23	8.53	0	35.56	43
1690-	3.67	5.27	0	22.86	50
1695-	4.83	7.39	0	22.64	17
1700-	1.97	3.71	0	20.00	42
1705-	2.26	4.94	0	35.44	60
Total	4.56	6.68	0	35.56	295

Separation Rate, temporary & final (monthly)

	mean	sd	min	max	count
1675-	16.77	14.75	0	48.78	50
1680-	12.11	13.18	0	52.83	33
1685-	12.75	13.75	0	54.95	43
1690-	5.93	7.77	0	38.60	50
1695-	6.14	9.72	0	28.57	17
1700-	4.58	10.44	0	60.00	42
1705-	8.06	21.61	0	134.18	60
Total	9.70	14.97	0	134.18	295

Table A.3: Churn Estimates, Quarterly, Any

Note: these figures report rates based on any appearance by a worker in each quarter.

Creation Rate (quarterly, any)

	mean	sd	min	max	count
1675-	5.97	9.36	0	27.45	16
1680-	5.01	8.90	0	33.33	20
1685-	14.53	26.45	0	90.00	20
1690-	10.35	11.56	0	41.67	20
1695-	9.64	14.41	0	51.43	20
1700-	15.92	24.71	0	88.37	20
1705-	7.80	9.03	0	30.05	20
Total	10.00	16.72	0	90.00	136

Job Destruction Rate (quarterly, any)

	mean	sd	min	max	count
1675-	13.49	12.47	0	31.93	16
1680-	8.86	10.23	0	26.09	20
1685-	13.06	17.50	0	71.60	20
1690-	7.78	15.82	0	52.38	20
1695-	10.37	19.85	0	73.17	20
1700-	13.74	29.89	0	100.00	20
1705-	3.87	9.21	0	30.93	20
Total	10.07	17.75	0	100.00	136

Hiring Rate, first starts (quarterly, any)

	mean	sd	min	max	count
1675-	11.23	12.81	0	49.11	16
1680-	4.63	5.98	0	21.28	20
1685-	18.86	25.20	0	86.67	20
1690-	11.29	8.31	0	28.26	20
1695-	7.34	8.40	0	34.57	20
1700-	8.57	11.01	0	32.32	20
1705-	9.15	8.05	0	27.12	20
Total	10.12	13.27	0	86.67	136

Hiring Rate, starts & returns (quarterly, any)

	mean	sd	min	max	count
1675-	17.70	14.94	0	51.25	16
1680-	11.41	11.02	0	34.62	20
1685-	23.19	26.91	0	91.67	20
1690-	17.07	12.08	0	45.83	20
1695-	14.04	15.15	0	57.14	20
1700-	18.42	25.30	0	88.37	20
1705-	12.18	9.89	2	33.16	20
Total	16.25	17.76	0	91.67	136

Separation Rate, final (quarterly, any)

	mean	sd	min	max	count
1675-	18.62	11.15	0	37.45	16
1680-	9.23	6.58	0	23.08	20
1685-	16.50	14.18	0	49.38	20
1690-	10.96	10.94	0	38.10	20
1695-	8.79	8.76	0	28.99	20
1700-	6.02	8.25	0	25.53	20
1705-	5.58	6.49	0	27.16	20
Total	10.59	10.57	0	49.38	136

Separation Rate, temporary & final (quarterly, any)

	mean	sd	min	max	count
1675-	25.22	12.81	2	42.70	16
1680-	15.27	9.70	0	34.78	20
1685-	21.73	18.41	2	74.07	20
1690-	14.51	15.54	0	61.90	20
1695-	14.77	19.33	0	73.17	20
1700-	16.23	29.38	0	100.00	20
1705-	8.26	10.63	0	37.11	20
Total	16.31	18.10	0	100.00	136

Table A.4: Churn Estimates, Quarterly, Quasi-Census

Note: these figures report rates based on any appearance by a worker in the final monthly account of a quarter, replicating the 'end of quarter' approach.

Job Creation Rate (quarterly, quasi-census)

	mean	sd	min	max	count
1675-	11.73	19.48	0	72.82	16
1680-	5.59	10.38	0	24.00	8
1685-	17.93	30.03	0	85.71	14
1690-	10.35	12.41	0	46.81	20
1695-	11.28	18.06	0	41.03	6
1700-	10.46	18.68	0	63.83	13
1705-	8.29	10.72	0	32.50	20
Total	10.93	17.73	0	85.71	97

Job Destruction Rate (quarterly, quasi-census)

	mean	sd	min	max	count
1675-	15.65	20.93	0	59.83	16
1680-	11.66	13.60	0	30.77	8
1685-	19.99	26.33	0	75.47	14
1690-	7.37	11.30	0	40.00	20
1695-	16.74	22.49	0	47.06	6
1700-	5.43	18.43	0	66.67	13
1705-	4.29	8.34	0	23.20	20
Total	10.59	17.81	0	75.47	97

Hiring Rate, first starts (quarterly, quasi-census)

	mean	sd	min	max	count
1675-	4.81	8.28	0	32.82	16
1680-	0.42	1.20	0	3.39	8
1685-	7.84	10.52	0	30.36	14
1690-	3.32	4.01	0	15.91	20
1695-	1.98	1.55	0	3.33	6
1700-	3.71	7.95	0	27.59	13
1705-	2.66	2.33	0	8.62	20
Total	3.81	6.49	0	32.82	97

Hiring Rate, starts & returns (quarterly, quasi-census)

	mean	sd	min	max	count
1675-	17.60	12.54	0	42.67	16
1680-	10.70	8.80	0	24.00	8
1685-	14.68	17.42	0	56.00	14
1690-	10.44	10.36	0	38.30	20
1695-	7.25	9.83	0	26.67	6
1700-	6.93	12.26	0	38.30	13
1705-	7.24	6.23	0	25.53	20
Total	10.93	11.81	0	56.00	97

Separation Rate, final (quarterly, quasi-census)

	mean	sd	min	max	count
1675-	6.68	8.91	0	34.91	16
1680-	6.94	6.16	0	16.33	8
1685-	8.13	8.24	0	26.59	14
1690-	4.63	6.07	0	21.54	20
1695-	8.90	10.78	0	26.47	6
1700-	2.75	5.66	0	20.51	13
1705-	3.61	5.33	0	23.63	20
Total	5.47	7.17	0	34.91	97

Separation Rate, temporary & final(quarterly, quasi-census)

	mean	sd	min	max	count
1675-	29.93	18.84	6	67.92	16
1680-	19.58	13.34	7	40.68	8
1685-	29.97	24.41	2	79.25	14
1690-	15.57	13.90	0	52.31	20
1695-	20.09	23.21	0	50.00	6
1700-	10.68	17.37	0	66.67	13
1705-	9.87	9.33	1	29.83	20
Total	18.80	18.36	0	79.25	97

Appendix B: Robustness Checks and Alternative Specifications

This appendix considers whether the results for the intensity of work are robust to changes in how "full-time" is defined, to the use of a fractional logit model, to the inclusion of external shocks that may have affected hiring at St. Paul's, and to the exclusion of possible foremen.

B1. Are our main results robust to changes in the "full-time" boundary?

The 85% of max days worked in a period boundary includes 7,189 of 19,861 (36.18%) observations for the construction period excluding the first few years and those working their first shift. Table B.1 shows that lowering or raising the boundary causes the percent of observations considered full-time to increase or decrease. At an 80% boundary, over half of observations are included as full-time workers. At a 95% boundary, less than one quarter of observations are included as full-time.

Table B.1: Percent of workers full-time and not full-time at different boundaries

	% Full-time	% Not full-time
Full-time > 75	57.99	42.01
Full-time > 80	50.86	49.14
Full-time > 85	36.18	63.82
Full-time > 90	26.03	73.97
Full-time > 95	18.40	81.60

Figure B.1 gives the density of observations across 5-year buckets of the percent of maximum days worked by any labourer in the period. Over half of observations are past 80% of maximum days worked. The 85% boundary excludes the clusters of observations around 80% to capture the top end of the distribution in terms of days worked. Figure B.2 gives this histogram by decade. The 80% breakpoint is noticeable in each decade, especially after 1700.

Figure B.1: 5-year bucket density observations with percentage of maximum days worked by any labourer in the period

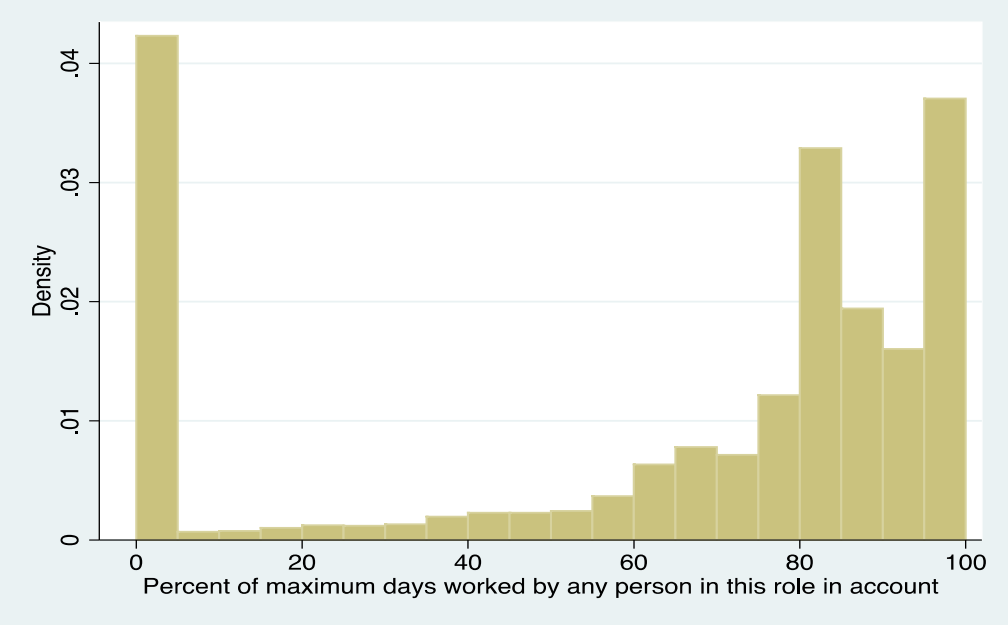


Figure B.2 5-year bucket density observations with percentage of maximum days worked by any labourer in the period by decade.

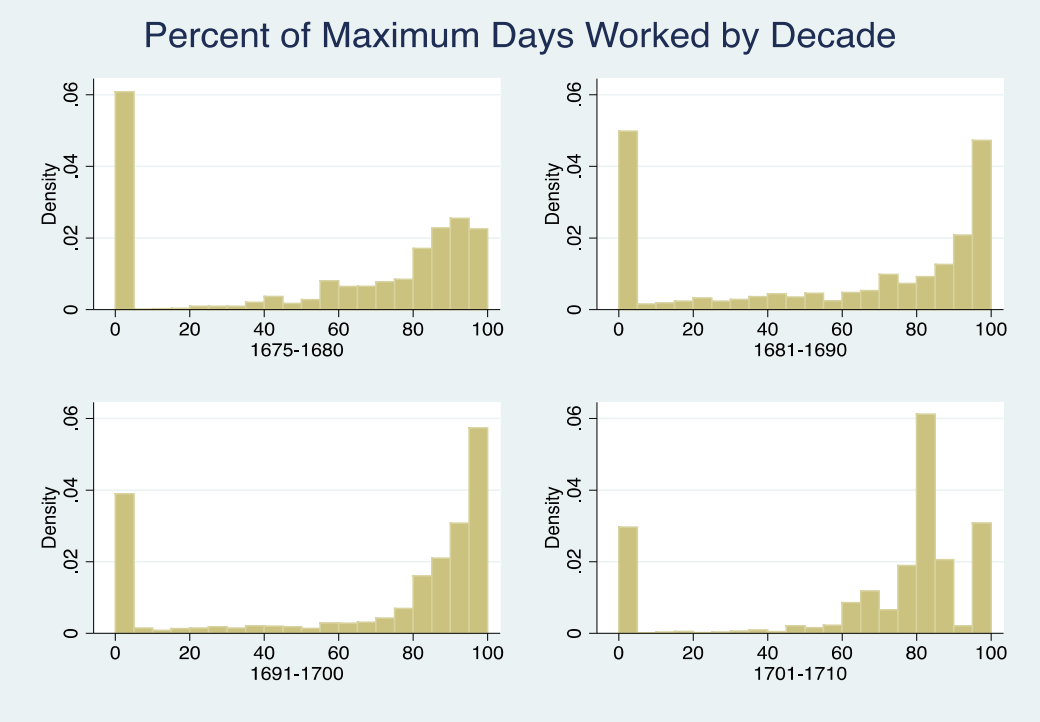


Table B.2 gives the coefficients and marginal effects from a logit model for the probability of a labourer working full-time during an accounting period. The independent variable of interest is tenure in terms of the percentile rank of cumulative days worked previously. Columns (1) and (2) are the results where a worker is considered full-time at more than 80% of the maximum days worked during the accounting period. (3) and (4) give the results for the assumed full-time boundary of 85%. (5) and (6) use a full-time boundary of over 90%, and (7) and (8) use a full-time boundary of over 95%.

Table B.3 is structured the same way, capturing tenure through the percentile rank of elapsed time since the worker began at the cathedral.

Both Table B.2 and Table B.3 indicate that the relationship of tenure to the intensity of work during an accounting period is robust to changing the boundary for when a worker is considered full-time. In all models in Table B.2, the marginal effects indicate that a one quartile increase in a labourer's percentile rank of tenure in terms of cumulative days corresponds to over a 10 percentage point increase in the probability that the labourer worked full-time during an accounting period, even as the boundary for full-time is adjusted ($p < 0.001$, $25 * 0.0040 = 0.10$). Likewise, the models in Table B.3 indicate that a one quartile increase in a labourer's percentile rank of tenure in terms of elapsed time corresponds to over a 7.5 percentage point increase in the probability that the labourer worked full-time during an accounting period, even as the boundary for full-time is adjusted ($p < 0.001$, $25 * 0.0030 = 0.075$).

Table B.2: Probability of a labourer working full-time at different full-time boundaries

	FT 80 - Coef (1)	FT 80 - Margins (2)	FT 85 - Coef (3)	FT 85 - Margins (4)	FT 90 - Coef (5)	FT 90 - Margins (6)	FT 95 - Coef (7)	FT 95 - Margins (8)
Tenure - Cum. Days	0.0235***	0.0047***	0.0267***	0.0049***	0.0295***	0.0045***	0.0329***	0.0040***
	(0.0020)	(0.0004)	(0.0023)	(0.0004)	(0.0027)	(0.0004)	(0.0030)	(0.0005)
Constant	-3.5724***		-3.7217***		-6.6361***		-7.4575***	
	(0.2160)		(0.2213)		(0.5982)		(0.9737)	
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Num. of observations	19861	19861	19861	19861	19861	19861	19861	19861
Num. of individuals	798		798		798		798	
Pseudo R2	0.163		0.172		0.189		0.184	

Robust standard errors, adjusted for clustering by individual, are presented in parentheses. Tenure given in percentile.
* p<0.05, ** p<0.01, *** p<0.001

Table B.3: Probability of a labourer working full-time at different full-time boundaries

	FT 80 - Coef (1)	FT 80 - Margins (2)	FT 85 - Coef (3)	FT 85 - Margins (4)	FT 90 - Coef (5)	FT 90 - Margins (6)	FT 95 - Coef (7)	FT 95 - Margins (8)
Tenure - Elap. Time	0.0148***	0.0031***	0.0180***	0.0035***	0.0205***	0.0033***	0.0235***	0.0030***
	(0.0023)	(0.0005)	(0.0026)	(0.0005)	(0.0030)	(0.0005)	(0.0033)	(0.0005)
Constant	-2.7713***		-2.8929***		-5.7406***		-6.5117***	
	(0.2051)		(0.2206)		(0.6447)		(1.0644)	
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Num. of observations	19861	19861	19861	19861	19861	19861	19861	19861
Num. of individuals	798		798		798		798	
Pseudo R2	0.126		0.131		0.146		0.139	

Robust standard errors, adjusted for clustering by individual, are presented in parentheses. Tenure given in percentile.
* p<0.05, ** p<0.01, *** p<0.001

B.2: Are our main results robust to a non-binary dependent variable?

We can also check the robustness of our results by using a fractional dependent variable for the raw percentage of maximum days worked in a period. The model specification is a fractional logit model with year and month fixed effects. These results are given in Table B.4.

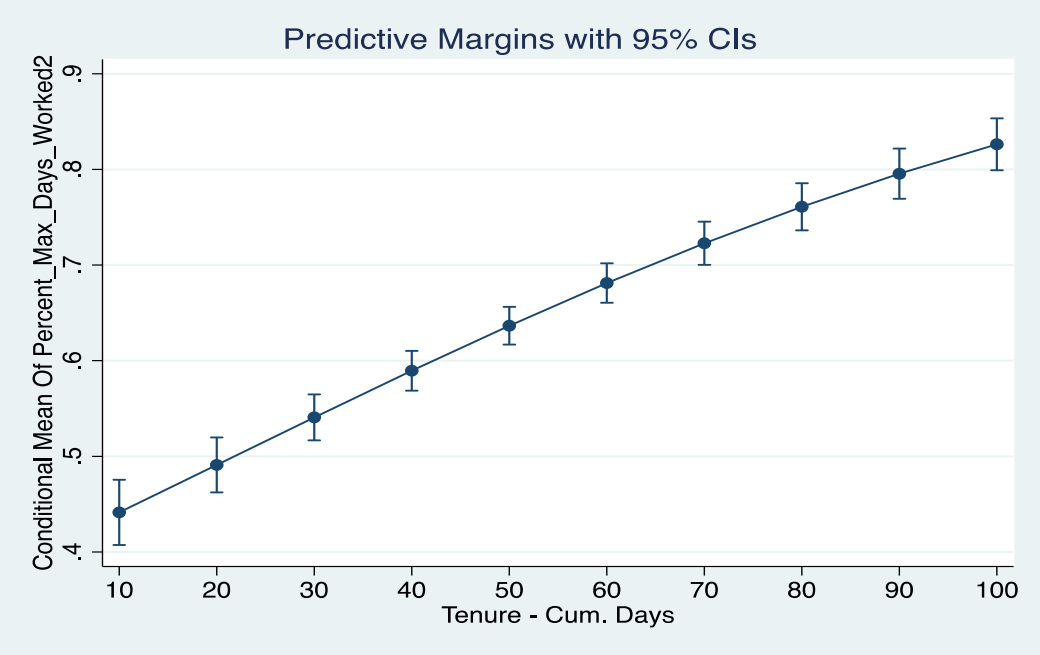
Columns (1) and (2) use the percentile rank of cumulative days previously worked as the measure of tenure. The marginal effect indicates that a one quartile increase in percentile rank of tenure corresponds to a 10.75 percentage point increase in the percent of maximum days worked in an accounting period ($p<0.001$, $25*0.0043 = 10.75$). Columns (3) and (4), using elapsed time percentile rank as the measure of tenure, indicate that a one quartile increase in percentile rank of tenure corresponds to a 7.8 percentage point increase in the percent of maximum days worked in an accounting period ($p<0.001$, $25*0.0031 = 7.8$). Figure B.3 graphs the marginal effects for the model in (1) and (2). As the percentile rank increases, the percent of maximum days worked increases.

Table B.4: Percent of maximum days worked in the accounting period

	Cum. Days Frac. Logit - Coef (1)	Cum. Days Frac. Logit - Margins (2)	Elap. Time Frac. Logit - Coef (3)	Elap. Time Frac. Logit - Margins (4)
Tenure - Cum. Days	0.0215***	0.0043***		
	(0.0017)	(0.0003)		
Tenure - Elap. Time			0.0150***	0.0031***
			(0.0019)	(0.0004)
Constant	-2.5237***		-1.9146***	
	(0.1677)		(0.1575)	
Year Fixed Effects	Yes	Yes	Yes	Yes
Month Fixed Effects	Yes	Yes	Yes	Yes
Num. of observations	19861	19861	19861	19861
Num. of individuals	798		798	
Pseudo R2	0.107		0.078	

* $p<0.05$, ** $p<0.01$, *** $p<0.001$. Robust standard errors, adjusted for clustering by individual, are presented in parentheses. Tenure given in percentile.

Figure B.3: Marginal effects for the model (1) and (2) in Table B.4, showing percentile rank and percent of maximum days worked.



B.3: Are our main results robust to the inclusion of external shocks which may have affected St. Paul's?

Over the period of the reconstruction of St. Paul's, there were numerous external shocks which could have shaped the tightness of the construction labour force. In this Appendix, we briefly examine whether some of the major shocks of the period affect our main results on the relationship of tenure to the amount of days worked in each accounting period. We control for four types of historical shocks in our analysis in this Appendix: temperature, wars, mortality, and financial volatility (after 1688).

Because construction is an extremely seasonal industry, variations in the weather patterns across years could affect the intensity of work in a given month. We control for these variations by including the mean monthly temperature of Central England in our analysis. This monthly time series is taken from Manley (1974).[24]

Wars are disruptive to general economic activity and can draw young male labourers out of the workforce. As this population might overlap the labourers we observe at St. Paul's, we include a dummy variable in our analysis indicating whether England was engaged in a war during each accounting period. This variable is based on Peter Brecke's Conflict Catalogue, which gives the start and end dates of international conflicts during this period.[25]

We also include a measure of general mortality in London to capture the effects of pestilence and disease on the labour force. The data we use is the number of burials each month in

[24] Manley, G. 1974. "Central England Temperatures: Monthly Means 1659 to 1973," Quarterly Journal of the Royal Meteorological Society, pp. 389-405

[25] Brecke, Peter. 2012. Dataset: Conflict Catalogue (Violent Conflicts 1400 A.D. to the Present in Different Regions of the World). Available at http://www.cgeh.nl/data.

London. These data were kindly shared with us by John Landers, who developed the monthly series based on the London Bills of Mortality from 1675-1825.[26]

Finally, we include a measure of the number of bankruptcies in London throughout the period as a proxy for general financial volatility. The Cathedral was a large project that relied heavily on borrowing, and thus employment and hiring at the Cathedral could have been shaped by the state of financial markets. Our annual series of bankruptcies in London is from Julian Hoppitt's 1987 study of English business, used for the eighteenth century by Schwarz (1992) .[27]

The results of our robustness checks incorporating these additional variables are given in Table 1 and Table 2. Our time series on bankruptcies in London begins only in 1688, so we first present the models without this variable for the entire construction period, and then including this variable but only for the period after 1688.

Table B.5 indicates that our main results are robust to the inclusion of these additional controls. The marginal effects in column (2) imply that a one quartile increase in the percentile rank of a labourer's tenure in terms of cumulative days worked increases their probability of working full-time by 12.25 percentage points ($p < 0.001$, $25 * 0.0049 = 0.1225$). This is identical to the main results in the paper. Likewise, the marginal effect for tenure in terms of elapsed time, given in column (5), is also identical. However, the within-labourer effects are not significant with either of these measures of tenure. All of the additional controls we include have the sign that is expected, with work intensity increasing with higher average temperatures, decreasing with wars, and decreasing, though not significantly, with mortality.

[26] Landers, John. 1987. "Mortality and Metropolis: the Case of London 1675-1825." *Population Studies* 41/1, pp. 59-76.
[27] Hoppit 1987, p.45; Schwarz 1992, p. 90-91 n.24.

Table B.5: Probability of a labourer working fulltime with controls for historical shocks

	Cum. Days Logit - Coef (1)	Cum. Days Logit - Margins (2)	Cum. Days Cond. Logit (FE) - Coef (3)	Elap. Time Logit - Coef (4)	Elap. Time Logit - Margins (5)	Elap. Time Cond. Logit (FE) - Coef (6)
Tenure - Cum. Days	0.0269***	0.0049***	0.0109			
	(0.0023)	(0.0004)	(0.0059)			
Tenure - Elap. Time				0.0181***	0.0035***	0.0085
				(0.0026)	(0.0005)	(0.0069)
Monthly Burials	-0.0001	-0.0000	-0.0003*	-0.0001	-0.0000	-0.0003*
	(0.0001)	(0.0000)	(0.0001)	(0.0001)	(0.0000)	(0.0001)
Monthly Avg. Temp	0.0827***	0.0150***	0.1069***	0.0791***	0.0152***	0.1067***
	(0.0140)	(0.0025)	(0.0174)	(0.0134)	(0.0025)	(0.0174)
Conflict Indicator	-0.9211***	-0.1671***	-1.2571***	-0.8857***	-0.1702***	-1.2625***
	(0.1162)	(0.0209)	(0.1416)	(0.1106)	(0.0209)	(0.1409)
Constant	-2.8397***			-2.0094***		
	(0.2884)			(0.2778)		
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Month Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Labourer Fixed Effects	No	No	Yes	No	No	Yes
Num. of observations	19861	19861	18921	19861	19861	18921
Num. of individuals	798			798		
Pseudo R2	0.175		0.163	0.135		0.162

* p<0.05, ** p<0.01, *** p<0.001. Robust standard errors, adjusted for clustering by individual, are presented in parentheses. Tenure given in percentile.

Table B.6 incorporates the London bankruptcy data into the analysis, which restricts the years of the analysis to 1688-1710. Our results are robust to the inclusion of this variable. The marginal effect of tenure in terms of cumulative days worked increases from 0.0049 to 0.0051 ($p<0.001$), and the marginal effect in terms of elapsed time also increases from 0.0035 to 0.0041 ($p<0.001$). As in Table B.5, the within-labourer effects are not significant. Somewhat surprisingly, the effect of bankruptcies is to increase the intensity of labour at St. Paul's Cathedral.

Table B.6: Probability of a labourer working fulltime with controls for historical shocks and bankruptcies, 1688-1710

	Cum. Days Logit - Coef	Cum. Days Logit - Margins	Cum. Days Cond. Logit (FE) - Coef	Elap. Time Logit - Coef	Elap. Time Logit - Margins	Elap. Time Cond. Logit (FE) - Coef
	(1)	(2)	(3)	(4)	(5)	(6)
Tenure - Cum. Days	0.0289***	0.0051***	0.0042			
	(0.0030)	(0.0005)	(0.0080)			
Tenure - Elap. Time				0.0223***	0.0041***	0.0085
				(0.0031)	(0.0006)	(0.0069)
Monthly Burials	-0.0003*	-0.0001*	-0.0005**	-0.0003*	-0.0001*	-0.0003*
	(0.0001)	(0.0000)	(0.0002)	(0.0001)	(0.0000)	(0.0001)
Monthly Avg. Temp	0.0042	0.0007	0.0130	0.0036	0.0007	0.1067***
	(0.0145)	(0.0026)	(0.0200)	(0.0139)	(0.0026)	(0.0174)
Conflict Indicator	-0.7379***	-0.1304***	-1.1376***	-0.7243***	-0.1338***	-1.2625***
	(0.1436)	(0.0251)	(0.1833)	(0.1361)	(0.0248)	(0.1409)
Annual Bankruptcies	0.0147***	0.0026***	0.0167	0.0136***	0.0025**	
	(0.0041)	(0.0008)	(0.0099)	(0.0041)	(0.0008)	
Constant	-2.0320***			-1.5860***		
	(0.3284)			(0.3189)		
Year Fixed Effects	Yes	No	Yes	Yes	No	Yes
Month Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Labourer Fixed Effects	No	No	Yes	No	No	Year
Num. of observations	13401	13401	12733	13401	13401	18921
Num. of individuals	473			473		
Pseudo R2	0.198		0.168	0.167		0.162

* p<0.05, ** p<0.01, *** p<0.001. Robust standard errors, adjusted for clustering by individual, are presented in parentheses. Tenure given in percentile.

B.4: Are our main results robust to the exclusion of labourers that might have been foremen?

During the period of construction, fewer than ten men were paid more than the standard day rates of 16d and 18d. Historical records suggest that these men were foremen, acting in a managerial role.[28] As foremen, they would have worked most days in an accounting period and had significant tenure. It is thus possible that they impacted the relationship we find between tenure and intensity of work.

To check whether this is the case, as a robustness check we run the main models excluding any labourer who earned over 18 pence per day during their time working for St. Paul's. This results in dropping 548 observations representing the work of 7 out of 797 labourers. The results are almost identical to those from the main model, presented in Table B.7.

[28] See Campbell (2007) pp.42-44.

Table B.7 Probability of a labourer working fulltime, with foremen excluded from sample

	Cum. Days Logit - Coef (1)	Cum. Days Logit - Margins (2)	Cum. Days Cond. Logit (FE) - Coef (3)	Elap. Time Logit - Coef (4)	Elap. Time Logit - Margins (5)	Elap. Time Cond. Logit (FE) - Coef (6)
Tenure - Cum. Days	0.0256***	0.0046***	0.0114			
	(0.0023)	(0.0004)	(0.0059)			
Tenure - Elap. Time				0.0179***	0.0034***	0.0093
				(0.0027)	(0.0005)	(0.0068)
Constant	-3.7124***			-2.9761***		
	(0.2295)			(0.2220)		
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Month Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Labourer Fixed Effects	No	No	Yes	No	No	Yes
Num. of observations	19313	19313	18447	19313	19313	18447
Num. of individuals	790			790		
Pseudo R2	0.173		0.155	0.140		0.154

* p<0.05, ** p<0.01, *** p<0.001. Robust standard errors, adjusted for clustering by individual, are presented in parentheses. Tenure given in percentile.

Appendix C: Change Over Time

The results presented in Table 3 in the main text indicate that long-standing labourers were given more days of work in each accounting period than labourers with less tenure. How did the relationship between tenure and days worked change over time?

First, St. Paul's was built in stages (Campbell, 2007:102-3). From the late 1660s demolition work was carried out and this was not finally completed until the late 1680s even as the lower walls of the new cathedral were raised, and the masonry walls of the choir were up by 1690. Roofing was carried out throughout the first decade of the new century. One stage of building which challenged the skills of all on site was the construction of the dome from 1705 through completion in 1711. This building phase was experimental and required bricklayers, carpenters and plasterers to work alongside masons with innovations in scaffoldings and materials (Campbell 2007:121-137) which may have required more experience than other general labouring jobs. Without raising wage rates, it is possible that St. Paul's awarded more working days per month, and more consistent working days, to secure experienced labourers to complete the construction of the dome.

Table C.1 presents three models exploring whether the relationship between tenure and days worked in a month changed during the period of dome construction at the cathedral. The dependent variable is the probability of working full-time during the accounting period, defined as in Table 3 in the main text. Prior tenure is measured by cumulative days worked in previous accounting periods in columns (1) and (2), and by elapsed time since the labourer began working at St. Paul's in columns (3) and (4). All models have year and month fixed effects with clustered standard errors.

Column (1), our primary results, give the coefficients and marginal effects of a logit model using the cumulative days measure of tenure. The significant interaction term indicates that the relationship between tenure and whether labourers worked fulltime did change during the period of dome construction. The marginal effects, given in the third panel of Table 3, imply that a one quartile increase in a labourer's tenure percentile rank increases the probability of working full-time by 8.5 percentage points in the period prior to dome construction ($p < 0.05$, $25*0.0034 = 0.085$), and by 13.5 percentage points during the period of dome construction ($p < 0.05$, $25*0.0054 = 0.135$). Figure C.1 shows that in both periods, labourers with more tenure were more likely to work full-time, but that the returns to tenure were steeper during the period of dome construction.

Table C.1: Probability of a labourer working full-time, dome building vs. rest of building

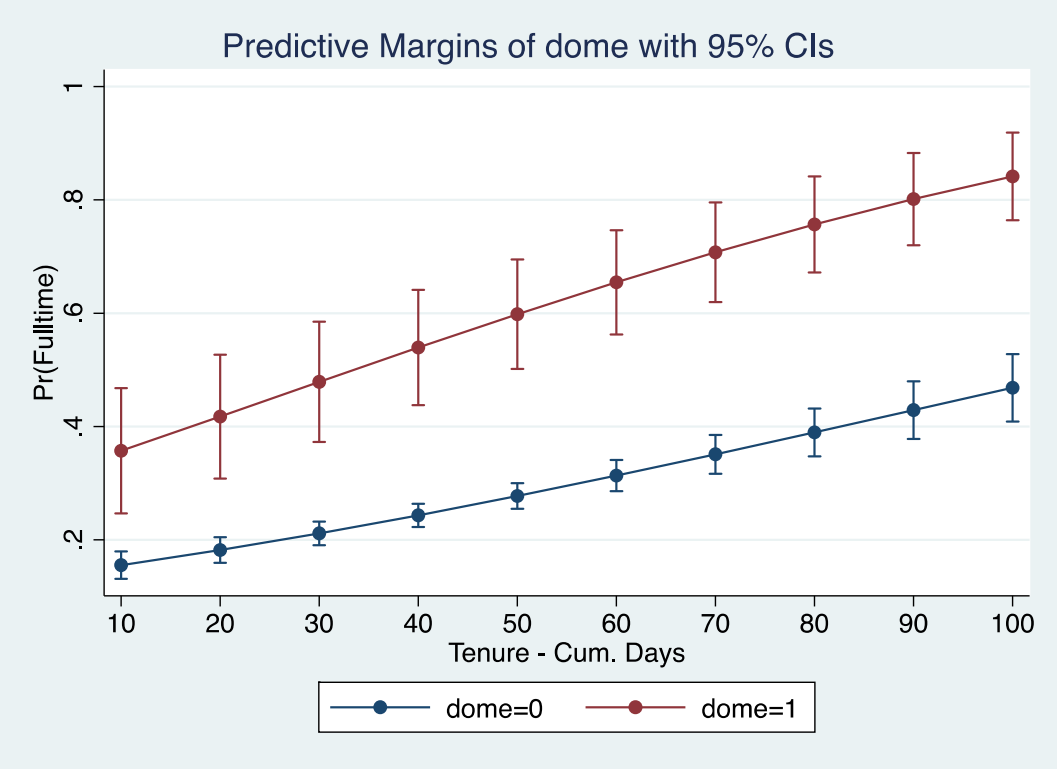
	Cum. Days Logit - Coef	Cum. Days Cond. Logit (FE) - Coef	Elap. Time Logit - Coef	Elap. Time Cond. Logit (FE) - Coef
	(1) b/se	(2) b/se	(3) b/se	(4) b/se
Tenure - Cum. Days	0.0232***	0.0094		
	(0.0027)	(0.0060)		
Dome = 1	1.3000*	-0.1795	0.8801*	-0.0696
	(0.4087)	(0.9003)	(0.4287)	(1.0492)
Dome * Tenure - Cum. Days	0.0128*	0.0313**		
	(0.0057)	(0.0083)		
Tenure - Elap. Time			0.0136***	0.0079
			(0.0032)	(0.0068)
Dome * Tenure - Elap. Time			0.0144**	0.0280**
			(0.0058)	(0.0087)
Constant	-3.4701***		-2.6447***	
	(0.2360)		(0.2318)	
Year Fixed Effects	Yes	Yes	Yes	Yes
Month Fixed Effects	Yes	Yes	Yes	Yes
Labourer Fixed Effects	No	Yes	No	Yes
Average marginal effects				
Tenure – Cum. Days				
Dome = 0	0.0034***			
Dome = 1	0.0054***			
Tenure – Elap. Time				
Dome = 0			0.0022***	
Dome = 1			0.0047***	
Num. of observations	19861	18921	19861	18921
Num. of individuals	798		798	
Pseudo R2	0.175	0.158	0.136	0.157

Robust standard errors, adjusted for clustering by individual, are presented in parentheses. Tenure given in percentile.
* p<0.05, ** p<0.01, *** p<0.001

Column (2) presents estimates from a conditional logit specification with labourer fixed effects. The results are robust to the inclusion of individual fixed effects, as the interaction effect increases in both magnitude and significance.

Column (3) gives the results from a logit specification using the percentile rank of elapsed time as the measure of prior tenure. The results are similarly striking. A one quartile increase in a labourer's tenure percentile rank in terms of elapsed time increases the probability of working full-time by 5.5 percentage points in before the dome construction ($p < 0.01$, $25*0.0022 = 0.055$) and by 11.75 percentage points during dome construction ($p < 0.01$, $25*0.0047 = 0.1175$). These results are robust to the inclusion of labourer fixed effects in column (4).

Figure C.1 Returns to tenure through construction phase.



Appendix D: Maintenance Period

Most of the data collected represents the construction period of St. Paul's through 1711. Less than 3% of the data in our panel is from the maintenance period. This appendix explores whether there was a change in the relationship between tenure and intensity of work during the maintenance period.

Columns (1) and (2) of Table D.1 indicate that there was a significant relationship between tenure in terms of cumulative days worked and whether a labourer worked full-time during the maintenance period. The marginal effects in (2) indicate that a one quartile increase in the labourer's percentile rank increases the probability of working full-time by 8.5 percentage points ($p<0.05$, $25*0.0033 = 0.0825$). However, this result is not robust to the inclusion of labourer fixed effects in column (3), or to the elapsed time measure of tenure in columns (4)-(6).

The relationship between tenure and whether a labourer worked more than 85% of the maximum days in an accounting period thus was weaker and possibly insignificant during the maintenance period.

Table D.1: Probability of a labourer working full-time during maintenance period

	Cum. Days Logit - Coef (1)	Cum. Days Logit - Margins (2)	Cum. Days Cond. Logit (FE) - Coef (3)	Elap. Time Logit - Coef (4)	Elap. Time Logit - Margins (5)	Cum. Days Cond. Logit (FE) - Coef (6)
Tenure - Cum. Days	0.0178*	0.0033**	0.0042			
	(0.0079)	(0.0013)	(0.0263)			
Tenure - Elap. Time				0.0130	0.0025*	0.0057
				(0.0071)	(0.0012)	(0.0211)
Constant	-0.9479			-0.6937		
	(0.5250)			(0.4775)		
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Month Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Labourer Fixed Effects	No	No	Yes	No	No	Yes
Num. of observations	545	545	456	545	545	456
Num. of individuals	54			54		
Pseudo R2	0.200		0.258	0.187		0.258

* $p<0.05$, ** $p<0.01$, *** $p<0.001$. Robust standard errors, adjusted for clustering by individual, are presented in parentheses. Tenure given in percentile.

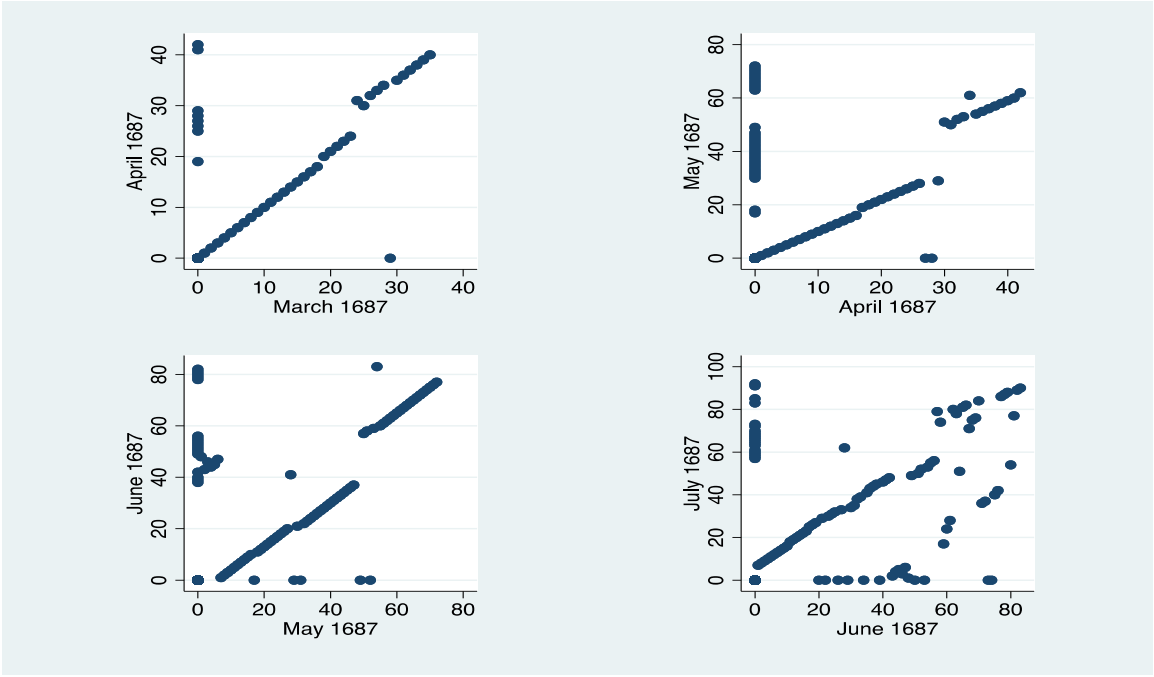
Appendix E: The ranking of labourers in the accounts

The organization of the accounts suggests that the clerk possessed a clear idea about who was to be hired and what they were entrusted with. In each period, hiring occurred in a sequence, with preferred workers taken on first. Long-term labourers were allotted a higher place in the queue for whatever work was available. The structure of the account also argues against the idea that labourers were being hired as gangs.

We are able to observe this process because of how the clerk kept the accounts for the majority of the period. For seven years from 1675-1682, the accounts were organized alphabetically; this affects 21% of the series. Before and after this, however, the order of labourers' names seems to reflect the order of hiring.[29] The only exception to this is that first and last positions were sometimes determined by status, and were at times occupied by the foreman and clerk of works.

The order in which the labourers' names were given in the accounts was usually repeated consistently from month to month. This was not wholly mechanical. Labourers did change position. Figure E.1 illustrates this by showing the relationship between positions of labourers in the sequence of accounts in the four months between March 1687 and July 1687. Each sub-plot shows the position of an individual labourer in two sequential months. The labourers' position in the first month is plotted along the x-axis. Their position in the second month is plotted on the y-axis. Each month saw some labourers arrive and some leave. The lines of points on the y-axis show groups of labourers being taken on, while labourers left individually – and so are scattered along the x-axis, as they have a position in the first month, but not the second.

Figure E1. Rank of labourers name in the sequence of accounts between March 1687 and July 1687.



[29] Some of the longer accounting records seem to contain several sequential lists of work, which can be identified by the repeated appearance of the labourer who appears to be acting as foreman and then the set of workers that follow. These have been treated as separate accounts for this analysis. The watchmen's shifts are listed separately after the labourers is finished, so those individuals appear twice in the account

The contrast between the two stages of arrival and departure provides good reason to reject the idea that labourers were being employed as gangs, with an internal management structure separate to their employer. While the hiring of gangs would be compatible with the pattern of clusters of labourers entering the account in a group. That separations were scattered across the list of labourers indicates that no group structure was maintained between workers within the site. We would expect workers to arrive and separate collectively if they were part of a gang. There is no sign of this.

The relationship between tenure and access to work is discussed in depth in the text. Table E.1 complements Table 5 in the main text, and shows how the different quartiles of the clerk's list were composed of labourers with widely differing degrees of experience on the Cathedral. Only 0.3% of labourers listed in the top quarter were new entrants to the workforce; 14% of those listed in the fourth quartile of people were new that period. At the other extreme, 93% of those listed in the top quartile of each account had been active for more than a year, as were 74% of those in the second quartile.

Table E.1: placement of workers in the clerk's list and time since entry

	Time since entry to workforce							
Place in account (quartile)	New	2-3 months	4-6 months	7-9 months	10-12 months	>1 year	%	N
Share of each quartile made up by labourers from each category (row)								
0-25	0.22	0.94	1.92	2.39	2.44	92.09	100.00	3,603
26-50	1.53	7.17	7.28	6.85	6.14	71.03	100.00	3,793
51-75	8.02	19.73	10.54	6.17	4.95	50.59	100.00	3,841
76-100	7.05	7.85	4.64	2.99	2.99	74.49	100.00	3,645
Total	4.24	9.07	6.18	4.65	4.17	71.7	100.00	14,882

Note: table reports labourers recorded in non-alphabetical accounts produced during the period of construction